APPLICATION NOTE

AT07627: ASF Manual (SAM D21)

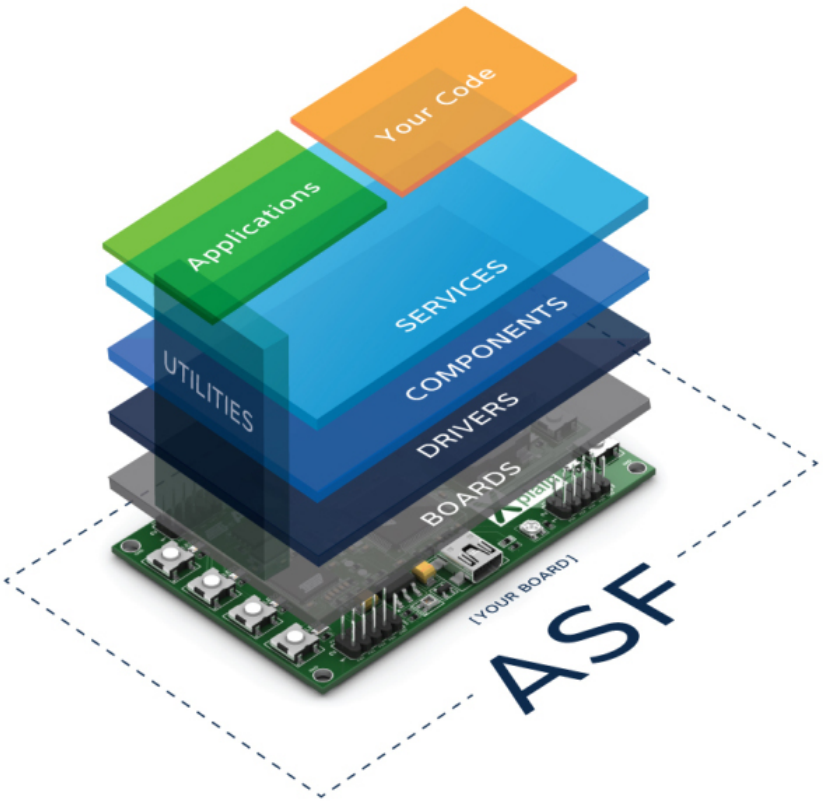
ASF PROGRAMMERS MANUAL

Preface

The Atmel® Software Framework (ASF) is a collection of free embedded software for Atmel microcontroller devices. It simplifies the usage of Atmel products, providing an abstraction to the hardware and high-value middleware.

ASF is designed to be used for evaluation, prototyping, design and production phases. ASF is integrated in the Atmel Studio IDE with a graphical user interface or available as a standalone package for several commercial and open source compilers.

This document describes the API interfaces to the low level ASF module drivers of the device.



For more information on ASF please refer to the online documentation at www.atmel.com/asf.

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Software License

1. SAM D20/D21 Analog Comparator Driver (AC)

This driver for SAM D20/D21 devices provides an interface for the configuration and management of the device's Analog Comparator functionality, for the comparison of analog voltages against a known reference voltage to determine its relative level. The following driver API modes are covered by this manual:

- Polled APIs
- Callback APIs

The following peripherals are used by this module:

- AC (Analog Comparator)

The outline of this documentation is as follows:

1.1 Prerequisites

There are no prerequisites for this module.

1.2 Module Overview

The Analog Comparator module provides an interface for the comparison of one or more analog voltage inputs (sourced from external or internal inputs) against a known reference voltage, to determine if the unknown voltage is higher or lower than the reference. Additionally, window functions are provided so that two comparators can be connected together to determine if an input is below, inside, above or outside the two reference points of the window.

Each comparator requires two analog input voltages, a positive and negative channel input. The result of the comparison is a binary `true` if the comparator's positive channel input is higher than the comparator's negative input channel, and `false` if otherwise.

1.2.1 Window Comparators and Comparator Pairs

Each comparator module contains one or more comparator pairs, a set of two distinct comparators which can be used independently or linked together for Window Comparator mode. In this latter mode, the two comparator units in a comparator pair are linked together to allow the module to detect if an input voltage is below, inside, above or outside a window set by the upper and lower threshold voltages set by the two comparators. If not required, window comparison mode can be turned off and the two comparator units can be configured and used separately.

1.2.2 Positive and Negative Input MUXs

Each comparator unit requires two input voltages, a positive and negative channel (note that these names refer to the logical operation that the unit performs, and both voltages should be above GND) which are then compared with one another. Both the positive and negative channel inputs are connected to a pair of MUXs, which allows one of several possible inputs to be selected for each comparator channel.

The exact channels available for each comparator differ for the positive and negative inputs, but the same MUX choices are available for all comparator units (i.e. all positive MUXes are identical, all negative MUXes are identical). This allows the user application to select which voltages are compared to one-another.

When used in window mode, both comparators in the window pair should have their positive channel input MUXs configured to the same input channel, with the negative channel input MUXs used to set the lower and upper window bounds.

1.2.3 Output Filtering

The output of each comparator unit can either be used directly with no filtering (giving a lower latency signal, with potentially more noise around the comparison threshold) or it can be passed through a multiple stage digital majority filter. Several filter lengths are available, with the longer stages producing a more stable result, at the expense of a higher latency.

When output filtering is used in single shot mode, a single trigger of the comparator will automatically perform the required number of samples to produce a correctly filtered result.

1.2.4 Input Hysteresis

To prevent unwanted noise around the threshold where the comparator unit's positive and negative input channels are close in voltage to one another, an optional hysteresis can be used to widen the point at which the output result flips. This mode will prevent a change in the comparison output unless the inputs cross one-another beyond the hysteresis gap introduces by this mode.

1.2.5 Single Shot and Continuous Sampling Modes

Comparators can be configured to run in either Single Shot or Continuous sampling modes; when in Single Shot mode, the comparator will only perform a comparison (and any resulting filtering, see Output Filtering) when triggered via a software or event trigger. This mode improves the power efficiency of the system by only performing comparisons when actually required by the application.

For systems requiring a lower latency or more frequent comparisons, continuous mode will place the comparator into continuous sampling mode, which increases the module's power consumption, but decreases the latency between each comparison result by automatically performing a comparison on every cycle of the module's clock.

1.2.6 Events

Each comparator unit is capable of being triggered by both software and hardware triggers. Hardware input events allow for other peripherals to automatically trigger a comparison on demand - for example, a timer output event could be used to trigger comparisons at a desired regular interval.

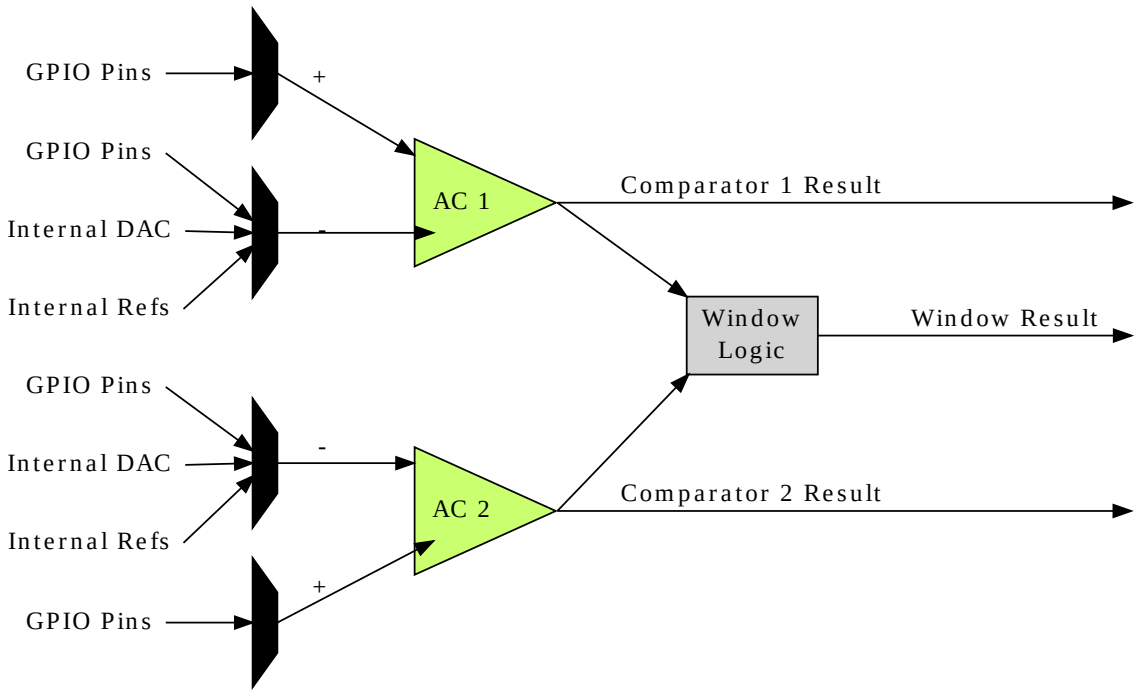
The module's output events can similarly be used to trigger other hardware modules each time a new comparison result is available. This scheme allows for reduced levels of CPU usage in an application and lowers the overall system response latency by directly triggering hardware peripherals from one another without requiring software intervention.

Note The connection of events between modules requires the use of the SAM D20/D21 Event System Driver (EVENTS) to route output event of one module to the the input event of another. For more information on event routing, refer to the event driver documentation.

1.2.7 Physical Connection

Physically, the modules are interconnected within the device as shown in Figure 1-1: Physical Connection on page 16.

Figure 1-1. Physical Connection



1.3 Special Considerations

The number of comparator pairs (and, thus, window comparators) within a single hardware instance of the Analog Comparator module is device-specific. Some devices will contain a single comparator pair, while others may have two pairs; refer to your device specific datasheet for details.

1.4 Extra Information

For extra information see Extra Information for AC Driver. This includes:

- Acronyms
- Dependencies
- Errata
- Module History

1.5 Examples

For a list of examples related to this driver, see Examples for AC Driver.

1.6 API Overview

1.6.1 Variable and Type Definitions

1.6.1.1 Type ac_callback_t

```
typedef void(* ac_callback_t )(struct ac_module *const module_inst)
```

Type definition for a AC module callback function.

1.6.2 Structure Definitions

1.6.2.1 Struct ac_chan_config

Configuration structure for a Comparator channel, to configure the input and output settings of the comparator.

Table 1-1. Members

Type	Name	Description
bool	enable_hysteresis	When true, hysteresis mode is enabled on the comparator inputs.
enum ac_chan_filter	filter	Filtering mode for the comparator output, when the comparator is used in a supported mode.
enum ac_chan_interrupt_selection	interrupt_selection	Interrupt criteria for the comparator channel, to select the condition that will trigger a callback.
enum ac_chan_neg_mux	negative_input	Input multiplexer selection for the comparator's negative input pin.
enum ac_chan_output	output_mode	Output mode of the comparator, whether it should be available for internal use, or asynchronously/ synchronously linked to a GPIO pin.
enum ac_chan_pos_mux	positive_input	Input multiplexer selection for the comparator's positive input pin.
enum ac_chan_sample_mode	sample_mode	Sampling mode of the comparator channel.
uint8_t	vcc_scale_factor	Scaled VCC voltage division factor for the channel, when a comparator pin is connected to the VCC voltage scalar input. The formular is: Vscale = Vdd * vcc_scale_factor / 64. If the VCC voltage scalar is not selected as a comparator channel pin's input, this value will be ignored.

1.6.2.2 Struct ac_config

Configuration structure for a Comparator channel, to configure the input and output settings of the comparator.

Table 1-2. Members

Type	Name	Description
bool	run_in_standby[]	If true, the comparator pairs will continue to sample during sleep mode when triggered.
enum gclk_generator	source_generator	Source generator for AC GCLK.

1.6.2.3 Struct ac_events

Event flags for the Analog Comparator module. This is used to enable and disable events via ac_enable_events() and ac_disable_events().

Table 1-3. Members

Type	Name	Description
bool	generate_event_on_state[]	If true, an event will be generated when a comparator state changes.
bool	generate_event_on_window[]	If true, an event will be generated when a comparator window state changes.
bool	on_event_sample[]	If true, a comparator will be sampled each time an event is received.

1.6.2.4 Struct ac_module

AC software instance structure, used to retain software state information of an associated hardware module instance.

Note The fields of this structure should not be altered by the user application; they are reserved for module-internal use only.

1.6.2.5 Struct ac_win_config

Table 1-4. Members

Type	Name	Description
enum ac_win_interrupt_selection	interrupt_selection	Interrupt criteria for the comparator window channel, to select the condition that will trigger a callback.

1.6.3 Macro Definitions

1.6.3.1 AC window channel status flags

AC window channel status flags, returned by ac_win_get_status().

Macro AC_WIN_STATUS_UNKNOWN

```
#define AC_WIN_STATUS_UNKNOWN (1UL << 0)
```

Unknown output state; the comparator window channel was not ready.

Macro AC_WIN_STATUS_ABOVE

```
#define AC_WIN_STATUS_ABOVE (1UL << 1)
```

Window Comparator's input voltage is above the window

Macro AC_WIN_STATUS_INSIDE

```
#define AC_WIN_STATUS_INSIDE (1UL << 2)
```

Window Comparator's input voltage is inside the window

Macro AC_WIN_STATUS_BELOW

```
#define AC_WIN_STATUS_BELOW (1UL << 3)
```

Window Comparator's input voltage is below the window

Macro AC_WIN_STATUS_INTERRUPT_SET

```
#define AC_WIN_STATUS_INTERRUPT_SET (1UL << 4)
```

This state reflects the window interrupt flag. When the interrupt flag should be set is configured in ac_win_set_config(). This state needs to be cleared by the of ac_win_clear_status().

1.6.3.2 AC channel status flags

AC channel status flags, returned by ac_chan_get_status().

Macro AC_CHAN_STATUS_UNKNOWN

```
#define AC_CHAN_STATUS_UNKNOWN (1UL << 0)
```

Unknown output state; the comparator channel was not ready.

Macro AC_CHAN_STATUS_NEG_ABOVE_POS

```
#define AC_CHAN_STATUS_NEG_ABOVE_POS (1UL << 1)
```

Comparator's negative input pin is higher in voltage than the positive input pin.

Macro AC_CHAN_STATUS_POS_ABOVE_NEG

```
#define AC_CHAN_STATUS_POS_ABOVE_NEG (1UL << 2)
```

Comparator's positive input pin is higher in voltage than the negative input pin.

Macro AC_CHAN_STATUS_INTERRUPT_SET

```
#define AC_CHAN_STATUS_INTERRUPT_SET (1UL << 3)
```

This state reflects the channel interrupt flag. When the interrupt flag should be set is configured in ac_chan_set_config(). This state needs to be cleared by the of ac_chan_clear_status().

1.6.4 Function Definitions

1.6.4.1 Configuration and Initialization

Function ac_reset()

Resets and disables the Analog Comparator driver.

```
enum status_code ac_reset(
  struct ac_module *const module_inst)
```

Resets and disables the Analog Comparator driver, resets the internal states and registers of the hardware module to their power-on defaults.

Table 1-5. Parameters

Data direction	Parameter name	Description
[out]	module_inst	Pointer to the AC software instance struct

Function ac_init()

Initializes and configures the Analog Comparator driver.

```
enum status_code ac_init(
  struct ac_module *const module_inst,
  Ac *const hw,
  struct ac_config *const config)
```

Initializes the Analog Comparator driver, configuring it to the user supplied configuration parameters, ready for use. This function should be called before enabling the Analog Comparator.

Note

Once called the Analog Comparator will not be running; to start the Analog Comparator call ac_enable() after configuring the module.

Table 1-6. Parameters

Data direction	Parameter name	Description
[out]	module_inst	Pointer to the AC software instance struct
[in]	hw	Pointer to the AC module instance
[in]	config	Pointer to the config struct, created by the user application

Function ac_is_syncing()

Determines if the hardware module(s) are currently synchronizing to the bus.

```
bool ac_is_syncing(
  struct ac_module *const module_inst)
```

Checks to see if the underlying hardware peripheral module(s) are currently synchronizing across multiple clock domains to the hardware bus, This function can be used to delay further operations on a module until such time that it is ready, to prevent blocking delays for synchronization in the user application.

Table 1-7. Parameters

Data direction	Parameter name	Description
[in]	module_inst	Pointer to the AC software instance struct

Returns Synchronization status of the underlying hardware module(s).

Table 1-8. Return Values

Return value	Description
true	if the module has completed synchronization
false	if the module synchronization is ongoing

Function ac_get_config_defaults()

Initializes all members of an Analog Comparator configuration structure to safe defaults.

```
void ac_get_config_defaults(
  struct ac_config *const config)
```

Initializes all members of a given Analog Comparator configuration structure to safe known default values. This function should be called on all new instances of these configuration structures before being modified by the user application.

The default configuration is as follows:

- All comparator pairs disabled during sleep mode
- Generator 0 is the default GCLK generator

Table 1-9. Parameters

Data direction	Parameter name	Description
[out]	config	Configuration structure to initialize to default values

Function ac_enable()

Enables an Analog Comparator that was previously configured.

```
void ac_enable(
  struct ac_module *const module_inst)
```

Enables an Analog Comparator that was previously configured via a call to ac_init().

Table 1-10. Parameters

Data direction	Parameter name	Description
[in]	module_inst	Software instance for the Analog Comparator peripheral

Function ac_disable()

Disables an Analog Comparator that was previously enabled.

```
void ac_disable(
  struct ac_module *const module_inst)
```

Disables an Analog Comparator that was previously started via a call to ac_enable().

Table 1-11. Parameters

Data direction	Parameter name	Description
[in]	module_inst	Software instance for the Analog Comparator peripheral

Function ac_enable_events()

Enables an Analog Comparator event input or output.

```
void ac_enable_events(
  struct ac_module *const module_inst,
  struct ac_events *const events)
```

Enables one or more input or output events to or from the Analog Comparator module. See here for a list of events this module supports.

Note Events cannot be altered while the module is enabled.

Table 1-12. Parameters

Data direction	Parameter name	Description
[in]	module_inst	Software instance for the Analog Comparator peripheral
[in]	events	Struct containing flags of events to enable

Function ac_disable_events()

Disables an Analog Comparator event input or output.

```
void ac_disable_events(
  struct ac_module *const module_inst,
  struct ac_events *const events)
```

Disables one or more input or output events to or from the Analog Comparator module. See here for a list of events this module supports.

Note Events cannot be altered while the module is enabled.

Table 1-13. Parameters

Data direction	Parameter name	Description
[in]	module_inst	Software instance for the Analog Comparator peripheral
[in]	events	Struct containing flags of events to disable

1.6.4.2 Channel Configuration and Initialization

Function ac_chan_get_config_defaults()

Initializes all members of an Analog Comparator channel configuration structure to safe defaults.

```
void ac_chan_get_config_defaults(
  struct ac_chan_config *const config)
```

Initializes all members of an Analog Comparator channel configuration structure to safe defaults. This function should be called on all new instances of these configuration structures before being modified by the user application.

The default configuration is as follows:

- Continuous sampling mode
- Majority of 5 sample output filter
- Hysteresis enabled on the input pins
- Internal comparator output mode
- Comparator pin multiplexer 0 selected as the positive input
- Scaled VCC voltage selected as the negative input
- VCC voltage scaler set for a division factor of 2
- Channel interrupt set to occur when the compare threshold is passed

Table 1-14. Parameters

Data direction	Parameter name	Description
[out]	config	Channel configuration structure to initialize to default values

Function ac_chan_set_config()

Writes an Analog Comparator channel configuration to the hardware module.

```
enum status_code ac_chan_set_config(
  struct ac_module *const module_inst,
```

```
  const enum ac_chan_channel channel,
  struct ac_chan_config *const config)
```

Writes a given Analog Comparator channel configuration to the hardware module.

Table 1-15. Parameters

Data direction	Parameter name	Description
[in]	module_inst	Software instance for the Analog Comparator peripheral
[in]	channel	Analog Comparator channel to configure
[in]	config	Pointer to the channel configuration struct

Function ac_chan_enable()

Enables an Analog Comparator channel that was previously configured.

```
void ac_chan_enable(
  struct ac_module *const module_inst,
  const enum ac_chan_channel channel)
```

Enables an Analog Comparator channel that was previously configured via a call to ac_chan_set_config().

Table 1-16. Parameters

Data direction	Parameter name	Description
[in]	module_inst	Software instance for the Analog Comparator peripheral
[in]	channel	Comparator channel to enable

Function ac_chan_disable()

Disables an Analog Comparator channel that was previously enabled.

```
void ac_chan_disable(
  struct ac_module *const module_inst,
  const enum ac_chan_channel channel)
```

Stops an Analog Comparator channel that was previously started via a call to ac_chan_enable().

Table 1-17. Parameters

Data direction	Parameter name	Description
[in]	module_inst	Software instance for the Analog Comparator peripheral
[in]	channel	Comparator channel to disable

1.6.4.3 Channel Control

Function ac_chan_trigger_single_shot()

Triggers a comparison on a comparator that is configured in single shot mode.

```
void ac_chan_trigger_single_shot(
  struct ac_module *const module_inst,
  const enum ac_chan_channel channel)
```

Triggers a single conversion on a comparator configured to compare on demand (single shot mode) rather than continuously.

Table 1-18. Parameters

Data direction	Parameter name	Description
[in]	module_inst	Software instance for the Analog Comparator peripheral
[in]	channel	Comparator channel to trigger

Function ac_chan_is_ready()

Determines if a given comparator channel is ready for comparisons.

```
bool ac_chan_is_ready(
  struct ac_module *const module_inst,
  const enum ac_chan_channel channel)
```

Checks a comparator channel to see if the comparator is currently ready to begin comparisons.

Table 1-19. Parameters

Data direction	Parameter name	Description
[in]	module_inst	Software instance for the Analog Comparator peripheral
[in]	channel	Comparator channel to test

Returns Comparator channel readiness state.

Function ac_chan_get_status()

Determines the output state of a comparator channel.

```
uint8_t ac_chan_get_status(
  struct ac_module *const module_inst,
  const enum ac_chan_channel channel)
```

Retrieves the last comparison value (after filtering) of a given comparator. If the comparator was not ready at the time of the check, the comparison result will be indicated as being unknown.

Table 1-20. Parameters

Data direction	Parameter name	Description
[in]	module_inst	Software instance for the Analog Comparator peripheral

Data direction	Parameter name	Description
[in]	channel	Comparator channel to test

Returns Bit mask of comparator channel status flags.

Function ac_chan_clear_status()

Clears an interrupt status flag.

```
void ac_chan_clear_status(
  struct ac_module *const module_inst,
  const enum ac_chan_channel channel)
```

This function is used to clear the AC_CHAN_STATUS_INTERRUPT_SET flag it will clear the flag for the channel indicated by the channel argument

Table 1-21. Parameters

Data direction	Parameter name	Description
[in]	module_inst	Software instance for the Analog Comparator peripheral
[in]	channel	Comparator channel to clear

1.6.4.4 Window Mode Configuration and Initialization

Function ac_win_get_config_defaults()

Initializes an Analog Comparator window configuration structure to defaults.

```
void ac_win_get_config_defaults(
  struct ac_win_config *const config)
```

Initializes a given Analog Comparator channel configuration structure to a set of known default values. This function should be called if window interrupts are needed and before ac_win_set_config().

The default configuration is as follows:

- Channel interrupt set to occur when the measurement is above the window

Table 1-22. Parameters

Data direction	Parameter name	Description
[out]	config	Window configuration structure to initialize to default values

Function ac_win_set_config()

Function used to setup interrupt selection of a window.

```
enum status_code ac_win_set_config(
  struct ac_module *const module_inst,
```

```
  enum ac_win_channel const win_channel,
  struct ac_win_config *const config)
```

This function is used to setup when an interrupt should occur for a given window.

Note This must be done before enabling the channel.

Table 1-23. Parameters

Data direction	Parameter name	Description
[in]	module_inst	Pointer to software instance struct
[in]	win_channel	Window channel to setup
[in]	config	Configuration for the given window channel

Table 1-24. Return Values

Return value	Description
STATUS_OK	Function exited successful
STATUS_ERR_INVALID_ARG	win_channel argument incorrect

Function ac_win_enable()

Enables an Analog Comparator window channel that was previously configured.

```
enum status_code ac_win_enable(
  struct ac_module *const module_inst,
  const enum ac_win_channel win_channel)
```

Enables and starts an Analog Comparator window channel.

Note The comparator channels used by the window channel must be configured and enabled before calling this function. The two comparator channels forming each window comparator pair must have identical configurations other than the negative pin multiplexer setting.

Table 1-25. Parameters

Data direction	Parameter name	Description
[in]	module_inst	Software instance for the Analog Comparator peripheral
[in]	win_channel	Comparator window channel to enable

Returns Status of the window enable procedure.

Table 1-26. Return Values

Return value	Description
STATUS_OK	The window comparator was enabled

Return value	Description
STATUS_ERR_IO	One or both comparators in the window comparator pair is disabled
STATUS_ERR_BAD_FORMAT	The comparator channels in the window pair were not configured correctly

Function ac_win_disable()

Disables an Analog Comparator window channel that was previously enabled.

```
void ac_win_disable(
  struct ac_module *const module_inst,
  const enum ac_win_channel win_channel)
```

Stops an Analog Comparator window channel that was previously started via a call to ac_win_enable().

Table 1-27. Parameters

Data direction	Parameter name	Description
[in]	module_inst	Software instance for the Analog Comparator peripheral
[in]	win_channel	Comparator window channel to disable

1.6.4.5 Window Mode Control

Function ac_win_is_ready()

Determines if a given Window Comparator is ready for comparisons.

```
bool ac_win_is_ready(
  struct ac_module *const module_inst,
  const enum ac_win_channel win_channel)
```

Checks a Window Comparator to see if the both comparators used for window detection is currently ready to begin comparisons.

Table 1-28. Parameters

Data direction	Parameter name	Description
[in]	module_inst	Software instance for the Analog Comparator peripheral
[in]	win_channel	Window Comparator channel to test

Returns Window Comparator channel readiness state.

Function ac_win_get_status()

Determines the state of a specified Window Comparator.

```
uint8_t ac_win_get_status(
  struct ac_module *const module_inst,
  const enum ac_win_channel win_channel)
```

Retrieves the current window detection state, indicating what the input signal is currently comparing to relative to the window boundaries.

Table 1-29. Parameters

Data direction	Parameter name	Description
[in]	module_inst	Software instance for the Analog Comparator peripheral
[in]	win_channel	Comparator Window channel to test

Returns Bit mask of Analog Comparator window channel status flags

Function ac_win_clear_status()

Clears an interrupt status flag.

```
void ac_win_clear_status(
  struct ac_module *const module_inst,
  const enum ac_win_channel win_channel)
```

This function is used to clear the AC_WIN_STATUS_INTERRUPT_SET flag it will clear the flag for the channel indicated by the win_channel argument

Table 1-30. Parameters

Data direction	Parameter name	Description
[in]	module_inst	Software instance for the Analog Comparator peripheral
[in]	win_channel	Window channel to clear

1.6.5 Enumeration Definitions

1.6.5.1 Enum ac_callback

Enum for possible callback types for the AC module

Table 1-31. Members

Enum value	Description
AC_CALLBACK_COMPARATOR_0	Callback for comparator 0
AC_CALLBACK_COMPARATOR_1	Callback for comparator 1
AC_CALLBACK_WINDOW_0	Callback for window 0

1.6.5.2 Enum ac_chan_channel

Enum for the possible comparator channels.

Table 1-32. Members

Enum value	Description
AC_CHAN_CHANNEL_0	Comparator channel 0 (Pair 0, Comparator 0)
AC_CHAN_CHANNEL_1	Comparator channel 1 (Pair 0, Comparator 1)
AC_CHAN_CHANNEL_2	Comparator channel 2 (Pair 1, Comparator 0)
AC_CHAN_CHANNEL_3	Comparator channel 3 (Pair 1, Comparator 1)

1.6.5.3 Enum ac_chan_filter

Enum for the possible channel output filtering configurations of an Analog Comparator channel.

Table 1-33. Members

Enum value	Description
AC_CHAN_FILTER_NONE	No output filtering is performed on the comparator channel.
AC_CHAN_FILTER_MAJORITY_3	Comparator channel output is passed through a Majority-of-Three filter.
AC_CHAN_FILTER_MAJORITY_5	Comparator channel output is passed through a Majority-of-Five filter.

1.6.5.4 Enum ac_chan_interrupt_selection

This enum is used to select when a channel interrupt should occur.

Table 1-34. Members

Enum value	Description
AC_CHAN_INTERRUPT_SELECTION_TOGGLE	An interrupt will be generated when the comparator level is passed
AC_CHAN_INTERRUPT_SELECTION_RISING	An interrupt will be generated when the measurement goes above the compare level
AC_CHAN_INTERRUPT_SELECTION_FALLING	An interrupt will be generated when the measurement goes below the compare level
AC_CHAN_INTERRUPT_SELECTION_END_OF_COMPARE	An interrupt will be generated when a new measurement is complete. Interrupts will only be generated in single shot mode. This state needs to be cleared by the use of ac_chan_cleare_status().

1.6.5.5 Enum ac_chan_neg_mux

Enum for the possible channel negative pin input of an Analog Comparator channel.

Table 1-35. Members

Enum value	Description
AC_CHAN_NEG_MUX_PIN0	Negative comparator input is connected to physical AC input pin 0.

Enum value	Description
AC_CHAN_NEG_MUX_PIN1	Negative comparator input is connected to physical AC input pin 1.
AC_CHAN_NEG_MUX_PIN2	Negative comparator input is connected to physical AC input pin 2.
AC_CHAN_NEG_MUX_PIN3	Negative comparator input is connected to physical AC input pin 3.
AC_CHAN_NEG_MUX_GND	Negative comparator input is connected to the internal ground plane.
AC_CHAN_NEG_MUX_SCALED_VCC	Negative comparator input is connected to the channel's internal VCC plane voltage scalar.
AC_CHAN_NEG_MUX_BANDGAP	Negative comparator input is connected to the internal band gap voltage reference.
AC_CHAN_NEG_MUX_DAC0	Negative comparator input is connected to the channel's internal DAC channel 0 output.

1.6.5.6 Enum ac_chan_output

Enum for the possible channel GPIO output routing configurations of an Analog Comparator channel.

Table 1-36. Members

Enum value	Description
AC_CHAN_OUTPUT_INTERNAL	Comparator channel output is not routed to a physical GPIO pin, and is used internally only.
AC_CHAN_OUTPUT_ASYNCRONOUS	Comparator channel output is routed to its matching physical GPIO pin, via an asynchronous path.
AC_CHAN_OUTPUT_SYNCHRONOUS	Comparator channel output is routed to its matching physical GPIO pin, via a synchronous path.

1.6.5.7 Enum ac_chan_pos_mux

Enum for the possible channel positive pin input of an Analog Comparator channel.

Table 1-37. Members

Enum value	Description
AC_CHAN_POS_MUX_PIN0	Positive comparator input is connected to physical AC input pin 0.
AC_CHAN_POS_MUX_PIN1	Positive comparator input is connected to physical AC input pin 1.
AC_CHAN_POS_MUX_PIN2	Positive comparator input is connected to physical AC input pin 2.
AC_CHAN_POS_MUX_PIN3	Positive comparator input is connected to physical AC input pin 3.

1.6.5.8 Enum ac_chan_sample_mode

Enum for the possible channel sampling modes of an Analog Comparator channel.

Table 1-38. Members

Enum value	Description
AC_CHAN_MODE_CONTINUOUS	Continuous sampling mode; when the channel is enabled the comparator output is available for reading at any time.
AC_CHAN_MODE_SINGLE_SHOT	Single shot mode; when used the comparator channel must be triggered to perform a comparison before reading the result.

1.6.5.9 Enum ac_win_channel

Enum for the possible window comparator channels.

Table 1-39. Members

Enum value	Description
AC_WIN_CHANNEL_0	Window channel 0 (Pair 0, Comparators 0 and 1)
AC_WIN_CHANNEL_1	Window channel 1 (Pair 1, Comparators 2 and 3)

1.6.5.10 Enum ac_win_interrupt_selection

This enum is used to select when a window interrupt should occur.

Table 1-40. Members

Enum value	Description
AC_WIN_INTERRUPT_SELECTION_ABOVE	Interrupt is generated when the compare value goes above the window
AC_WIN_INTERRUPT_SELECTION_INSIDE	Interrupt is generated when the compare value goes inside the window
AC_WIN_INTERRUPT_SELECTION_BELOW	Interrupt is generated when the compare value goes below the window
AC_WIN_INTERRUPT_SELECTION_OUTSIDE	Interrupt is generated when the compare value goes outside the window

1.7 Extra Information for AC Driver

1.7.1 Acronyms

Below is a table listing the acronyms used in this module, along with their intended meanings.

Acronym	Description
AC	Analog Comparator
DAC	Digital-to-Analog Converter
MUX	Multiplexer

1.7.2 Dependencies

This driver has the following dependencies:

- System Pin Multiplexer Driver

1.7.3 Errata

There are no errata related to this driver.

1.7.4 Module History

An overview of the module history is presented in the table below, with details on the enhancements and fixes made to the module since its first release. The current version of this corresponds to the newest version in the table.

Changelog
Added support for SAMD21
Initial Release

1.8 Examples for AC Driver

This is a list of the available Quick Start guides (QSGs) and example applications for SAM D20/D21 Analog Comparator Driver (AC). QSGs are simple examples with step-by-step instructions to configure and use this driver in a selection of use cases. Note that QSGs can be compiled as a standalone application or be added to the user application.

- Quick Start Guide for AC - Basic
- Quick Start Guide for AC - Callback

1.8.1 Quick Start Guide for AC - Basic

In this use case, the Analog Comparator module is configured for:

- Comparator peripheral in manually triggered (i.e. "Single Shot" mode)
- One comparator channel connected to input MUX pin 0 and compared to a scaled VCC/2 voltage

This use case sets up the Analog Comparator to compare an input voltage fed into a GPIO pin of the device against a scaled voltage of the microcontroller's VCC power rail. The comparisons are made on-demand in single-shot mode, and the result stored into a local variable which is then output to the board LED to visually show the comparison state.

1.8.1.1 Setup

Prerequisites

There are no special setup requirements for this use-case.

Code

Copy-paste the following setup code to your user application:

```
/* AC module software instance (must not go out of scope while in use) */
static struct ac_module ac_instance;

/* Comparator channel that will be used */
#define AC_COMPARATOR_CHANNEL    AC_CHAN_CHANNEL_0
```

```
void configure_ac(void)
{
    /* Create a new configuration structure for the Analog Comparator settings
     * and fill with the default module settings. */
    struct ac_config config_ac;
    ac_get_config_defaults(&config_ac);

    /* Alter any Analog Comparator configuration settings here if required */

    /* Initialize and enable the Analog Comparator with the user settings */
    ac_init(&ac_instance, AC, &config_ac);
}

void configure_ac_channel(void)
{
    /* Create a new configuration structure for the Analog Comparator channel
     * settings and fill with the default module channel settings. */
    struct ac_chan_config ac_chan_conf;
    ac_chan_get_config_defaults(&ac_chan_conf);

    /* Set the Analog Comparator channel configuration settings */
    ac_chan_conf.sample_mode      = AC_CHAN_MODE_SINGLE_SHOT;
    ac_chan_conf.positive_input   = AC_CHAN_POS_MUX_PIN0;
    ac_chan_conf.negative_input   = AC_CHAN_NEG_MUX_SCALED_VCC;
    ac_chan_conf.vcc_scale_factor = 32;

    /* Set up a pin as an AC channel input */
    struct system_pinmux_config ac0_pin_conf;
    system_pinmux_get_config_defaults(&ac0_pin_conf);
    ac0_pin_conf.direction    = SYSTEM_PINMUX_PIN_DIR_INPUT;
    ac0_pin_conf.mux_position = MUX_PA04B_AC_AIN0;
    system_pinmux_pin_set_config(PIN_PA04B_AC_AIN0, &ac0_pin_conf);

    /* Initialize and enable the Analog Comparator channel with the user
     * settings */
    ac_chan_set_config(&ac_instance, AC_COMPARATOR_CHANNEL, &ac_chan_conf);
    ac_chan_enable(&ac_instance, AC_COMPARATOR_CHANNEL);
}
```

Add to user application initialization (typically the start of `main()`):

```
system_init();
configure_ac();
configure_ac_channel();
ac_enable(&ac_instance);
```

Workflow

1. Create an AC device instance struct, which will be associated with an Analog Comparator peripheral hardware instance.

   ```
   static struct ac_module ac_instance;
   ```

Note Device instance structures shall **never** go out of scope when in use.

2. Define a macro to select the comparator channel that will be sampled, for convenience.

```
#define AC_COMPARATOR_CHANNEL    AC_CHAN_CHANNEL_0
```

3. Create a new function `configure_ac()`, which will be used to configure the overall Analog Comparator peripheral.

```
void configure_ac(void)
```

4. Create an Analog Comparator peripheral configuration structure that will be filled out to set the module configuration.

```
struct ac_config config_ac;
```

5. Fill the Analog Comparator peripheral configuration structure with the default module configuration values.

```
ac_get_config_defaults(&config_ac);
```

6. Initialize the Analog Comparator peripheral and associate it with the software instance structure that was defined previously.

```
ac_init(&ac_instance, AC, &config_ac);
```

7. Create a new function `configure_ac_channel()`, which will be used to configure the overall Analog Comparator peripheral.

```
void configure_ac_channel(void)
```

8. Create an Analog Comparator channel configuration structure that will be filled out to set the channel configuration.

```
struct ac_chan_config ac_chan_conf;
```

9. Fill the Analog Comparator channel configuration structure with the default channel configuration values.

```
ac_chan_get_config_defaults(&ac_chan_conf);
```

10. Alter the channel configuration parameters to set the channel to one-shot mode, with the correct negative and positive MUX selections and the desired voltage scaler.

```
ac_chan_conf.sample_mode      = AC_CHAN_MODE_SINGLE_SHOT;
ac_chan_conf.positive_input   = AC_CHAN_POS_MUX_PIN0;
ac_chan_conf.negative_input   = AC_CHAN_NEG_MUX_SCALED_VCC;
ac_chan_conf.vcc_scale_factor = 32;
```

Note The voltage scalar formula is documented in description for ac_chan_config::vcc_scale_factor.

11. Configure the physical pin that will be routed to the AC module channel 0.

```
struct system_pinmux_config ac0_pin_conf;
system_pinmux_get_config_defaults(&ac0_pin_conf);
```

```
ac0_pin_conf.direction    = SYSTEM_PINMUX_PIN_DIR_INPUT;
ac0_pin_conf.mux_position = MUX_PA04B_AC_AIN0;
system_pinmux_pin_set_config(PIN_PA04B_AC_AIN0, &ac0_pin_conf);
```

12. Initialize the Analog Comparator channel and configure it with the desired settings.

```
ac_chan_set_config(&ac_instance, AC_COMPARATOR_CHANNEL, &ac_chan_conf);
```

13. Enable the now initialized Analog Comparator channel.

```
ac_chan_enable(&ac_instance, AC_COMPARATOR_CHANNEL);
```

14. Enable the now initialized Analog Comparator peripheral.

```
ac_enable(&ac_instance);
```

1.8.1.2 Implementation

Code

Copy-paste the following code to your user application:

```
ac_chan_trigger_single_shot(&ac_instance, AC_COMPARATOR_CHANNEL);

uint8_t last_comparison = AC_CHAN_STATUS_UNKNOWN;

while (true) {
    if (ac_chan_is_ready(&ac_instance, AC_COMPARATOR_CHANNEL)) {
        do {
            last_comparison = ac_chan_get_status(&ac_instance,
                    AC_COMPARATOR_CHANNEL);
        } while (last_comparison & AC_CHAN_STATUS_UNKNOWN);

        port_pin_set_output_level(LED_0_PIN,
                (last_comparison & AC_CHAN_STATUS_NEG_ABOVE_POS));

        ac_chan_trigger_single_shot(&ac_instance, AC_COMPARATOR_CHANNEL);
    }
}
```

Workflow

1. Trigger the first comparison on the comparator channel.

```
ac_chan_trigger_single_shot(&ac_instance, AC_COMPARATOR_CHANNEL);
```

2. Create a local variable to maintain the current comparator state. Since no comparison has taken place, it is initialized to AC_CHAN_STATUS_UNKNOWN.

```
uint8_t last_comparison = AC_CHAN_STATUS_UNKNOWN;
```

3. Make the application loop infinitely, while performing triggered comparisons.

```
while (true) {
```

4. Check if the comparator is ready for the last triggered comparison result to be read.

```
if (ac_chan_is_ready(&ac_instance, AC_COMPARATOR_CHANNEL)) {
```

5. Read the comparator output state into the local variable for application use, re-trying until the comparison state is ready.

```
do {
    last_comparison = ac_chan_get_status(&ac_instance,
            AC_COMPARATOR_CHANNEL);
} while (last_comparison & AC_CHAN_STATUS_UNKNOWN);
```

6. Set the board LED state to mirror the last comparison state.

```
port_pin_set_output_level(LED_0_PIN,
        (last_comparison & AC_CHAN_STATUS_NEG_ABOVE_POS));
```

7. Trigger the next conversion on the Analog Comparator channel.

```
ac_chan_trigger_single_shot(&ac_instance, AC_COMPARATOR_CHANNEL);
```

1.8.2 Quick Start Guide for AC - Callback

In this use case, the Analog Comparator module is configured for:

- Comparator peripheral in manually triggered (i.e. "Single Shot" mode)
- One comparator channel connected to input MUX pin 0 and compared to a scaled VCC/2 voltage

This use case sets up the Analog Comparator to compare an input voltage fed into a GPIO pin of the device against a scaled voltage of the microcontroller's VCC power rail. The comparisons are made on-demand in single-shot mode, and the result stored into a local variable which is then output to the board LED to visually show the comparison state.

1.8.2.1 Setup

Prerequisites

There are no special setup requirements for this use-case.

Code

Copy-paste the following setup code to your user application:

```
/* AC module software instance (must not go out of scope while in use) */
static struct ac_module ac_instance;

/* Comparator channel that will be used */
#define AC_COMPARATOR_CHANNEL   AC_CHAN_CHANNEL_0

void configure_ac(void)
{
    /* Create a new configuration structure for the Analog Comparator settings
     * and fill with the default module settings. */
    struct ac_config config_ac;
    ac_get_config_defaults(&config_ac);

    /* Alter any Analog Comparator configuration settings here if required */
```

```
    /* Initialize and enable the Analog Comparator with the user settings */
    ac_init(&ac_instance, AC, &config_ac);
}

void configure_ac_channel(void)
{
    /* Create a new configuration structure for the Analog Comparator channel
     * settings and fill with the default module channel settings. */
    struct ac_chan_config config_ac_chan;
    ac_chan_get_config_defaults(&config_ac_chan);

    /* Set the Analog Comparator channel configuration settings */
    config_ac_chan.sample_mode         = AC_CHAN_MODE_SINGLE_SHOT;
    config_ac_chan.positive_input      = AC_CHAN_POS_MUX_PIN0;
    config_ac_chan.negative_input      = AC_CHAN_NEG_MUX_SCALED_VCC;
    config_ac_chan.vcc_scale_factor    = 32;
    config_ac_chan.interrupt_selection = AC_CHAN_INTERRUPT_SELECTION_END_OF_COMPARE;

    /* Set up a pin as an AC channel input */
    struct system_pinmux_config ac0_pin_conf;
    system_pinmux_get_config_defaults(&ac0_pin_conf);
    ac0_pin_conf.direction    = SYSTEM_PINMUX_PIN_DIR_INPUT;
    ac0_pin_conf.mux_position = MUX_PA04B_AC_AIN0;
    system_pinmux_pin_set_config(PIN_PA04B_AC_AIN0, &ac0_pin_conf);

    /* Initialize and enable the Analog Comparator channel with the user
     * settings */
    ac_chan_set_config(&ac_instance, AC_COMPARATOR_CHANNEL, &config_ac_chan);
    ac_chan_enable(&ac_instance, AC_COMPARATOR_CHANNEL);
}

void callback_function_ac(struct ac_module *const module_inst)
{
    callback_status = true;
}

void configure_ac_callback(void)
{
    ac_register_callback(&ac_instance, callback_function_ac, AC_CALLBACK_COMPARATOR_0);
    ac_enable_callback(&ac_instance, AC_CALLBACK_COMPARATOR_0);
}
```

Add to user application initialization (typically the start of `main()`):

```
system_init();
configure_ac();
configure_ac_channel();
configure_ac_callback();

ac_enable(&ac_instance);
```

Workflow

1. Create an AC device instance struct, which will be associated with an Analog Comparator peripheral hardware instance.

   ```
   static struct ac_module ac_instance;
   ```

Note Device instance structures shall **never** go out of scope when in use.

2. Define a macro to select the comparator channel that will be sampled, for convenience.

```
#define AC_COMPARATOR_CHANNEL    AC_CHAN_CHANNEL_0
```

3. Create a new function `configure_ac()`, which will be used to configure the overall Analog Comparator peripheral.

```
void configure_ac(void)
{
```

4. Create an Analog Comparator peripheral configuration structure that will be filled out to set the module configuration.

```
struct ac_config config_ac;
```

5. Fill the Analog Comparator peripheral configuration structure with the default module configuration values.

```
ac_get_config_defaults(&config_ac);
```

6. Initialize the Analog Comparator peripheral and associate it with the software instance structure that was defined previously.

```
ac_init(&ac_instance, AC, &config_ac);
```

7. Create a new function `configure_ac_channel()`, which will be used to configure the overall Analog Comparator peripheral.

```
void configure_ac_channel(void)
{
```

8. Create an Analog Comparator channel configuration structure that will be filled out to set the channel configuration.

```
struct ac_chan_config config_ac_chan;
```

9. Fill the Analog Comparator channel configuration structure with the default channel configuration values.

```
ac_chan_get_config_defaults(&config_ac_chan);
```

10. Alter the channel configuration parameters to set the channel to one-shot mode, with the correct negative and positive MUX selections and the desired voltage scaler.

Note The voltage scalar formula is documented in description for ac_chan_config::vcc_scale_factor.

11. Select when the interrupt should occur. In this case an interrupt will occur at every finished conversion.

```
config_ac_chan.sample_mode          = AC_CHAN_MODE_SINGLE_SHOT;
```

```
config_ac_chan.positive_input      = AC_CHAN_POS_MUX_PIN0;
config_ac_chan.negative_input      = AC_CHAN_NEG_MUX_SCALED_VCC;
config_ac_chan.vcc_scale_factor    = 32;
config_ac_chan.interrupt_selection = AC_CHAN_INTERRUPT_SELECTION_END_OF_COMPARE;
```

12. Configure the physical pin that will be routed to the AC module channel 0.

```
struct system_pinmux_config ac0_pin_conf;
system_pinmux_get_config_defaults(&ac0_pin_conf);
ac0_pin_conf.direction    = SYSTEM_PINMUX_PIN_DIR_INPUT;
ac0_pin_conf.mux_position = MUX_PA04B_AC_AIN0;
system_pinmux_pin_set_config(PIN_PA04B_AC_AIN0, &ac0_pin_conf);
```

13. Initialize the Analog Comparator channel and configure it with the desired settings.

```
ac_chan_set_config(&ac_instance, AC_COMPARATOR_CHANNEL, &config_ac_chan);
```

14. Enable the initialized Analog Comparator channel.

```
ac_chan_enable(&ac_instance, AC_COMPARATOR_CHANNEL);
```

15. Create a new callback function.

```
void callback_function_ac(struct ac_module *const module_inst)
{
    callback_status = true;
}
```

16. Create a callback status software flag

```
bool volatile callback_status = false;
```

17. Let the callback function set the calback_status flag to true

```
callback_status = true;
```

18. Create a new function `configure_ac_callback()`, which will be used to configure the callbacks.

```
void configure_ac_callback(void)
{
    ac_register_callback(&ac_instance, callback_function_ac, AC_CALLBACK_COMPARATOR_0);
    ac_enable_callback(&ac_instance, AC_CALLBACK_COMPARATOR_0);
}
```

19. Register callback function.

```
ac_register_callback(&ac_instance, callback_function_ac, AC_CALLBACK_COMPARATOR_0);
```

20. Enable the callbacks.

```
ac_enable_callback(&ac_instance, AC_CALLBACK_COMPARATOR_0);
```

21. Enable the now initialized Analog Comparator peripheral.

```
ac_enable(&ac_instance);
```

Note This should not be done until after the AC is setup and ready to be used

1.8.2.2 Implementation

Code

Copy-paste the following code to your user application:

```
ac_chan_trigger_single_shot(&ac_instance, AC_COMPARATOR_CHANNEL);

uint8_t last_comparison = AC_CHAN_STATUS_UNKNOWN;
port_pin_set_output_level(LED_0_PIN, true);
while (true) {
    if (callback_status == true) {
        do
        {
            last_comparison = ac_chan_get_status(&ac_instance,
                    AC_COMPARATOR_CHANNEL);
        } while (last_comparison & AC_CHAN_STATUS_UNKNOWN);
        port_pin_set_output_level(LED_0_PIN,
                (last_comparison & AC_CHAN_STATUS_NEG_ABOVE_POS));
        callback_status = false;
        ac_chan_trigger_single_shot(&ac_instance, AC_COMPARATOR_CHANNEL);
    }
}
```

Workflow

1. Trigger the first comparison on the comparator channel.

   ```
   ac_chan_trigger_single_shot(&ac_instance, AC_COMPARATOR_CHANNEL);
   ```

2. Create a local variable to maintain the current comparator state. Since no comparison has taken place, it is initialized to AC_CHAN_STATUS_UNKNOWN.

   ```
   uint8_t last_comparison = AC_CHAN_STATUS_UNKNOWN;
   ```

3. Make the application loop infinitely, while performing triggered comparisons.

   ```
   while (true) {
   ```

4. Check if a new comparison is complete.

   ```
   if (callback_status == true) {
   ```

5. Check if the comparator is ready for the last triggered comparison result to be read.

   ```
   do
   {
       last_comparison = ac_chan_get_status(&ac_instance,
               AC_COMPARATOR_CHANNEL);
   ```

```
} while (last_comparison & AC_CHAN_STATUS_UNKNOWN);
```

6. Read the comparator output state into the local variable for application use, re-trying until the comparison state is ready.

```
do
{
    last_comparison = ac_chan_get_status(&ac_instance,
            AC_COMPARATOR_CHANNEL);
} while (last_comparison & AC_CHAN_STATUS_UNKNOWN);
```

7. Set the board LED state to mirror the last comparison state.

```
port_pin_set_output_level(LED_0_PIN,
        (last_comparison & AC_CHAN_STATUS_NEG_ABOVE_POS));
```

8. After the interrupt is handled, set the software callback flag to false.

```
callback_status = false;
```

9. Trigger the next conversion on the Analog Comparator channel.

```
ac_chan_trigger_single_shot(&ac_instance, AC_COMPARATOR_CHANNEL);
```

2. SAM D20/D21 Analog to Digital Converter Driver (ADC)

This driver for SAM D20/D21 devices provides an interface for the configuration and management of the device's Analog to Digital Converter functionality, for the conversion of analog voltages into a corresponding digital form. The following driver API modes are covered by this manual:

- Polled APIs
- Callback APIs

The following peripherals are used by this module:

- ADC (Analog to Digital Converter)

The outline of this documentation is as follows:

- Prerequisites
- Module Overview
- Special Considerations
- Extra Information
- Examples
- API Overview

2.1 Prerequisites

There are no prerequisites for this module.

2.2 Module Overview

This driver provides an interface for the Analog-to-Digital conversion functions on the device, to convert analog voltages to a corresponding digital value. The ADC has up to 12-bit resolution, and is capable of converting up to 500k samples per second (ksps).

The ADC has a compare function for accurate monitoring of user defined thresholds with minimum software intervention required. The ADC may be configured for 8-, 10- or 12-bit result, reducing the conversion time from 2.0µs for 12-bit to 1.4µs for 8-bit result. ADC conversion results are provided left or right adjusted which eases calculation when the result is represented as a signed integer.

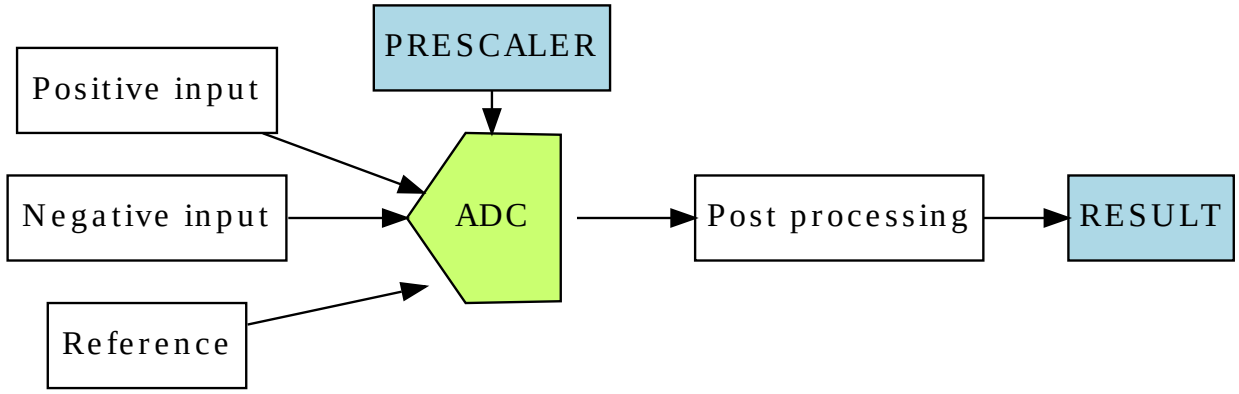
The input selection is flexible, and both single-ended and differential measurements can be made. For differential measurements, an optional gain stage is available to increase the dynamic range. In addition, several internal signal inputs are available. The ADC can provide both signed and unsigned results.

The ADC measurements can either be started by application software or an incoming event from another peripheral in the device, and both internal and external reference voltages can be selected.

Note Internal references will be enabled by the driver, but not disabled. Any reference not used by the application should be disabled by the application.

A simplified block diagram of the ADC can be seen in Figure 2-1: Module Overview on page 44.

Figure 2-1. Module Overview



2.2.1 Sample Clock Prescaler

The ADC features a prescaler which enables conversion at lower clock rates than the input Generic Clock to the ADC module. This feature can be used to lower the synchronization time of the digital interface to the ADC module via a high speed Generic Clock frequency, while still allowing the ADC sampling rate to be reduced.

2.2.2 ADC Resolution

The ADC supports full 8-bit, 10-bit or 12-bit resolution. Hardware oversampling and decimation can be used to increase the effective resolution at the expense of throughput. Using oversampling and decimation mode the ADC resolution is increased from 12-bits to an effective 13, 14, 15 or 16-bits. In these modes the conversion rate is reduced, as a greater number of samples is used to achieve the increased resolution. The available resolutions and effective conversion rate is listed in Table 2-1: Effective ADC conversion speed using oversampling on page 44.

Table 2-1. Effective ADC conversion speed using oversampling

Resolution	Effective conversion rate
13-bits	Conversion rate divided by 4
14-bits	Conversion rate divided by 16
15-bits	Conversion rate divided by 64
16-bits	Conversion rate divided by 256

2.2.3 Conversion Modes

ADC conversions can be software triggered on demand by the user application, if continuous sampling is not required. It is also possible to configure the ADC in free-running mode, where new conversions are started as soon as the previous conversion is completed, or configure the ADC to scan across a number of input pins (see Pin Scan).

2.2.4 Differential and Single-Ended Conversion

The ADC has two conversion modes; differential and single-ended. When measuring signals where the positive input pin is always at a higher voltage than the negative input pin, the single-ended conversion mode should be used in order to achieve a full 12-bit output resolution.

If however the positive input pin voltage may drop below the negative input pin the signed differential mode should be used.

2.2.5 Sample Time

The sample time for each ADC conversion is configurable as a number of half prescaled ADC clock cycles (depending on the prescaler value), allowing the user application to achieve faster or slower sampling depending on the source impedance of the ADC input channels. For applications with high impedance inputs the sample time can be increased to give the ADC an adequate time to sample and convert the input channel.

The resulting sampling time is given by the following equation:

$$t_{SAMPLE} = (sample\_length + 1) \times \frac{ADC_{CLK}}{2} \quad (2.1)$$

2.2.6 Averaging

The ADC can be configured to trade conversion speed for accuracy by averaging multiple samples in hardware. This feature is suitable when operating in noisy conditions.

You can specify any number of samples to accumulate (up to 1024) and the divide ratio to use (up to divide by 128). To modify these settings the ADC_RESOLUTION_CUSTOM needs to be set as the resolution. When this is set the number of samples to accumulate and the division ratio can be set by the configuration struct members adc_config::accumulate_samples and adc_config::divide_result When using this mode the ADC result register will be set to be 16-bits wide to accommodate the larger result sizes produced by the accumulator.

The effective ADC conversion rate will be reduced by a factor of the number of accumulated samples; however the effective resolution will be increased according to Table 2-2: Effective ADC resolution from various hardware averaging modes on page 45.

Table 2-2. Effective ADC resolution from various hardware averaging modes

Number of Samples	Final Result
1	12-bits
2	13-bits
4	14-bits
8	15-bits
16	16-bits
32	16-bits
64	16-bits
128	16-bits
256	16-bits
512	16-bits
1024	16-bits

2.2.7 Offset and Gain Correction

Inherent gain and offset errors affect the absolute accuracy of the ADC.

The offset error is defined as the deviation of the ADC's actual transfer function from ideal straight line at zero input voltage.

The gain error is defined as the deviation of the last output step's midpoint from the ideal straight line, after compensating for offset error.

The offset correction value is subtracted from the converted data before the result is ready. The gain correction value is multiplied with the offset corrected value.

The equation for both offset and gain error compensation is shown below:

$$ADC_{RESULT} = (VALUE_{CONV} + CORR_{OFFSET}) \times CORR_{GAIN} \quad (2.2)$$

When enabled, a given set of offset and gain correction values can be applied to the sampled data in hardware, giving a corrected stream of sample data to the user application at the cost of an increased sample latency.

In single conversion, a latency of 13 ADC Generic Clock cycles is added for the final sample result availability. As the correction time is always less than the propagation delay, in free running mode this latency appears only during the first conversion. After the first conversion is complete future conversion results are available at the defined sampling rate.

2.2.8 Pin Scan

In pin scan mode, the first ADC conversion will begin from the configured positive channel, plus the requested starting offset. When the first conversion is completed, the next conversion will start at the next positive input channel and so on, until all requested pins to scan have been sampled and converted.

Pin scanning gives a simple mechanism to sample a large number of physical input channel samples, using a single physical ADC channel.

2.2.9 Window Monitor

The ADC module window monitor function can be used to automatically compare the conversion result against a preconfigured pair of upper and lower threshold values.

The threshold values are evaluated differently, depending on whether differential or single-ended mode is selected. In differential mode, the upper and lower thresholds are evaluated as signed values for the comparison, while in single-ended mode the comparisons are made as a set of unsigned values.

The significant bits of the lower window monitor threshold and upper window monitor threshold values are user-configurable, and follow the overall ADC sampling bit precision set when the ADC is configured by the user application. For example, only the eight lower bits of the window threshold values will be compares to the sampled data whilst the ADC is configured in 8-bit mode. In addition, if using differential mode, the 8th bit will be considered as the sign bit even if bit 9 is zero.

2.2.10 Events

Event generation and event actions are configurable in the ADC.

The ADC has two actions that can be triggered upon event reception:

- Start conversion
- Flush pipeline and start conversion

The ADC can generate two events:

- Window monitor
- Result ready

If the event actions are enabled in the configuration, any incoming event will trigger the action.

If the window monitor event is enabled, an event will be generated when the configured window condition is detected.

If the result ready event is enabled, an event will be generated when a conversion is completed.

Note The connection of events between modules requires the use of the SAM D20/D21 Event System Driver (EVENTS) to route output event of one module to the the input event of another. For more information on event routing, refer to the event driver documentation.

2.3 Special Considerations

An integrated analog temperature sensor is available for use with the ADC. The bandgap voltage, as well as the scaled IO and core voltages can also be measured by the ADC. For internal ADC inputs, the internal source(s) may need to be manually enabled by the user application before they can be measured.

2.4 Extra Information

For extra information see Extra Information for ADC Driver. This includes:

- Acronyms
- Dependencies

- Errata
- Module History

2.5 Examples

For a list of examples related to this driver, see Examples for ADC Driver.

2.6 API Overview

2.6.1 Variable and Type Definitions

2.6.1.1 Type adc_callback_t

```
typedef void(* adc_callback_t )(const struct adc_module *const module)
```

Type of the callback functions

2.6.2 Structure Definitions

2.6.2.1 Struct adc_config

Configuration structure for an ADC instance. This structure should be initialized by the adc_get_config_defaults() function before being modified by the user application.

Table 2-3. Members

Type	Name	Description
enum adc_accumulate_samples	accumulate_samples	Number of ADC samples to accumulate when using the ADC_RESOLUTION_CUSTOM mode
enum adc_clock_prescaler	clock_prescaler	Clock prescaler
enum gclk_generator	clock_source	GCLK generator used to clock the peripheral
struct adc_correction_config	correction	Gain and offset correction configuration structure
bool	differential_mode	Enables differential mode if true
enum adc_divide_result	divide_result	Division ration when using the ADC_RESOLUTION_CUSTOM mode
enum adc_event_action	event_action	Event action to take on incoming event
bool	freerunning	Enables free running mode if true
enum adc_gain_factor	gain_factor	Gain factor
bool	left_adjust	Left adjusted result
enum adc_negative_input	negative_input	Negative MUX input
struct adc_pin_scan_config	pin_scan	Pin scan configuration structure
enum adc_positive_input	positive_input	Positive MUX input
enum adc_reference	reference	Voltage reference
bool	reference_compensation_enable	Enables reference buffer offset compensation if true. This will

Type	Name	Description
		increase the accuracy of the gain stage, but decreases the input impedance; therefore the startup time of the reference must be increased.
enum adc_resolution	resolution	Result resolution
bool	run_in_standby	Enables ADC in standby sleep mode if true
uint8_t	sample_length	This value (0-63) control the ADC sampling time in number of half ADC prescaled clock cycles (depends of ADC_PRESCALER value), thus controlling the ADC input impedance. Sampling time is set according to the formula: Sample time = (sample_length+1) * (ADCclk / 2)
struct adc_window_config	window	Window monitor configuration structure

2.6.2.2 Struct adc_correction_config

Gain and offset correction configuration structure. Part of the adc_config struct and will be initialized by adc_get_config_defaults .

Table 2-4. Members

Type	Name	Description
bool	correction_enable	Enables correction for gain and offset based on values of gain_correction and offset_correction if set to true.
uint16_t	gain_correction	This value defines how the ADC conversion result is compensated for gain error before written to the result register. This is a fractional value, 1-bit integer plus an 11-bit fraction, therefore 1/2 <= gain_correction < 2. Valid gain_correction values ranges from 0b010000000000 to 0b111111111111.
int16_t	offset_correction	This value defines how the ADC conversion result is compensated for offset error before written to the result register. This is a 12-bit value in two's complement format.

2.6.2.3 Struct adc_events

Event flags for the ADC module. This is used to enable and disable events via adc_enable_events() and adc_disable_events().

Table 2-5. Members

Type	Name	Description
bool	generate_event_on_conversion_don	Enable event generation on conversion done
bool	generate_event_on_window_monitor	Enable event generation on window monitor

2.6.2.4 Struct adc_module

ADC software instance structure, used to retain software state information of an associated hardware module instance.

Note The fields of this structure should not be altered by the user application; they are reserved for module-internal use only.

2.6.2.5 Struct adc_pin_scan_config

Pin scan configuration structure. Part of the adc_config struct and will be initialized by adc_get_config_defaults .

Table 2-6. Members

Type	Name	Description
uint8_t	inputs_to_scan	Number of input pins to scan in pin scan mode. A value below 2 will disable pin scan mode.
uint8_t	offset_start_scan	Offset (relative to selected positive input) of the first input pin to be used in pin scan mode.

2.6.2.6 Struct adc_window_config

Window monitor configuration structure.

Table 2-7. Members

Type	Name	Description
int32_t	window_lower_value	Lower window value
enum adc_window_mode	window_mode	Selected window mode
int32_t	window_upper_value	Upper window value

2.6.3 Macro Definitions

2.6.3.1 Module status flags

ADC status flags, returned by adc_get_status() and cleared by adc_clear_status().

Macro ADC_STATUS_RESULT_READY

```
#define ADC_STATUS_RESULT_READY (1UL << 0)
```

ADC result ready

Macro ADC_STATUS_WINDOW

```
#define ADC_STATUS_WINDOW (1UL << 1)
```

Window monitor match

Macro ADC_STATUS_OVERRUN

```
#define ADC_STATUS_OVERRUN (1UL << 2)
```

ADC result overwritten before read

2.6.4 Function Definitions

2.6.4.1 Driver initialization and configuration

Function adc_init()

Initializes the ADC.

```
enum status_code adc_init(
  struct adc_module *const module_inst,
  Adc * hw,
  struct adc_config * config)
```

Initializes the ADC device struct and the hardware module based on the given configuration struct values.

Table 2-8. Parameters

Data direction	Parameter name	Description
[out]	module_inst	Pointer to the ADC software instance struct
[in]	hw	Pointer to the ADC module instance
[in]	config	Pointer to the configuration struct

Returns Status of the initialization procedure

Table 2-9. Return Values

Return value	Description
STATUS_OK	The initialization was successful
STATUS_ERR_INVALID_ARG	Invalid argument(s) were provided
STATUS_BUSY	The module is busy with a reset operation
STATUS_ERR_DENIED	The module is enabled

Function adc_get_config_defaults()

Initializes an ADC configuration structure to defaults.

```
void adc_get_config_defaults(
  struct adc_config *const config)
```

Initializes a given ADC configuration struct to a set of known default values. This function should be called on any new instance of the configuration struct before being modified by the user application.

The default configuration is as follows:

- GCLK generator 0 (GCLK main) clock source
- 1V from internal bandgap reference
- Div 4 clock prescaler
- 12 bit resolution
- Window monitor disabled
- No gain
- Positive input on ADC PIN 0
- Negative input on ADC PIN 1
- Averaging disabled
- Oversampling disabled
- Right adjust data
- Single-ended mode
- Free running disabled
- All events (input and generation) disabled
- Sleep operation disabled
- No reference compensation
- No gain/offset correction
- No added sampling time
- Pin scan mode disabled

Table 2-10. Parameters

Data direction	Parameter name	Description
[out]	config	Pointer to configuration struct to initialize to default values

2.6.4.2 Status Management

Function adc_get_status()

Retrieves the current module status.

```
uint32_t adc_get_status(
  struct adc_module *const module_inst)
```

Retrieves the status of the module, giving overall state information.

Table 2-11. Parameters

Data direction	Parameter name	Description
[in]	module_inst	Pointer to the ADC software instance struct

Returns Bitmask of ADC_STATUS_* flags

Table 2-12. Return Values

Return value	Description
ADC_STATUS_RESULT_READY	ADC Result is ready to be read
ADC_STATUS_WINDOW	ADC has detected a value inside the set window range
ADC_STATUS_OVERRUN	ADC result has overrun

Function adc_clear_status()

Clears a module status flag.

```
void adc_clear_status(
  struct adc_module *const module_inst,
  const uint32_t status_flags)
```

Clears the given status flag of the module.

Table 2-13. Parameters

Data direction	Parameter name	Description
[in]	module_inst	Pointer to the ADC software instance struct
[in]	status_flags	Bitmask of ADC_STATUS_* flags to clear

2.6.4.3 Enable, disable and reset ADC module, start conversion and read result

Function adc_is_syncing()

Determines if the hardware module(s) are currently synchronizing to the bus.

```
bool adc_is_syncing(
  struct adc_module *const module_inst)
```

Checks to see if the underlying hardware peripheral module(s) are currently synchronizing across multiple clock domains to the hardware bus, This function can be used to delay further operations on a module until such time that it is ready, to prevent blocking delays for synchronization in the user application.

Table 2-14. Parameters

Data direction	Parameter name	Description
[in]	module_inst	Pointer to the ADC software instance struct

Returns Synchronization status of the underlying hardware module(s).

Table 2-15. Return Values

Return value	Description
true	if the module has completed synchronization
false	if the module synchronization is ongoing

Function adc_enable()

Enables the ADC module.

```
enum status_code adc_enable(
  struct adc_module *const module_inst)
```

Enables an ADC module that has previously been configured. If any internal reference is selected it will be enabled.

Table 2-16. Parameters

Data direction	Parameter name	Description
[in]	module_inst	Pointer to the ADC software instance struct

Function adc_disable()

Disables the ADC module.

```
enum status_code adc_disable(
  struct adc_module *const module_inst)
```

Disables an ADC module that was previously enabled.

Table 2-17. Parameters

Data direction	Parameter name	Description
[in]	module_inst	Pointer to the ADC software instance struct

Function adc_reset()

Resets the ADC module.

```
enum status_code adc_reset(
  struct adc_module *const module_inst)
```

Resets an ADC module, clearing all module state and registers to their default values.

Table 2-18. Parameters

Data direction	Parameter name	Description
[in]	module_inst	Pointer to the ADC software instance struct

Function adc_enable_events()

Enables an ADC event input or output.

```
void adc_enable_events(
  struct adc_module *const module_inst,
  struct adc_events *const events)
```

Enables one or more input or output events to or from the ADC module. See here for a list of events this module supports.

Note Events cannot be altered while the module is enabled.

Table 2-19. Parameters

Data direction	Parameter name	Description
[in]	module_inst	Software instance for the ADC peripheral
[in]	events	Struct containing flags of events to enable

Function adc_disable_events()

Disables an ADC event input or output.

```
void adc_disable_events(
  struct adc_module *const module_inst,
  struct adc_events *const events)
```

Disables one or more input or output events to or from the ADC module. See here for a list of events this module supports.

Note Events cannot be altered while the module is enabled.

Table 2-20. Parameters

Data direction	Parameter name	Description
[in]	module_inst	Software instance for the ADC peripheral
[in]	events	Struct containing flags of events to disable

Function adc_start_conversion()

Starts an ADC conversion.

```
void adc_start_conversion(
  struct adc_module *const module_inst)
```

Starts a new ADC conversion.

Table 2-21. Parameters

Data direction	Parameter name	Description
[in]	module_inst	Pointer to the ADC software instance struct

Function adc_read()

Reads the ADC result.

```
enum status_code adc_read(
  struct adc_module *const module_inst,
  uint16_t * result)
```

Reads the result from an ADC conversion that was previously started.

Table 2-22. Parameters

Data direction	Parameter name	Description
[in]	module_inst	Pointer to the ADC software instance struct
[out]	result	Pointer to store the result value in

Returns Status of the ADC read request.

Table 2-23. Return Values

Return value	Description
STATUS_OK	The result was retrieved successfully
STATUS_BUSY	A conversion result was not ready
STATUS_ERR_OVERFLOW	The result register has been overwritten by the ADC module before the result was read by the software

2.6.4.4 Runtime changes of ADC module

Function adc_flush()

Flushes the ADC pipeline.

```
void adc_flush(
  struct adc_module *const module_inst)
```

Flushes the pipeline and restart the ADC clock on the next peripheral clock edge. All conversions in progress will be lost. When flush is complete, the module will resume where it left off.

Table 2-24. Parameters

Data direction	Parameter name	Description
[in]	module_inst	Pointer to the ADC software instance struct

Function adc_set_window_mode()

Sets the ADC window mode.

```
void adc_set_window_mode(
  struct adc_module *const module_inst,
  const enum adc_window_mode window_mode,
  const int16_t window_lower_value,
  const int16_t window_upper_value)
```

Sets the ADC window mode to a given mode and value range.

Table 2-25. Parameters

Data direction	Parameter name	Description
[in]	module_inst	Pointer to the ADC software instance struct
[in]	window_mode	Window monitor mode to set
[in]	window_lower_value	Lower window monitor threshold value
[in]	window_upper_value	Upper window monitor threshold value

Function adc_set_gain()

Sets ADC gain factor.

```
void adc_set_gain(
  struct adc_module *const module_inst,
  const enum adc_gain_factor gain_factor)
```

Sets the ADC gain factor to a specified gain setting.

Table 2-26. Parameters

Data direction	Parameter name	Description
[in]	module_inst	Pointer to the ADC software instance struct
[in]	gain_factor	Gain factor value to set

Function adc_set_pin_scan_mode()

Sets the ADC pin scan mode.

```
enum status_code adc_set_pin_scan_mode(
  struct adc_module *const module_inst,
  uint8_t inputs_to_scan,
  const uint8_t start_offset)
```

Configures the pin scan mode of the ADC module. In pin scan mode, the first conversion will start at the configured positive input + start_offset. When a conversion is done, a conversion will start on the next input, until `inputs_to_scan` number of conversions are made.

Table 2-27. Parameters

Data direction	Parameter name	Description
[in]	module_inst	Pointer to the ADC software instance struct
[in]	inputs_to_scan	Number of input pins to perform a conversion on (must be two or more)
[in]	start_offset	Offset of first pin to scan (relative to configured positive input)

Returns Status of the pin scan configuration set request.

Table 2-28. Return Values

Return value	Description
STATUS_OK	Pin scan mode has been set successfully
STATUS_ERR_INVALID_ARG	Number of input pins to scan or offset has an invalid value

Function adc_disable_pin_scan_mode()

Disables pin scan mode.

```
void adc_disable_pin_scan_mode(
  struct adc_module *const module_inst)
```

Disables pin scan mode. The next conversion will be made on only one pin (the configured positive input pin).

Table 2-29. Parameters

Data direction	Parameter name	Description
[in]	module_inst	Pointer to the ADC software instance struct

Function adc_set_positive_input()

Sets positive ADC input pin.

```
void adc_set_positive_input(
  struct adc_module *const module_inst,
  const enum adc_positive_input positive_input)
```

Sets the positive ADC input pin selection.

Table 2-30. Parameters

Data direction	Parameter name	Description
[in]	module_inst	Pointer to the ADC software instance struct
[in]	positive_input	Positive input pin

Function adc_set_negative_input()

Sets negative ADC input pin for differential mode.

```
void adc_set_negative_input(
  struct adc_module *const module_inst,
  const enum adc_negative_input negative_input)
```

Sets the negative ADC input pin, when the ADC is configured in differential mode.

Table 2-31. Parameters

Data direction	Parameter name	Description
[in]	module_inst	Pointer to the ADC software instance struct
[in]	negative_input	Negative input pin

2.6.4.5 Enable and disable interrupts

Function adc_enable_interrupt()

Enable interrupt.

```
void adc_enable_interrupt(
  struct adc_module *const module_inst,
  enum adc_interrupt_flag interrupt)
```

Enable the given interrupt request from the ADC module.

Table 2-32. Parameters

Data direction	Parameter name	Description
[in]	module_inst	Pointer to the ADC software instance struct
[in]	interrupt	Interrupt to enable

Function adc_disable_interrupt()

Disable interrupt.

```
void adc_disable_interrupt(
  struct adc_module *const module_inst,
  enum adc_interrupt_flag interrupt)
```

Disable the given interrupt request from the ADC module.

Table 2-33. Parameters

Data direction	Parameter name	Description
[in]	module_inst	Pointer to the ADC software instance struct
[in]	interrupt	Interrupt to disable

2.6.4.6 Callback Management

Function adc_register_callback()

Registers a callback.

```
void adc_register_callback(
  struct adc_module *const module,
  adc_callback_t callback_func,
  enum adc_callback callback_type)
```

Registers a callback function which is implemented by the user.

Note The callback must be enabled by for the interrupt handler to call it when the condition for the callback is met.

Table 2-34. Parameters

Data direction	Parameter name	Description
[in]	module	Pointer to ADC software instance struct
[in]	callback_func	Pointer to callback function
[in]	callback_type	Callback type given by an enum

Function adc_unregister_callback()

Unregisters a callback.

```
void adc_unregister_callback(
  struct adc_module * module,
  enum adc_callback callback_type)
```

Unregisters a callback function which is implemented by the user.

Table 2-35. Parameters

Data direction	Parameter name	Description
[in]	module	Pointer to ADC software instance struct
[in]	callback_type	Callback type given by an enum

Function adc_enable_callback()

Enables callback.

```
void adc_enable_callback(
  struct adc_module *const module,
  enum adc_callback callback_type)
```

Enables the callback function registered by adc_register_callback. The callback function will be called from the interrupt handler when the conditions for the callback type are met.

Table 2-36. Parameters

Data direction	Parameter name	Description
[in]	module	Pointer to ADC software instance struct
[in]	callback_type	Callback type given by an enum

Returns Status of the operation

Table 2-37. Return Values

Return value	Description
STATUS_OK	If operation was completed
STATUS_ERR_INVALID	If operation was not completed, due to invalid callback_type

Function adc_disable_callback()

Disables callback.

```
void adc_disable_callback(
  struct adc_module *const module,
  enum adc_callback callback_type)
```

Disables the callback function registered by the adc_register_callback.

Table 2-38. Parameters

Data direction	Parameter name	Description
[in]	module	Pointer to ADC software instance struct
[in]	callback_type	Callback type given by an enum

Returns Status of the operation

Table 2-39. Return Values

Return value	Description
STATUS_OK	If operation was completed
STATUS_ERR_INVALID	If operation was not completed, due to invalid callback_type

2.6.4.7 Job Management

Function adc_read_buffer_job()

Read multiple samples from ADC.

```
enum status_code adc_read_buffer_job(
  struct adc_module *const module_inst,
  uint16_t * buffer,
```

```
  uint16_t samples)
```

Read `samples` samples from the ADC into the buffer `buffer`. If there is no hardware trigger defined (event action) the driver will retrigger the ADC conversion whenever a conversion is complete until `samples` samples has been acquired. To avoid jitter in the sampling frequency using an event trigger is advised.

Table 2-40. Parameters

Data direction	Parameter name	Description
[in]	module_inst	Pointer to the ADC software instance struct
[in]	samples	Number of samples to acquire
[out]	buffer	Buffer to store the ADC samples

Returns Status of the job start

Table 2-41. Return Values

Return value	Description
STATUS_OK	The conversion job was started successfully and is in progress
STATUS_BUSY	The ADC is already busy with another job

Function adc_get_job_status()

Gets the status of a job.

```
enum status_code adc_get_job_status(
  struct adc_module * module_inst,
  enum adc_job_type type)
```

Gets the status of an ongoing or the last job.

Table 2-42. Parameters

Data direction	Parameter name	Description
[in]	module_inst	Pointer to the ADC software instance struct
[in]	type	Type of job to abort

Returns Status of the job

Function adc_abort_job()

Aborts an ongoing job.

```
void adc_abort_job(
  struct adc_module * module_inst,
  enum adc_job_type type)
```

Aborts an ongoing job.

Table 2-43. Parameters

Data direction	Parameter name	Description
[in]	module_inst	Pointer to the ADC software instance struct
[in]	type	Type of job to abort

2.6.5 Enumeration Definitions

2.6.5.1 Enum adc_accumulate_samples

Enum for the possible numbers of ADC samples to accumulate. This setting is only used when the ADC_RESOLUTION_CUSTOM on page 66 resolution setting is used.

Table 2-44. Members

Enum value	Description
ADC_ACCUMULATE_DISABLE	No averaging
ADC_ACCUMULATE_SAMPLES_2	Average 2 samples
ADC_ACCUMULATE_SAMPLES_4	Average 4 samples
ADC_ACCUMULATE_SAMPLES_8	Average 8 samples
ADC_ACCUMULATE_SAMPLES_16	Average 16 samples
ADC_ACCUMULATE_SAMPLES_32	Average 32 samples
ADC_ACCUMULATE_SAMPLES_64	Average 64 samples
ADC_ACCUMULATE_SAMPLES_128	Average 128 samples
ADC_ACCUMULATE_SAMPLES_256	Average 265 samples
ADC_ACCUMULATE_SAMPLES_512	Average 512 samples
ADC_ACCUMULATE_SAMPLES_1024	Average 1024 samples

2.6.5.2 Enum adc_callback

Callback types for ADC callback driver

Table 2-45. Members

Enum value	Description
ADC_CALLBACK_READ_BUFFER	Callback for buffer received
ADC_CALLBACK_WINDOW	Callback when window is hit
ADC_CALLBACK_ERROR	Callback for error

2.6.5.3 Enum adc_clock_prescaler

Enum for the possible clock prescaler values for the ADC.

Table 2-46. Members

Enum value	Description
ADC_CLOCK_PRESCALER_DIV4	ADC clock division factor 4

Enum value	Description
ADC_CLOCK_PRESCALER_DIV8	ADC clock division factor 8
ADC_CLOCK_PRESCALER_DIV16	ADC clock division factor 16
ADC_CLOCK_PRESCALER_DIV32	ADC clock division factor 32
ADC_CLOCK_PRESCALER_DIV64	ADC clock division factor 64
ADC_CLOCK_PRESCALER_DIV128	ADC clock division factor 128
ADC_CLOCK_PRESCALER_DIV256	ADC clock division factor 256
ADC_CLOCK_PRESCALER_DIV512	ADC clock division factor 512

2.6.5.4 Enum adc_divide_result

Enum for the possible division factors to use when accumulating multiple samples. To keep the same resolution for the averaged result and the actual input value the division factor must be equal to the number of samples accumulated. This setting is only used when the ADC_RESOLUTION_CUSTOM on page 66 resolution setting is used.

Table 2-47. Members

Enum value	Description
ADC_DIVIDE_RESULT_DISABLE	Don't divide result register after accumulation
ADC_DIVIDE_RESULT_2	Divide result register by 2 after accumulation
ADC_DIVIDE_RESULT_4	Divide result register by 4 after accumulation
ADC_DIVIDE_RESULT_8	Divide result register by 8 after accumulation
ADC_DIVIDE_RESULT_16	Divide result register by 16 after accumulation
ADC_DIVIDE_RESULT_32	Divide result register by 32 after accumulation
ADC_DIVIDE_RESULT_64	Divide result register by 64 after accumulation
ADC_DIVIDE_RESULT_128	Divide result register by 128 after accumulation

2.6.5.5 Enum adc_event_action

Enum for the possible actions to take on an incoming event.

Table 2-48. Members

Enum value	Description
ADC_EVENT_ACTION_DISABLED	Event action disabled
ADC_EVENT_ACTION_FLUSH_START_CONV	Flush ADC and start conversion
ADC_EVENT_ACTION_START_CONV	Start conversion

2.6.5.6 Enum adc_gain_factor

Enum for the possible gain factor values for the ADC.

Table 2-49. Members

Enum value	Description
ADC_GAIN_FACTOR_1X	1x gain
ADC_GAIN_FACTOR_2X	2x gain

Enum value	Description
ADC_GAIN_FACTOR_4X	4x gain
ADC_GAIN_FACTOR_8X	8x gain
ADC_GAIN_FACTOR_16X	16x gain
ADC_GAIN_FACTOR_DIV2	1/2x gain

2.6.5.7 Enum adc_interrupt_flag

Enum for the possible ADC interrupt flags

Table 2-50. Members

Enum value	Description
ADC_INTERRUPT_RESULT_READY	ADC result ready
ADC_INTERRUPT_WINDOW	Window monitor match
ADC_INTERRUPT_OVERRUN	ADC result overwritten before read

2.6.5.8 Enum adc_job_type

Enum for the possible types of ADC asynchronous jobs that may be issued to the driver.

Table 2-51. Members

Enum value	Description
ADC_JOB_READ_BUFFER	Asynchronous ADC read into a user provided buffer

2.6.5.9 Enum adc_negative_input

Enum for the possible negative MUX input selections for the ADC.

Table 2-52. Members

Enum value	Description
ADC_NEGATIVE_INPUT_PIN0	ADC0 pin
ADC_NEGATIVE_INPUT_PIN1	ADC1 pin
ADC_NEGATIVE_INPUT_PIN2	ADC2 pin
ADC_NEGATIVE_INPUT_PIN3	ADC3 pin
ADC_NEGATIVE_INPUT_PIN4	ADC4 pin
ADC_NEGATIVE_INPUT_PIN5	ADC5 pin
ADC_NEGATIVE_INPUT_PIN6	ADC6 pin
ADC_NEGATIVE_INPUT_PIN7	ADC7 pin
ADC_NEGATIVE_INPUT_GND	Internal ground
ADC_NEGATIVE_INPUT_IOGND	I/O ground

2.6.5.10 Enum adc_oversampling_and_decimation

Enum for the possible numbers of bits resolution can be increased by when using oversampling and decimation.

Table 2-53. Members

Enum value	Description
ADC_OVERSAMPLING_AND_DECIMATION_DISABLE	Don't use oversampling and decimation mode
ADC_OVERSAMPLING_AND_DECIMATION_1BIT	1 bit resolution increase
ADC_OVERSAMPLING_AND_DECIMATION_2BIT	2 bits resolution increase
ADC_OVERSAMPLING_AND_DECIMATION_3BIT	3 bits resolution increase
ADC_OVERSAMPLING_AND_DECIMATION_4BIT	4 bits resolution increase

2.6.5.11 Enum adc_positive_input

Enum for the possible positive MUX input selections for the ADC.

Table 2-54. Members

Enum value	Description
ADC_POSITIVE_INPUT_PIN0	ADC0 pin
ADC_POSITIVE_INPUT_PIN1	ADC1 pin
ADC_POSITIVE_INPUT_PIN2	ADC2 pin
ADC_POSITIVE_INPUT_PIN3	ADC3 pin
ADC_POSITIVE_INPUT_PIN4	ADC4 pin
ADC_POSITIVE_INPUT_PIN5	ADC5 pin
ADC_POSITIVE_INPUT_PIN6	ADC6 pin
ADC_POSITIVE_INPUT_PIN7	ADC7 pin
ADC_POSITIVE_INPUT_PIN8	ADC8 pin
ADC_POSITIVE_INPUT_PIN9	ADC9 pin
ADC_POSITIVE_INPUT_PIN10	ADC10 pin
ADC_POSITIVE_INPUT_PIN11	ADC11 pin
ADC_POSITIVE_INPUT_PIN12	ADC12 pin
ADC_POSITIVE_INPUT_PIN13	ADC13 pin
ADC_POSITIVE_INPUT_PIN14	ADC14 pin
ADC_POSITIVE_INPUT_PIN15	ADC15 pin
ADC_POSITIVE_INPUT_PIN16	ADC16 pin
ADC_POSITIVE_INPUT_PIN17	ADC17 pin
ADC_POSITIVE_INPUT_PIN18	ADC18 pin
ADC_POSITIVE_INPUT_PIN19	ADC19 pin
ADC_POSITIVE_INPUT_TEMP	Temperature reference
ADC_POSITIVE_INPUT_BANDGAP	Bandgap voltage
ADC_POSITIVE_INPUT_SCALEDCOREVCC	1/4 scaled core supply
ADC_POSITIVE_INPUT_SCALEDIOVCC	1/4 scaled I/O supply
ADC_POSITIVE_INPUT_DAC	DAC input

2.6.5.12 Enum adc_reference

Enum for the possible reference voltages for the ADC.

Table 2-55. Members

Enum value	Description
ADC_REFERENCE_INT1V	1.0V voltage reference
ADC_REFERENCE_INTVCC0	1/1.48 VCC reference
ADC_REFERENCE_INTVCC1	1/2 VCC (only for internal Vcc > 2.1v)
ADC_REFERENCE_AREFA	External reference A
ADC_REFERENCE_AREFB	External reference B

2.6.5.13 Enum adc_resolution

Enum for the possible resolution values for the ADC.

Table 2-56. Members

Enum value	Description
ADC_RESOLUTION_12BIT	ADC 12-bit resolution
ADC_RESOLUTION_16BIT	ADC 16-bit resolution using oversampling and decimation
ADC_RESOLUTION_10BIT	ADC 10-bit resolution
ADC_RESOLUTION_8BIT	ADC 8-bit resolution
ADC_RESOLUTION_13BIT	ADC 13-bit resolution using oversampling and decimation
ADC_RESOLUTION_14BIT	ADC 14-bit resolution using oversampling and decimation
ADC_RESOLUTION_15BIT	ADC 15-bit resolution using oversampling and decimation
ADC_RESOLUTION_CUSTOM	ADC 16-bit result register for use with averaging. When using this mode the ADC result register will be set to 16-bit wide, and the number of samples to accumulate and the division factor is configured by the adc_config::accumulate_samples and adc_config::divide_result members in the configuration struct

2.6.5.14 Enum adc_window_mode

Enum for the possible window monitor modes for the ADC.

Table 2-57. Members

Enum value	Description
ADC_WINDOW_MODE_DISABLE	No window mode
ADC_WINDOW_MODE_ABOVE_LOWER	RESULT > WINLT
ADC_WINDOW_MODE_BELOW_UPPER	RESULT < WINUT
ADC_WINDOW_MODE_BETWEEN	WINLT < RESULT < WINUT
ADC_WINDOW_MODE_BETWEEN_INVERTED	!(WINLT < RESULT < WINUT)

2.7 Extra Information for ADC Driver

2.7.1 Acronyms

Below is a table listing the acronyms used in this module, along with their intended meanings.

Acronym	Description
ADC	Analog-to-Digital Converter
DAC	Digital-to-Analog Converter
LSB	Least Significant Bit
MSB	Most Significant Bit
DMA	Direct Memory Access

2.7.2 Dependencies

This driver has the following dependencies:

- System Pin Multiplexer Driver

2.7.3 Errata

There are no errata related to this driver.

2.7.4 Module History

An overview of the module history is presented in the table below, with details on the enhancements and fixes made to the module since its first release. The current version of this corresponds to the newest version in the table.

Changelog
Added support for SAMD21 and new DMA quick start guide.
Added ADC calibration constant loading from the device signature row when the module is initialized.
Initial Release

2.8 Examples for ADC Driver

This is a list of the available Quick Start guides (QSGs) and example applications for SAM D20/D21 Analog to Digital Converter Driver (ADC). QSGs are simple examples with step-by-step instructions to configure and use this driver in a selection of use cases. Note that QSGs can be compiled as a standalone application or be added to the user application.

- Quick Start Guide for ADC - Basic
- Quick Start Guide for ADC - Callback
- Quick Start Guide for Using DMA with ADC/DAC

2.8.1 Quick Start Guide for ADC - Basic

In this use case, the ADC will be configured with the following settings:

- 1V from internal bandgap reference
- Div 4 clock prescaler
- 12 bit resolution
- Window monitor disabled
- No gain

- Positive input on ADC PIN 0
- Negative input on ADC PIN 1
- Averaging disabled
- Oversampling disabled
- Right adjust data
- Single-ended mode
- Free running disabled
- All events (input and generation) disabled
- Sleep operation disabled
- No reference compensation
- No gain/offset correction
- No added sampling time
- Pin scan mode disabled

2.8.1.1 Setup

Prerequisites

There are no special setup requirements for this use-case.

Code

Add to the main application source file, outside of any functions:

```
struct adc_module adc_instance;
```

Copy-paste the following setup code to your user application:

```
void configure_adc(void)
{
    struct adc_config config_adc;
    adc_get_config_defaults(&config_adc);

    adc_init(&adc_instance, ADC, &config_adc);

    adc_enable(&adc_instance);
}
```

Add to user application initialization (typically the start of `main()`):

```
configure_adc();
```

Workflow

1. Create a module software instance structure for the ADC module to store the ADC driver state while it is in use.

   ```
   struct adc_module adc_instance;
   ```

Note This should never go out of scope as long as the module is in use. In most cases, this should be global.

2. Configure the ADC module.

   a. Create a ADC module configuration struct, which can be filled out to adjust the configuration of a physical ADC peripheral.

```
struct adc_config config_adc;
```

   b. Initialize the ADC configuration struct with the module's default values.

```
adc_get_config_defaults(&config_adc);
```

Note This should always be performed before using the configuration struct to ensure that all values are initialized to known default settings.

   c. Enable the ADC module so that conversions can be made.

```
adc_enable(&adc_instance);
```

2.8.1.2 Use Case

Code

Copy-paste the following code to your user application:

```
adc_start_conversion(&adc_instance);

uint16_t result;

do {
    /* Wait for conversion to be done and read out result */
} while (adc_read(&adc_instance, &result) == STATUS_BUSY);

while (1) {
    /* Infinite loop */
}
```

Workflow

1. Start conversion.

```
adc_start_conversion(&adc_instance);
```

2. Wait until conversion is done and read result.

```
uint16_t result;

do {
    /* Wait for conversion to be done and read out result */
} while (adc_read(&adc_instance, &result) == STATUS_BUSY);
```

3. Enter an infinite loop once the conversion is complete.

```
while (1) {
    /* Infinite loop */
}
```

2.8.2 Quick Start Guide for ADC - Callback

In this use case, the ADC will be convert 128 samples using interrupt driven conversion. When all samples have been sampled, a callback will be called that signals the main application that conversion is compete.

The ADC will be set up as follows:

- VCC / 2 as reference
- Div 8 clock prescaler
- 12 bit resolution
- Window monitor disabled
- 1/2 gain
- Positive input on ADC PIN 0
- Negative input to GND (Single ended)
- Averaging disabled
- Oversampling disabled
- Right adjust data
- Single-ended mode
- Free running disabled
- All events (input and generation) disabled
- Sleep operation disabled
- No reference compensation
- No gain/offset correction
- No added sampling time
- Pin scan mode disabled

2.8.2.1 Setup

Prerequisites

There are no special setup requirements for this use-case.

Code

Add to the main application source file, outside of any functions:

```
struct adc_module adc_instance;
```

```
#define ADC_SAMPLES 128
```

```
uint16_t adc_result_buffer[ADC_SAMPLES];
```

Callback function:

```
volatile bool adc_read_done = false;

void adc_complete_callback(
        const struct adc_module *const module)
{
    adc_read_done = true;
}
```

Copy-paste the following setup code to your user application:

```
void configure_adc(void)
{
    struct adc_config config_adc;
    adc_get_config_defaults(&config_adc);

    config_adc.gain_factor     = ADC_GAIN_FACTOR_DIV2;
    config_adc.clock_prescaler = ADC_CLOCK_PRESCALER_DIV8;
    config_adc.reference       = ADC_REFERENCE_INTVCC1;
    config_adc.positive_input  = ADC_POSITIVE_INPUT_PIN4;
    config_adc.resolution      = ADC_RESOLUTION_12BIT;

    adc_init(&adc_instance, ADC, &config_adc);

    adc_enable(&adc_instance);
}

void configure_adc_callbacks(void)
{
    adc_register_callback(&adc_instance,
            adc_complete_callback, ADC_CALLBACK_READ_BUFFER);
    adc_enable_callback(&adc_instance, ADC_CALLBACK_READ_BUFFER);
}
```

Add to user application initialization (typically the start of `main()`):

```
configure_adc();
configure_adc_callbacks();
```

Workflow

1. Create a module software instance structure for the ADC module to store the ADC driver state while it is in use.

   ```
   struct adc_module adc_instance;
   ```

Note This should never go out of scope as long as the module is in use. In most cases, this should be global.

2. Create a buffer for the ADC samples to be stored in by the driver asynchronously.

   ```
   #define ADC_SAMPLES 128
   uint16_t adc_result_buffer[ADC_SAMPLES];
   ```

3. Create a callback function that will be called each time the ADC completes an asynchronous read job.

```
volatile bool adc_read_done = false;

void adc_complete_callback(
        const struct adc_module *const module)
{
    adc_read_done = true;
}
```

4. Configure the ADC module.

   a. Create a ADC module configuration struct, which can be filled out to adjust the configuration of a physical ADC peripheral.

```
struct adc_config config_adc;
```

   b. Initialize the ADC configuration struct with the module's default values.

```
adc_get_config_defaults(&config_adc);
```

Note This should always be performed before using the configuration struct to ensure that all values are initialized to known default settings.

   c. Change the ADC module configuration to suit the application.

```
config_adc.gain_factor     = ADC_GAIN_FACTOR_DIV2;
config_adc.clock_prescaler = ADC_CLOCK_PRESCALER_DIV8;
config_adc.reference       = ADC_REFERENCE_INTVCC1;
config_adc.positive_input  = ADC_POSITIVE_INPUT_PIN4;
config_adc.resolution      = ADC_RESOLUTION_12BIT;
```

   d. Enable the ADC module so that conversions can be made.

```
adc_enable(&adc_instance);
```

5. Register and enable the ADC Read Buffer Complete callback handler

   a. Register the user-provided Read Buffer Complete callback function with the driver, so that it will be run when an asynchronous buffer read job completes.

```
adc_register_callback(&adc_instance,
        adc_complete_callback, ADC_CALLBACK_READ_BUFFER);
```

   b. Enable the Read Buffer Complete callback so that it will generate callbacks.

```
adc_enable_callback(&adc_instance, ADC_CALLBACK_READ_BUFFER);
```

2.8.2.2 Use Case

Code

Copy-paste the following code to your user application:

```
system_interrupt_enable_global();

adc_read_buffer_job(&adc_instance, adc_result_buffer, ADC_SAMPLES);

while (adc_read_done == false) {
    /* Wait for asynchronous ADC read to complete */
}

while (1) {
    /* Infinite loop */
}
```

Workflow

1. Enable global interrupts, so that callbacks can be generated by the driver.

   ```
   system_interrupt_enable_global();
   ```

2. Start an asynchronous ADC conversion, to store ADC samples into the global buffer and generate a callback when complete.

   ```
   adc_read_buffer_job(&adc_instance, adc_result_buffer, ADC_SAMPLES);
   ```

3. Wait until the asynchronous conversion is complete.

   ```
   while (adc_read_done == false) {
       /* Wait for asynchronous ADC read to complete */
   }
   ```

4. Enter an infinite loop once the conversion is complete.

   ```
   while (1) {
       /* Infinite loop */
   }
   ```

2.8.3 Quick Start Guide for Using DMA with ADC/DAC

The supported device list:

- SAMD21

This quick start will convert an analog input signal from PA4 and output the converted value to DAC on PA2. The data between ADC and DAC with be transferred through DMA instead of a CPU intervene.

The ADC will be configured with the following settings:

- 1/2 VDDANA
- Div 16 clock prescaler
- 10 bit resolution
- Window monitor disabled
- No gain
- Positive input on ADC PIN 4

- Averaging disabled
- Oversampling disabled
- Right adjust data
- Single-ended mode
- Free running enable
- All events (input and generation) disabled
- Sleep operation disabled
- No reference compensation
- No gain/offset correction
- No added sampling time
- Pin scan mode disabled

The DAC will be configured with the following settings:

- Analog VCC as reference
- Internal output disabled
- Drive the DAC output to PA2
- Right adjust data
- The output buffer is disabled when the chip enters STANDBY sleep mode

The DMA will be configured with the following settings:

- Move data from peripheral to peripheral
- Using ADC result ready trigger
- Using DMA priority level 0
- Beat transfer will be triggered on each trigger
- Loopback descriptor for DAC conversion

2.8.3.1 Setup

Prerequisites

There are no special setup requirements for this use-case.

Code

Add to the main application source file, outside of any functions:

```
struct dac_module dac_instance;
```

```
struct adc_module adc_instance;
```

```
struct dma_resource example_resource;
```

```
COMPILER_ALIGNED(16)
DmacDescriptor example_descriptor;
```

Copy-paste the following setup code to your user application:

```
void configure_adc(void)
{
    struct adc_config config_adc;

    adc_get_config_defaults(&config_adc);

    config_adc.gain_factor     = ADC_GAIN_FACTOR_DIV2;
    config_adc.clock_prescaler = ADC_CLOCK_PRESCALER_DIV16;
    config_adc.reference       = ADC_REFERENCE_INTVCC1;
    config_adc.positive_input  = ADC_POSITIVE_INPUT_PIN4;
    config_adc.resolution      = ADC_RESOLUTION_10BIT;
    config_adc.freerunning     = true;
    config_adc.left_adjust     = false;

    adc_init(&adc_instance, ADC, &config_adc);

    adc_enable(&adc_instance);
}

void configure_dac(void)
{
    struct dac_config config_dac;

    dac_get_config_defaults(&config_dac);

    config_dac.reference = DAC_REFERENCE_AVCC;

    dac_init(&dac_instance, DAC, &config_dac);

    dac_enable(&dac_instance);
}

void configure_dac_channel(void)
{
    struct dac_chan_config config_dac_chan;

    dac_chan_get_config_defaults(&config_dac_chan);

    dac_chan_set_config(&dac_instance, DAC_CHANNEL_0, &config_dac_chan);

    dac_chan_enable(&dac_instance, DAC_CHANNEL_0);
}

void configure_dma_resource(struct dma_resource *resource)
{
    struct dma_resource_config config;

    dma_get_config_defaults(&config);

    config.peripheral_trigger = ADC_DMAC_ID_RESRDY;
    config.trigger_action = DMA_TRIGGER_ACTON_BEAT;
```

```
    dma_allocate(resource, &config);
}

void setup_transfer_descriptor(DmacDescriptor *descriptor)
{
    struct dma_descriptor_config descriptor_config;

    dma_descriptor_get_config_defaults(&descriptor_config);

    descriptor_config.beat_size = DMA_BEAT_SIZE_HWORD;
    descriptor_config.dst_increment_enable = false;
    descriptor_config.src_increment_enable = false;
    descriptor_config.block_transfer_count = 1000;
    descriptor_config.source_address = (uint32_t)(&adc_instance.hw->RESULT.reg);
    descriptor_config.destination_address = (uint32_t)(&dac_instance.hw->DATA.reg);
    descriptor_config.next_descriptor_address = (uint32_t)descriptor;

    dma_descriptor_create(descriptor, &descriptor_config);
}
```

Add to user application initialization (typically the start of `main()`):

```
configure_adc();

configure_dac();

configure_dac_channel();

configure_dma_resource(&example_resource);

setup_transfer_descriptor(&example_descriptor);

dma_add_descriptor(&example_resource, &example_descriptor);
```

Workflow

Configure the ADC

1. Create a module software instance structure for the ADC module to store the ADC driver state while it is in use.

   ```
   struct adc_module adc_instance;
   ```

Note This should never go out of scope as long as the module is in use. In most cases, this should be global.

2. Configure the ADC module.

   a. Create a ADC module configuration struct, which can be filled out to adjust the configuration of a physical ADC peripheral.

      ```
      struct adc_config config_adc;
      ```

   b. Initialize the ADC configuration struct with the module's default values.

      ```
      adc_get_config_defaults(&config_adc);
      ```

Note This should always be performed before using the configuration struct to ensure that all values are initialized to known default settings.

c. Set extra configurations

```
config_adc.gain_factor     = ADC_GAIN_FACTOR_DIV2;
config_adc.clock_prescaler = ADC_CLOCK_PRESCALER_DIV16;
config_adc.reference       = ADC_REFERENCE_INTVCC1;
config_adc.positive_input  = ADC_POSITIVE_INPUT_PIN4;
config_adc.resolution      = ADC_RESOLUTION_10BIT;
config_adc.freerunning     = true;
config_adc.left_adjust     = false;
```

d. Set ADC configurations

```
adc_init(&adc_instance, ADC, &config_adc);
```

e. Enable the ADC module so that conversions can be made.

```
adc_enable(&adc_instance);
```

Configure the DAC

1. Create a module software instance structure for the DAC module to store the DAC driver state while it is in use.

```
struct dac_module dac_instance;
```

Note This should never go out of scope as long as the module is in use. In most cases, this should be global.

2. Configure the DAC module.

a. Create a DAC module configuration struct, which can be filled out to adjust the configuration of a physical DAC peripheral.

```
struct dac_config config_dac;
```

b. Initialize the DAC configuration struct with the module's default values.

```
dac_get_config_defaults(&config_dac);
```

Note This should always be performed before using the configuration struct to ensure that all values are initialized to known default settings.

c. Set extra DAC configurations.

```
config_dac.reference = DAC_REFERENCE_AVCC;
```

d. Set DAC configurations to DAC instance.

```
dac_init(&dac_instance, DAC, &config_dac);
```

e. Enable the DAC module so that channels can be configured.

```
dac_enable(&dac_instance);
```

3. Configure the DAC channel.

a. Create a DAC channel configuration struct, which can be filled out to adjust the configuration of a physical DAC output channel.

```
struct dac_chan_config config_dac_chan;
```

b. Initialize the DAC channel configuration struct with the module's default values.

```
dac_chan_get_config_defaults(&config_dac_chan);
```

Note This should always be performed before using the configuration struct to ensure that all values are initialized to known default settings.

c. Configure the DAC channel with the desired channel settings.

```
dac_chan_set_config(&dac_instance, DAC_CHANNEL_0, &config_dac_chan);
```

d. Enable the DAC channel so that it can output a voltage.

```
dac_chan_enable(&dac_instance, DAC_CHANNEL_0);
```

Configure the DMA

1. Create a DMA resource configuration structure, which can be filled out to adjust the configuration of a single DMA transfer.

```
struct dma_resource_config config;
```

2. Initialize the DMA resource configuration struct with the module's default values.

```
dma_get_config_defaults(&config);
```

Note This should always be performed before using the configuration struct to ensure that all values are initialized to known default settings.

3. Set extra configurations for the DMA resource. ADC_DMAC_ID_RESRDY trigger and trigger causes a beat transfer in this example.

```
config.peripheral_trigger = ADC_DMAC_ID_RESRDY;
config.trigger_action = DMA_TRIGGER_ACTON_BEAT;
```

4. Allocate a DMA resource with the configurations.

```
dma_allocate(resource, &config);
```

5. Create a DMA transfer descriptor configuration structure, which can be filled out to adjust the configuration of a single DMA transfer.

```
struct dma_descriptor_config descriptor_config;
```

6. Initialize the DMA transfer descriptor configuration struct with the module's default values.

```
dma_descriptor_get_config_defaults(&descriptor_config);
```

Note This should always be performed before using the configuration struct to ensure that all values are initialized to known default settings.

7. Set the specific parameters for a DMA transfer with transfer size, source address, destination address.

```
descriptor_config.beat_size = DMA_BEAT_SIZE_HWORD;
descriptor_config.dst_increment_enable = false;
descriptor_config.src_increment_enable = false;
descriptor_config.block_transfer_count = 1000;
descriptor_config.source_address = (uint32_t)(&adc_instance.hw->RESULT.reg);
descriptor_config.destination_address = (uint32_t)(&dac_instance.hw->DATA.reg);
descriptor_config.next_descriptor_address = (uint32_t)descriptor;
```

8. Create the DMA transfer descriptor.

```
dma_descriptor_create(descriptor, &descriptor_config);
```

9. Add DMA descriptor to DMA resource.

```
dma_add_descriptor(&example_resource, &example_descriptor);
```

2.8.3.2 Use Case

Code

Copy-paste the following code to your user application:

```
adc_start_conversion(&adc_instance);

dma_start_transfer_job(&example_resource);

while (true) {
}
```

Workflow

1. Start ADC conversion.

```
adc_start_conversion(&adc_instance);
```

2. Start the transfer job.

```
dma_start_transfer_job(&example_resource);
```

3. Enter endless loop

```
while (true) {
}
```

3. SAM D20/D21 Brown Out Detector Driver (BOD)

This driver for SAM D20/D21 devices provides an interface for the configuration and management of the device's Brown Out Detector (BOD) modules, to detect and respond to under-voltage events and take an appropriate action.

The following peripherals are used by this module:

- SYSCTRL (System Control)

The outline of this documentation is as follows:

- Prerequisites
- Module Overview
- Special Considerations
- Extra Information
- Examples
- API Overview

3.1 Prerequisites

There are no prerequisites for this module.

3.2 Module Overview

The SAM D20/D21 devices contain a number of Brown Out Detector (BOD) modules. Each BOD monitors the supply voltage for any dips that go below the set threshold for the module. In case of a BOD detection the BOD will either reset the system or raise a hardware interrupt so that a safe power-down sequence can be attempted.

3.3 Special Considerations

The time between a BOD interrupt being raised and a failure of the processor to continue executing (in the case of a core power failure) is system specific; care must be taken that all critical BOD detection events can complete within the amount of time available.

3.4 Extra Information

For extra information see Extra Information for BOD Driver. This includes:

- Acronyms
- Dependencies
- Errata
- Module History

3.5 Examples

For a list of examples related to this driver, see Examples for BOD Driver.

3.6 API Overview

3.6.1 Structure Definitions

3.6.1.1 Struct bod_config

Configuration structure for a BOD module.

Table 3-1. Members

Type	Name	Description
enum bod_action	action	Action to perform when a low power detection is made.
bool	hysteresis	If true, enables detection hysteresis.
uint8_t	level	BOD level to trigger at (see electrical section of device datasheet).
enum bod_mode	mode	Sampling configuration mode for the BOD.
enum bod_prescale	prescaler	Input sampler clock prescaler factor, to reduce the 1KHz clock from the ULP32K to lower the sampling rate of the BOD.
bool	run_in_standby	If true, the BOD is kept enabled and sampled during device sleep.

3.6.2 Function Definitions

3.6.2.1 Configuration and Initialization

Function bod_get_config_defaults()

Get default BOD configuration.

```
void bod_get_config_defaults(
  struct bod_config *const conf)
```

The default BOD configuration is:

- Clock prescaler set to divide the input clock by 2
- Continuous mode
- Reset on BOD detect
- Hysteresis enabled
- BOD level 0x12
- BOD kept enabled during device sleep

Table 3-2. Parameters

Data direction	Parameter name	Description
[out]	conf	BOD configuration struct to set to default settings

Function bod_set_config()

Configure a Brown Out Detector module.

```
enum status_code bod_set_config(
  const enum bod bod_id,
  struct bod_config *const conf)
```

Configures a given BOD module with the settings stored in the given configuration structure.

Table 3-3. Parameters

Data direction	Parameter name	Description
[in]	bod_id	BOD module to configure
[in]	conf	Configuration settings to use for the specified BOD

Table 3-4. Return Values

Return value	Description
STATUS_OK	Operation completed successfully
STATUS_ERR_INVALID_ARG	An invalid BOD was supplied
STATUS_ERR_INVALID_OPTION	The requested BOD level was outside the acceptable range

Function bod_enable()

Enables a configured BOD module.

```
enum status_code bod_enable(
  const enum bod bod_id)
```

Enables the specified BOD module that has been previously configured.

Table 3-5. Parameters

Data direction	Parameter name	Description
[in]	bod_id	BOD module to enable

Returns Error code indicating the status of the enable operation.

Table 3-6. Return Values

Return value	Description
STATUS_OK	If the BOD was successfully enabled
STATUS_ERR_INVALID_ARG	An invalid BOD was supplied

Function bod_disable()

Disables an enabled BOD module.

```
enum status_code bod_disable(
  const enum bod bod_id)
```

Disables the specified BOD module that was previously enabled.

Table 3-7. Parameters

Data direction	Parameter name	Description
[in]	bod_id	BOD module to disable

Returns Error code indicating the status of the disable operation.

Table 3-8. Return Values

Return value	Description
STATUS_OK	If the BOD was successfully disabled
STATUS_ERR_INVALID_ARG	An invalid BOD was supplied

Function bod_is_detected()

Checks if a specified BOD low voltage detection has occurred.

```
bool bod_is_detected(
  const enum bod bod_id)
```

Determines if a specified BOD has detected a voltage lower than its configured threshold.

Table 3-9. Parameters

Data direction	Parameter name	Description
[in]	bod_id	BOD module to check

Returns Detection status of the specified BOD.

Table 3-10. Return Values

Return value	Description
true	If the BOD has detected a low voltage condition
false	If the BOD has not detected a low voltage condition

Function bod_clear_detected()

Clears the low voltage detection state of a specified BOD.

```
void bod_clear_detected(
  const enum bod bod_id)
```

Clears the low voltage condition of a specified BOD module, so that new low voltage conditions can be detected.

Table 3-11. Parameters

Data direction	Parameter name	Description
[in]	bod_id	BOD module to clear

3.6.3 Enumeration Definitions

3.6.3.1 Enum bod

List of possible BOD controllers within the device.

Table 3-12. Members

Enum value	Description
BOD_BOD33	BOD33 External I/O voltage,

3.6.3.2 Enum bod_action

List of possible BOD actions when a BOD module detects a brown-out condition.

Table 3-13. Members

Enum value	Description
BOD_ACTION_NONE	A BOD detect will do nothing, and the BOD state must be polled.
BOD_ACTION_RESET	A BOD detect will reset the device.
BOD_ACTION_INTERRUPT	A BOD detect will fire an interrupt.

3.6.3.3 Enum bod_mode

List of possible BOD module voltage sampling modes.

Table 3-14. Members

Enum value	Description
BOD_MODE_CONTINUOUS	BOD will sample the supply line continuously.
BOD_MODE_SAMPLED	BOD will use the BOD sampling clock (1kHz) to sample the supply line.

3.6.3.4 Enum bod_prescale

List of possible BOD controller prescaler values, to reduce the sampling speed of a BOD to lower the power consumption.

Table 3-15. Members

Enum value	Description
BOD_PRESCALE_DIV_2	Divide input prescaler clock by 2
BOD_PRESCALE_DIV_4	Divide input prescaler clock by 4
BOD_PRESCALE_DIV_8	Divide input prescaler clock by 8
BOD_PRESCALE_DIV_16	Divide input prescaler clock by 16
BOD_PRESCALE_DIV_32	Divide input prescaler clock by 32
BOD_PRESCALE_DIV_64	Divide input prescaler clock by 64
BOD_PRESCALE_DIV_128	Divide input prescaler clock by 128
BOD_PRESCALE_DIV_256	Divide input prescaler clock by 256
BOD_PRESCALE_DIV_512	Divide input prescaler clock by 512
BOD_PRESCALE_DIV_1024	Divide input prescaler clock by 1024

Enum value	Description
BOD_PRESCALE_DIV_2048	Divide input prescaler clock by 2048
BOD_PRESCALE_DIV_4096	Divide input prescaler clock by 4096
BOD_PRESCALE_DIV_8192	Divide input prescaler clock by 8192
BOD_PRESCALE_DIV_16384	Divide input prescaler clock by 16384
BOD_PRESCALE_DIV_32768	Divide input prescaler clock by 32768
BOD_PRESCALE_DIV_65536	Divide input prescaler clock by 65536

3.7 Extra Information for BOD Driver

3.7.1 Acronyms

Below is a table listing the acronyms used in this module, along with their intended meanings.

Acronym	Definition
BOD	Brownout detector

3.7.2 Dependencies

This driver has the following dependencies:

- None

3.7.3 Errata

There are no errata related to this driver.

3.7.4 Module History

An overview of the module history is presented in the table below, with details on the enhancements and fixes made to the module since its first release. The current version of this corresponds to the newest version in the table.

Changelog
Added support for SAMD21 and removed BOD12 reference
Initial Release

3.8 Examples for BOD Driver

This is a list of the available Quick Start guides (QSGs) and example applications for SAM D20/D21 Brown Out Detector Driver (BOD). QSGs are simple examples with step-by-step instructions to configure and use this driver in a selection of use cases. Note that QSGs can be compiled as a standalone application or be added to the user application.

- Quick Start Guide for BOD - Basic
- Application Use Case for BOD - Application

3.8.1 Quick Start Guide for BOD - Basic

In this use case, the BOD33 will be configured with the following settings:

- Continuous sampling mode
- Prescaler setting of 2

- Reset action on low voltage detect

3.8.1.1 Quick Start

Prerequisites

There are no special setup requirements for this use-case.

Code

Copy-paste the following setup code to your user application:

```
void configure_bod33(void)
{
    struct bod_config config_bod33;
    bod_get_config_defaults(&config_bod33);

    bod_set_config(BOD_BOD33, &config_bod33);

    bod_enable(BOD_BOD33);
}
```

Add to user application initialization (typically the start of `main()`):

```
configure_bod33();
```

Workflow

1. Create a BOD module configuration struct, which can be filled out to adjust the configuration of a physical BOD peripheral.

   ```
   struct bod_config config_bod33;
   ```

2. Initialize the BOD configuration struct with the module's default values.

   ```
   bod_get_config_defaults(&config_bod33);
   ```

Note This should always be performed before using the configuration struct to ensure that all values are initialized to known default settings.

3. Configure the BOD module with the desired settings.

   ```
   bod_set_config(BOD_BOD33, &config_bod33);
   ```

4. Enable the BOD module so that it will monitor the power supply voltage.

   ```
   bod_enable(BOD_BOD33);
   ```

3.8.1.2 Use Case

Code

Copy-paste the following code to your user application:

```
while (true) {
```

```
    /* Infinite loop */
}
```

Workflow

1. Enter an infinite loop so that the BOD can continue to monitor the supply voltage level.

```
while (true) {
    /* Infinite loop */
}
```

3.8.2 Application Use Case for BOD - Application

The preferred method of setting BOD33 levels and settings is trough the fuses. when it is desirable to set it in software, please see the below use case.

In this use case, a new BOD33 level might be set in SW if the clock settings are adjusted up after a battery has charged to a higher level. When the battery discharges, the chip will reset when the battery level is below SW BOD33 level. Now the chip will run at a lower clock rate and the BOD33 level from fuse. The chip should always measure the voltage before adjusting the frequency up.

4. SAM D20/D21 Digital-to-Analog Driver (DAC)

This driver for SAM D20/D21 devices provides an interface for the conversion of digital values to analog voltage. The following driver API modes are covered by this manual:

- Polled APIs
- Callback APIs

The following peripherals are used by this module:

- DAC (Digital to Analog Converter)

The outline of this documentation is as follows:

4.1 Prerequisites

There are no prerequisites for this module.

4.2 Module Overview

The Digital-to-Analog converter converts a digital value to analog voltage. The SAM D20/D21 DAC module has one channel with 10-bit resolution, and is capable of converting up to 350k samples per second (ksps).

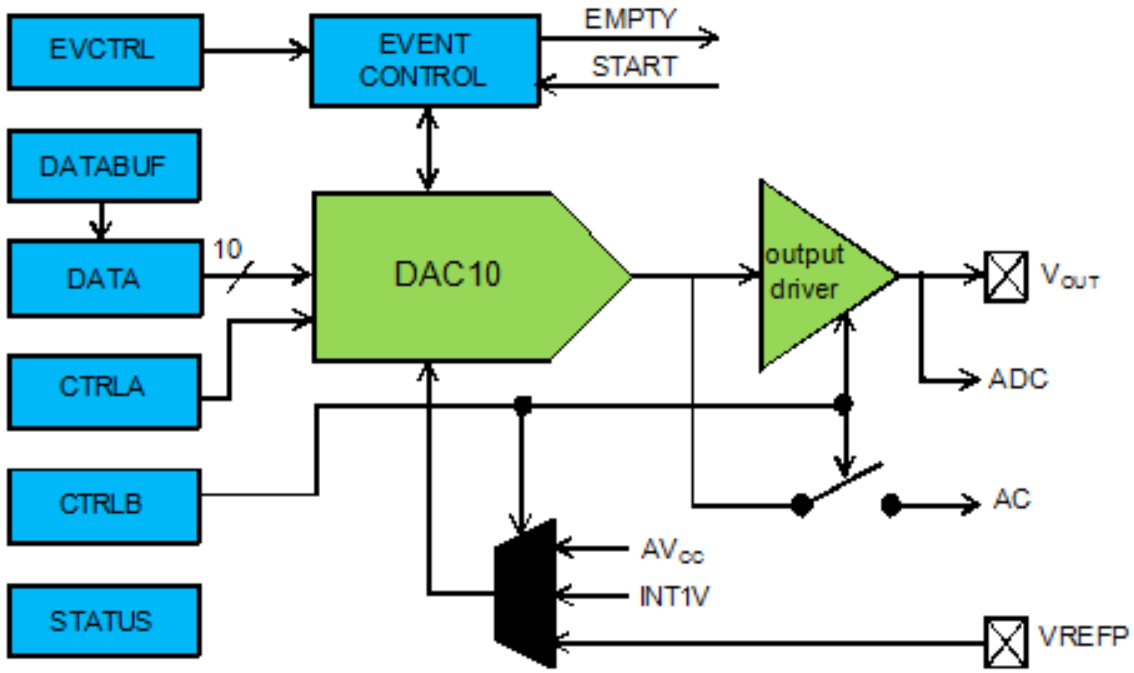
A common use of DAC is to generate audio signals by connecting the DAC output to a speaker, or to generate a reference voltage; either for an external circuit or an internal peripheral such as the Analog Comparator.

After being set up, the DAC will convert new digital values written to the conversion data register (DATA) to an analog value either on the VOUT pin of the device, or internally for use as an input to the AC, ADC and other analog modules.

Writing the DATA register will start a new conversion. It is also possible to trigger the conversion from the event system.

A simplified block diagram of the DAC can be seen in Figure 4-1: DAC Block Diagram on page 90.

Figure 4-1. DAC Block Diagram



4.2.1 Conversion Range

The conversion range is between GND and the selected voltage reference. Available voltage references are:

- AVCC voltage reference
- Internal 1V reference (INT1V)
- External voltage reference (AREF)

Note Internal references will be enabled by the driver, but not disabled. Any reference not used by the application should be disabled by the application.

The output voltage from a DAC channel is given as:

$$V_{OUT} = \frac{DATA}{0x3FF} \times VREF \quad (4.1)$$

4.2.2 Conversion

The digital value written to the conversion data register (DATA) will be converted to an analog value. Writing the DATA register will start a new conversion. It is also possible to write the conversion data to the DATABUF register, the writing of the DATA register can then be triggered from the event system, which will load the value from DATABUF to DATA.

4.2.3 Analog Output

The analog output value can be output to either the VOUT pin or internally, but not both at the same time.

4.2.3.1 External Output

The output buffer must be enabled in order to drive the DAC output to the VOUT pin. Due to the output buffer, the DAC has high drive strength, and is capable of driving both resistive and capacitive loads, as well as loads which combine both.

4.2.3.2 Internal Output

The analog value can be internally available for use as input to the AC or ADC modules.

4.2.4 Events

Events generation and event actions are configurable in the DAC. The DAC has one event line input and one event output: *Start Conversion* and *Data Buffer Empty*.

If the Start Conversion input event is enabled in the module configuration, an incoming event will load data from the data buffer to the data register and start a new conversion. This method synchronizes conversions with external events (such as those from a timer module) and ensures regular and fixed conversion intervals.

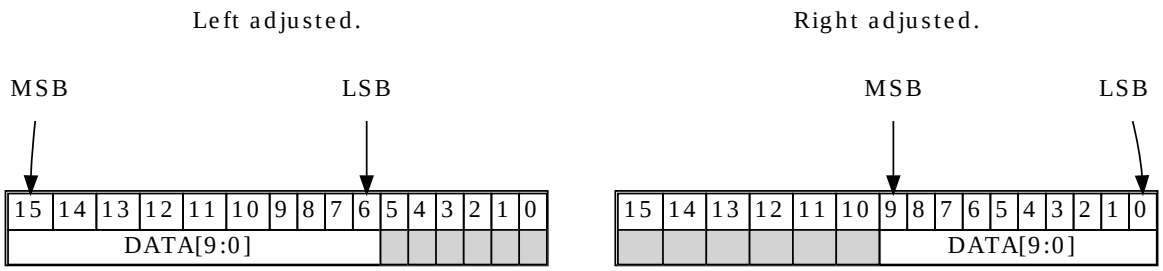
If the Data Buffer Empty output event is enabled in the module configuration, events will be generated when the DAC data buffer register becomes empty and new data can be loaded to the buffer.

Note The connection of events between modules requires the use of the SAM D20/D21 Event System Driver (EVENTS) to route output event of one module to the the input event of another. For more information on event routing, refer to the event driver documentation.

4.2.5 Left and Right Adjusted Values

The 10-bit input value to the DAC is contained in a 16-bit register. This can be configured to be either left or right adjusted. In Figure 4-2: Left and Right Adjusted Values on page 91 both options are shown, and the position of the most (MSB) and the least (LSB) significant bits are indicated. The unused bits should always be written to zero.

Figure 4-2. Left and Right Adjusted Values



4.2.6 Clock Sources

The clock for the DAC interface (CLK_DAC) is generated by the Power Manager. This clock is turned on by default, and can be enabled and disabled in the Power Manager.

Additionally, an asynchronous clock source (GCLK_DAC) is required. These clocks are normally disabled by default. The selected clock source must be enabled in the Power Manager before it can be used by the DAC. The DAC core operates asynchronously from the user interface and peripheral bus. As a consequence, the DAC needs two clock cycles of both CLK_DAC and GCLK_DAC to synchronize the values written to some of the control and data registers. The oscillator source for the GCLK_DAC clock is selected in the System Control Interface (SCIF).

4.3 Special Considerations

4.3.1 Output Driver

The DAC can only do conversions in Active or Idle modes. However, if the output buffer is enabled it will draw current even if the system is in sleep mode. Therefore, always make sure that the output buffer is not enabled when it is not needed, to ensure minimum power consumption.

4.3.2 Conversion Time

DAC conversion time is approximately 2.85us. The user must ensure that new data is not written to the DAC before the last conversion is complete. Conversions should be triggered by a periodic event from a Timer/Counter or another peripheral.

4.4 Extra Information

For extra information see Extra Information for DAC Driver. This includes:

- Acronyms
- Dependencies
- Errata
- Module History

4.5 Examples

For a list of examples related to this driver, see Examples for DAC Driver.

4.6 API Overview

4.6.1 Variable and Type Definitions

4.6.1.1 Type dac_callback_t

```
typedef void(* dac_callback_t )(uint8_t channel)
```

Type definition for a DAC module callback function.

4.6.2 Structure Definitions

4.6.2.1 Struct dac_chan_config

Configuration for a DAC channel. This structure should be initialized by the dac_chan_get_config_defaults() function before being modified by the user application.

4.6.2.2 Struct dac_config

Configuration structure for a DAC instance. This structure should be initialized by the dac_get_config_defaults() function before being modified by the user application.

Table 4-1. Members

Type	Name	Description
enum gclk_generator	clock_source	GCLK generator used to clock the peripheral
bool	left_adjust	Left adjusted data
enum dac_output	output	Select DAC output
enum dac_reference	reference	Reference voltage
bool	run_in_standby	The DAC behaves as in normal mode when the chip enters STANDBY sleep mode
bool	voltage_pump_disable	Voltage pump disable

4.6.2.3 Struct dac_events

Event flags for the DAC module. This is used to enable and disable events via dac_enable_events() and dac_disable_events().

Table 4-2. Members

Type	Name	Description
bool	generate_event_on_buffer_empty	Enable event generation on data buffer empty
bool	on_event_start_conversion	Start a new DAC conversion

4.6.2.4 Struct dac_module

DAC software instance structure, used to retain software state information of an associated hardware module instance.

Note The fields of this structure should not be altered by the user application; they are reserved for module-internal use only.

4.6.3 Macro Definitions

4.6.3.1 DAC status flags

DAC status flags, returned by dac_get_status() and cleared by dac_clear_status().

Macro DAC_STATUS_CHANNEL_0_EMPTY

```
#define DAC_STATUS_CHANNEL_0_EMPTY (1UL << 0)
```

Data Buffer Empty Channel 0 - Set when data is transferred from DATABUF to DATA by a start conversion event and DATABUF is ready for new data.

Macro DAC_STATUS_CHANNEL_0_UNDERRUN

```
#define DAC_STATUS_CHANNEL_0_UNDERRUN (1UL << 1)
```

Under-run Channel 0 - Set when a start conversion event occurs when DATABUF is empty.

4.6.3.2 Macro DAC_TIMEOUT

```
#define DAC_TIMEOUT 0xFFFF
```

Define DAC features set according to different device family

4.6.4 Function Definitions

4.6.4.1 Configuration and Initialization

Function dac_is_syncing()

Determines if the hardware module(s) are currently synchronizing to the bus.

```
bool dac_is_syncing(
  struct dac_module *const dev_inst)
```

Checks to see if the underlying hardware peripheral module(s) are currently synchronizing across multiple clock domains to the hardware bus, This function can be used to delay further operations on a module until such time that it is ready, to prevent blocking delays for synchronization in the user application.

Table 4-3. Parameters

Data direction	Parameter name	Description
[in]	dev_inst	Pointer to the DAC software instance struct

Returns

Synchronization status of the underlying hardware module(s).

Table 4-4. Return Values

Return value	Description
true	if the module has completed synchronization
false	if the module synchronization is ongoing

Function dac_get_config_defaults()

Initializes a DAC configuration structure to defaults.

```
void dac_get_config_defaults(
  struct dac_config *const config)
```

Initializes a given DAC configuration structure to a set of known default values. This function should be called on any new instance of the configuration structures before being modified by the user application.

The default configuration is as follows:

- 1V from internal bandgap reference
- Drive the DAC output to the VOUT pin
- Right adjust data
- GCLK generator 0 (GCLK main) clock source
- The output buffer is disabled when the chip enters STANDBY sleep mode

Table 4-5. Parameters

Data direction	Parameter name	Description
[out]	config	Configuration structure to initialize to default values

Function dac_init()

Initialize the DAC device struct.

```
enum status_code dac_init(
  struct dac_module *const dev_inst,
  Dac *const module,
  struct dac_config *const config)
```

Use this function to initialize the Digital to Analog Converter. Resets the underlying hardware module and configures it.

Note The DAC channel must be configured separately.

Table 4-6. Parameters

Data direction	Parameter name	Description
[out]	module_inst	Pointer to the DAC software instance struct
[in]	module	Pointer to the DAC module instance
[in]	config	Pointer to the config struct, created by the user application

Returns Status of initialization

Table 4-7. Return Values

Return value	Description
STATUS_OK	Module initiated correctly
STATUS_ERR_DENIED	If module is enabled
STATUS_BUSY	If module is busy resetting

Function dac_reset()

Resets the DAC module.

```
void dac_reset(
  struct dac_module *const dev_inst)
```

This function will reset the DAC module to its power on default values and disable it.

Table 4-8. Parameters

Data direction	Parameter name	Description
[in]	module_inst	Pointer to the DAC software instance struct

Function dac_enable()

Enable the DAC module.

```
void dac_enable(
  struct dac_module *const dev_inst)
```

Enables the DAC interface and the selected output. If any internal reference is selected it will be enabled.

Table 4-9. Parameters

Data direction	Parameter name	Description
[in]	module_inst	Pointer to the DAC software instance struct

Function dac_disable()

Disable the DAC module.

```
void dac_disable(
  struct dac_module *const dev_inst)
```

Disables the DAC interface and the output buffer.

Table 4-10. Parameters

Data direction	Parameter name	Description
[in]	module_inst	Pointer to the DAC software instance struct

Function dac_enable_events()

Enables a DAC event input or output.

```
void dac_enable_events(
  struct dac_module *const module_inst,
  struct dac_events *const events)
```

Enables one or more input or output events to or from the DAC module. See here for a list of events this module supports.

Note Events cannot be altered while the module is enabled.

Table 4-11. Parameters

Data direction	Parameter name	Description
[in]	module_inst	Software instance for the DAC peripheral
[in]	events	Struct containing flags of events to enable

Function dac_disable_events()

Disables a DAC event input or output.

```
void dac_disable_events(
  struct dac_module *const module_inst,
  struct dac_events *const events)
```

Disables one or more input or output events to or from the DAC module. See here for a list of events this module supports.

Note Events cannot be altered while the module is enabled.

Table 4-12. Parameters

Data direction	Parameter name	Description
[in]	module_inst	Software instance for the DAC peripheral
[in]	events	Struct containing flags of events to disable

4.6.4.2 Configuration and Initialization (Channel)

Function dac_chan_get_config_defaults()

Initializes a DAC channel configuration structure to defaults.

```
void dac_chan_get_config_defaults(
  struct dac_chan_config *const config)
```

Initializes a given DAC channel configuration structure to a set of known default values. This function should be called on any new instance of the configuration structures before being modified by the user application.

The default configuration is as follows:

- Start Conversion Event Input enabled
- Start Data Buffer Empty Event Output disabled

Table 4-13. Parameters

Data direction	Parameter name	Description
[out]	config	Configuration structure to initialize to default values

Function dac_chan_set_config()

Writes a DAC channel configuration to the hardware module.

```
void dac_chan_set_config(
  struct dac_module *const dev_inst,
  const enum dac_channel channel,
```

```
  struct dac_chan_config *const config)
```

Writes out a given channel configuration to the hardware module.

Note The DAC device instance structure must be initialized before calling this function.

Table 4-14. Parameters

Data direction	Parameter name	Description
[in]	module_inst	Pointer to the DAC software instance struct
[in]	channel	Channel to configure
[in]	config	Pointer to the configuration struct

Function dac_chan_enable()

Enable a DAC channel.

```
void dac_chan_enable(
  struct dac_module *const dev_inst,
  enum dac_channel channel)
```

Enables the selected DAC channel.

Table 4-15. Parameters

Data direction	Parameter name	Description
[in]	module_inst	Pointer to the DAC software instance struct
[in]	channel	Channel to enable

Function dac_chan_disable()

Disable a DAC channel.

```
void dac_chan_disable(
  struct dac_module *const dev_inst,
  enum dac_channel channel)
```

Disables the selected DAC channel.

Table 4-16. Parameters

Data direction	Parameter name	Description
[in]	module_inst	Pointer to the DAC software instance struct
[in]	channel	Channel to disable

Function dac_chan_enable_output_buffer()

Enable the output buffer.

```
void dac_chan_enable_output_buffer(
  struct dac_module *const dev_inst,
  const enum dac_channel channel)
```

Enables the output buffer and drives the DAC output to the VOUT pin.

Table 4-17. Parameters

Data direction	Parameter name	Description
[in]	module_inst	Pointer to the DAC software instance struct
[in]	channel	DAC channel to alter

Function dac_chan_disable_output_buffer()

Disable the output buffer.

```
void dac_chan_disable_output_buffer(
  struct dac_module *const dev_inst,
  const enum dac_channel channel)
```

Disables the output buffer.

Note The output buffer(s) should be disabled when a channel's output is not currently needed, as it will draw current even if the system is in sleep mode.

Table 4-18. Parameters

Data direction	Parameter name	Description
[in]	module_inst	Pointer to the DAC software instance struct
[in]	channel	DAC channel to alter

4.6.4.3 Channel Data Management

Function dac_chan_write()

Write to the DAC.

```
enum status_code dac_chan_write(
  struct dac_module *const dev_inst,
  enum dac_channel channel,
  const uint16_t data)
```

This function writes to the DATA or DATABUF register. If the conversion is not event-triggered, the data will be written to the DATA register and the conversion will start. If the conversion is event-triggered, the data will be written to DATABUF and transferred to the DATA register and converted when a Start Conversion Event is issued. Conversion data must be right or left adjusted according to configuration settings.

Note To be event triggered, the enable_start_on_event must be enabled in the configuration.

Table 4-19. Parameters

Data direction	Parameter name	Description
[in]	module_inst	Pointer to the DAC software device struct
[in]	channel	DAC channel to write to
[in]	data	Conversion data

Returns Status of the operation

Table 4-20. Return Values

Return value	Description
STATUS_OK	If the data was written

Function dac_chan_write_buffer_wait()

Write to the DAC.

```
enum status_code dac_chan_write_buffer_wait(
  struct dac_module *const module_inst,
  enum dac_channel channel,
  uint16_t * buffer,
  uint32_t length)
```

This function converts a specific number of digital data. The conversion should be event-triggered, the data will be written to DATABUF and transferred to the DATA register and converted when a Start Conversion Event is issued. Conversion data must be right or left adjusted according to configuration settings.

Note To be event triggered, the enable_start_on_event must be enabled in the configuration.

Table 4-21. Parameters

Data direction	Parameter name	Description
[in]	module_inst	Pointer to the DAC software device struct
[in]	channel	DAC channel to write to
[in]	buffer	Pointer to the digital data write buffer to be converted
[in]	length	Length of the write buffer

Returns Status of the operation

Table 4-22. Return Values

Return value	Description
STATUS_OK	If the data was written or no data conversion required

Return value	Description
STATUS_ERR_UNSUPPORTED_DEV	The DAC is not configured as using event trigger.
STATUS_BUSY	The DAC is busy to convert.

4.6.4.4 Status Management

Function dac_get_status()

Retrieves the current module status.

```
uint32_t dac_get_status(
  struct dac_module *const module_inst)
```

Checks the status of the module and returns it as a bitmask of status flags

Table 4-23. Parameters

Data direction	Parameter name	Description
[in]	module_inst	Pointer to the DAC software device struct

Returns

Bitmask of status flags

Table 4-24. Return Values

Return value	Description
DAC_STATUS_CHANNEL_0_EMPTY	Data has been transferred from DATABUF to DATA by a start conversion event and DATABUF is ready for new data.
DAC_STATUS_CHANNEL_0_UNDERRUN	A start conversion event has occurred when DATABUF is empty

Function dac_clear_status()

Clears a module status flag.

```
void dac_clear_status(
  struct dac_module *const module_inst,
  uint32_t status_flags)
```

Clears the given status flag of the module.

Table 4-25. Parameters

Data direction	Parameter name	Description
[in]	module_inst	Pointer to the DAC software device struct
[in]	status_flags	Bit mask of status flags to clear

4.6.4.5 Callback configuration and initialization

Function dac_chan_write_buffer_job()

Convert a specific number digital data to analog through DAC.

```
enum status_code dac_chan_write_buffer_job(
  struct dac_module *const module_inst,
  const uint32_t channel,
  uint16_t * buffer,
  uint32_t buffer_size)
```

This function will perform a conversion of specific number of digital data. The conversion should be event-triggered, the data will be written to DATABUF and transferred to the DATA register and converted when a Start Conversion Event is issued. Conversion data must be right or left adjusted according to configuration settings.

Note To be event triggered, the enable_start_on_event must be enabled in the configuration.

Table 4-26. Parameters

Data direction	Parameter name	Description
[in]	module_inst	Pointer to the DAC software device struct
[in]	channel	DAC channel to write to
[in]	buffer	Pointer to the digital data write buffer to be converted
[in]	length	Size of the write buffer

Returns Status of the operation

Table 4-27. Return Values

Return value	Description
STATUS_OK	If the data was written
STATUS_ERR_UNSUPPORTED_DEV	If a callback that requires event driven mode was specified with a DAC instance configured in non-event mode.
STATUS_BUSY	The DAC is busy to accept new job.

Function dac_chan_write_job()

Convert one digital data job.

```
enum status_code dac_chan_write_job(
  struct dac_module *const module_inst,
  const uint32_t channel,
  uint16_t data)
```

This function will perform a conversion of specfic number of digital data. The conversion is event-triggered, the data will be written to DATABUF and transferred to the DATA register and converted when a Start Conversion Event is issued. Conversion data must be right or left adjusted according to configuration settings.

Note To be event triggered, the enable_start_on_event must be enabled in the configuration.

Table 4-28. Parameters

Data direction	Parameter name	Description
[in]	module_inst	Pointer to the DAC software device struct
[in]	channel	DAC channel to write to
[in]	data	Digital data to be converted

Returns Status of the operation

Table 4-29. Return Values

Return value	Description
STATUS_OK	If the data was written
STATUS_ERR_UNSUPPORTED_DEV	If a callback that requires event driven mode was specified with a DAC instance configured in non-event mode.
STATUS_BUSY	The DAC is busy to accept new job.

Function dac_register_callback()

Registers an asynchronous callback function with the driver.

```
enum status_code dac_register_callback(
  struct dac_module *const module,
  const uint32_t channel,
  const dac_callback_t callback,
  const enum dac_callback type)
```

Registers an asynchronous callback with the DAC driver, fired when a callback condition occurs.

Table 4-30. Parameters

Data direction	Parameter name	Description
[in, out]	module_inst	Pointer to the DAC software instance struct
[in]	callback	Pointer to the callback function to register
[in]	channel	Logical channel to regiseter callback function
[in]	type	Type of callback function to register

Returns Status of the registration operation.

Table 4-31. Return Values

Return value	Description
STATUS_OK	The callback was registered successfully.

Return value	Description
STATUS_ERR_INVALID_ARG	If an invalid callback type was supplied.
STATUS_ERR_UNSUPPORTED_DEV	If a callback that requires event driven mode was specified with a DAC instance configured in non-event mode.

Function dac_unregister_callback()

Unregisters an asynchronous callback function with the driver.

```
enum status_code dac_unregister_callback(
  struct dac_module *const module,
  const uint32_t channel,
  const enum dac_callback type)
```

Unregisters an asynchronous callback with the DAC driver, removing it from the internal callback registration table.

Table 4-32. Parameters

Data direction	Parameter name	Description
[in, out]	module_inst	Pointer to the DAC software instance struct
[in]	channel	Logical channel to unregiseter callback function
[in]	type	Type of callback function to unregister

Returns

Status of the de-registration operation.

Table 4-33. Return Values

Return value	Description
STATUS_OK	The callback was unregistered successfully.
STATUS_ERR_INVALID_ARG	If an invalid callback type was supplied.
STATUS_ERR_UNSUPPORTED_DEV	If a callback that requires event driven mode was specified with a DAC instance configured in non-event mode.

4.6.4.6 Callback enabling and disabling (Channel)

Function dac_chan_enable_callback()

Enables asynchronous callback generation for a given channel and type.

```
enum status_code dac_chan_enable_callback(
  struct dac_module *const module,
  const uint32_t channel,
  const enum dac_callback type)
```

Enables asynchronous callbacks for a given logical DAC channel and type. This must be called before a DAC channel will generate callback events.

Table 4-34. Parameters

Data direction	Parameter name	Description
[in, out]	dac_module	Pointer to the DAC software instance struct
[in]	channel	Logical channel to enable callback function
[in]	type	Type of callback function callbacks to enable

Returns Status of the callback enable operation.

Table 4-35. Return Values

Return value	Description
STATUS_OK	The callback was enabled successfully.
STATUS_ERR_UNSUPPORTED_DEV	If a callback that requires event driven mode was specified with a DAC instance configured in non-event mode.

Function dac_chan_disable_callback()

Disables asynchronous callback generation for a given channel and type.

```
enum status_code dac_chan_disable_callback(
  struct dac_module *const module,
  const uint32_t channel,
  const enum dac_callback type)
```

Disables asynchronous callbacks for a given logical DAC channel and type.

Table 4-36. Parameters

Data direction	Parameter name	Description
[in, out]	dac_module	Pointer to the DAC software instance struct
[in]	channel	Logical channel to disable callback function
[in]	type	Type of callback function callbacks to disable

Returns Status of the callback disable operation.

Table 4-37. Return Values

Return value	Description
STATUS_OK	The callback was disabled successfully.

Return value	Description
STATUS_ERR_UNSUPPORTED_DEV	If a callback that requires event driven mode was specified with a DAC instance configured in non-event mode.

Function dac_get_job_status()

Gets the status of a job.

```
enum status_code dac_get_job_status(
  struct dac_module * module_inst)
```

Gets the status of an ongoing or the last job.

Table 4-38. Parameters

Data direction	Parameter name	Description
[in]	module_inst	Pointer to the DAC software instance struct

Returns Status of the job

Function dac_abort_job()

Aborts an ongoing job.

```
void dac_abort_job(
  struct dac_module * module_inst)
```

Aborts an ongoing job.

Table 4-39. Parameters

Data direction	Parameter name	Description
[in]	module_inst	Pointer to the DAC software instance struct

4.6.5 Enumeration Definitions

4.6.5.1 Enum dac_callback

Enum for the possible callback types for the DAC module.

Table 4-40. Members

Enum value	Description
DAC_CALLBACK_DATA_EMPTY	Callback type for when a DAC channel data empty condition occurs (requires event triggered mode).

Enum value	Description
DAC_CALLBACK_DATA_UNDERRUN	Callback type for when a DAC channel data under-run condition occurs (requires event triggered mode).
DAC_CALLBACK_TRANSFER_COMPLETE	Callback type for when a DAC channel write buffer job complete. (requires event triggered mode).

4.6.5.2 Enum dac_channel

Enum for the DAC channel selection.

Table 4-41. Members

Enum value	Description
DAC_CHANNEL_0	DAC output channel 0.

4.6.5.3 Enum dac_output

Enum for the DAC output selection.

Table 4-42. Members

Enum value	Description
DAC_OUTPUT_EXTERNAL	DAC output to VOUT pin
DAC_OUTPUT_INTERNAL	DAC output as internal reference
DAC_OUTPUT_NONE	No output

4.6.5.4 Enum dac_reference

Enum for the possible reference voltages for the DAC.

Table 4-43. Members

Enum value	Description
DAC_REFERENCE_INT1V	1V from the internal band-gap reference.
DAC_REFERENCE_AVCC	Analog VCC as reference.
DAC_REFERENCE_AREF	External reference on AREF.

4.7 Extra Information for DAC Driver

4.7.1 Acronyms

The table below presents the acronyms used in this module:

Acronym	Description
ADC	Analog-to-Digital Converter

Acronym	Description
AC	Analog Comparator
DAC	Digital-to-Analog Converter
LSB	Least Significant Bit
MSB	Most Significant Bit
DMA	Direct Memory Access

4.7.2 Dependencies

This driver has the following dependencies:

- System Pin Multiplexer Driver

4.7.3 Errata

There are no errata related to this driver.

4.7.4 Module History

An overview of the module history is presented in the table below, with details on the enhancements and fixes made to the module since its first release. The current version of this corresponds to the newest version in the table.

Changelog
Added new configuration parameters `databuf_protection_bypass`, `voltage_pump_disable`. Added new callback functions `dac_chan_write_buffer_wait`, `dac_chan_write_buffer_job`, `dac_chan_write_job`, `dac_get_job_status`, `dac_abort_job` and new callback type `DAC_CALLBACK_TRANSFER_COMPLETE` for DAC conversion job
Initial Release

4.8 Examples for DAC Driver

This is a list of the available Quick Start guides (QSGs) and example applications for SAM D20/D21 Digital-to-Analog Driver (DAC). QSGs are simple examples with step-by-step instructions to configure and use this driver in a selection of use cases. Note that QSGs can be compiled as a standalone application or be added to the user application.

- Quick Start Guide for DAC - Basic
- Quick Start Guide for DAC - Callback
- Quick Start Guide for Using DMA with ADC/DAC

4.8.1 Quick Start Guide for DAC - Basic

In this use case, the DAC will be configured with the following settings:

- Analog VCC as reference
- Internal output disabled
- Drive the DAC output to the V_{OUT} pin
- Right adjust data
- The output buffer is disabled when the chip enters STANDBY sleep mode

4.8.1.1 Quick Start

Prerequisites

There are no special setup requirements for this use-case.

Code

Add to the main application source file, outside of any functions:

```
struct dac_module dac_instance;
```

Copy-paste the following setup code to your user application:

```
void configure_dac(void)
{
    struct dac_config config_dac;
    dac_get_config_defaults(&config_dac);

    dac_init(&dac_instance, DAC, &config_dac);

    dac_enable(&dac_instance);
}

void configure_dac_channel(void)
{
    struct dac_chan_config config_dac_chan;
    dac_chan_get_config_defaults(&config_dac_chan);

    dac_chan_set_config(&dac_instance, DAC_CHANNEL_0, &config_dac_chan);

    dac_chan_enable(&dac_instance, DAC_CHANNEL_0);
}
```

Add to user application initialization (typically the start of `main()`):

```
configure_dac();
configure_dac_channel();
```

Workflow

1. Create a module software instance structure for the DAC module to store the DAC driver state while it is in use.

   ```
   struct dac_module dac_instance;
   ```

Note This should never go out of scope as long as the module is in use. In most cases, this should be global.

2. Configure the DAC module.

   a. Create a DAC module configuration struct, which can be filled out to adjust the configuration of a physical DAC peripheral.

      ```
      struct dac_config config_dac;
      ```

   b. Initialize the DAC configuration struct with the module's default values.

```
dac_get_config_defaults(&config_dac);
```

Note This should always be performed before using the configuration struct to ensure that all values are initialized to known default settings.

c. Enable the DAC module so that channels can be configured.

```
dac_enable(&dac_instance);
```

3. Configure the DAC channel.

a. Create a DAC channel configuration struct, which can be filled out to adjust the configuration of a physical DAC output channel.

```
struct dac_chan_config config_dac_chan;
```

b. Initialize the DAC channel configuration struct with the module's default values.

```
dac_chan_get_config_defaults(&config_dac_chan);
```

Note This should always be performed before using the configuration struct to ensure that all values are initialized to known default settings.

c. Configure the DAC channel with the desired channel settings.

```
dac_chan_set_config(&dac_instance, DAC_CHANNEL_0, &config_dac_chan);
```

d. Enable the DAC channel so that it can output a voltage.

```
dac_chan_enable(&dac_instance, DAC_CHANNEL_0);
```

4.8.1.2 Use Case

Code

Copy-paste the following code to your user application:

```
uint16_t i = 0;

while (1) {
    dac_chan_write(&dac_instance, DAC_CHANNEL_0, i);

    if (++i == 0x3FF) {
        i = 0;
    }
}
```

Workflow

1. Create a temporary variable to track the current DAC output value.

```
uint16_t i = 0;
```

2. Enter an infinite loop to continuously output new conversion values to the DAC.

```
while (1) {
```

3. Write the next conversion value to the DAC, so that it will be output on the device's DAC analog output pin.

```
dac_chan_write(&dac_instance, DAC_CHANNEL_0, i);
```

4. Increment and wrap the DAC output conversion value, so that a ramp pattern will be generated.

```
if (++i == 0x3FF) {
    i = 0;
}
```

4.8.2 Quick Start Guide for DAC - Callback

In this use case, the DAC will be convert 16 samples using interrupt driven conversion. When all samples have been sampled, a callback will be called that signals the main application that conversion is compete.

The DAC will be set up as follows:

- Analog VCC as reference
- Internal output disabled
- Drive the DAC output to the V_{OUT} pin
- Right adjust data
- The output buffer is disabled when the chip enters STANDBY sleep mode
- DAC conversion is started with RTC overflow event

4.8.2.1 Setup

Prerequisites

There are no special setup requirements for this use-case.

Code

Add to the main application source file, outside of any functions:

```
#define DATA_LENGTH (16)
```

```
struct dac_module dac_instance;
```

```
struct rtc_module rtc_instance;
```

```
struct events_resource event_dac;
```

```
static volatile bool transfer_is_done = false;
```

```
static uint16_t dac_data[DATA_LENGTH];
```

Callback function:

```
void dac_callback(uint8_t channel)
{
    UNUSED(channel);

    transfer_is_done = true;
}
```

Copy-paste the following setup code to your user application:

```
void configure_rtc_count(void)
{
    struct rtc_count_events  rtc_event;

    struct rtc_count_config config_rtc_count;

    rtc_count_get_config_defaults(&config_rtc_count);

    config_rtc_count.prescaler           = RTC_COUNT_PRESCALER_DIV_1;
    config_rtc_count.mode                = RTC_COUNT_MODE_16BIT;
    config_rtc_count.continuously_update = true;

    rtc_count_init(&rtc_instance, RTC, &config_rtc_count);

    rtc_event.generate_event_on_overflow = true;

    rtc_count_enable_events(&rtc_instance, &rtc_event);

    rtc_count_enable(&rtc_instance);
}
```

```
void configure_dac(void)
{
    struct dac_config config_dac;

    dac_get_config_defaults(&config_dac);

    dac_instance.start_on_event = true;

    dac_init(&dac_instance, DAC, &config_dac);

    struct dac_events events =
        { .on_event_start_conversion = true };

    dac_enable_events(&dac_instance, &events);

    dac_enable(&dac_instance);
}
```

```
void configure_dac_channel(void)
{
```

```
    struct dac_chan_config config_dac_chan;

    dac_chan_get_config_defaults(&config_dac_chan);

    dac_chan_set_config(&dac_instance, DAC_CHANNEL_0,
            &config_dac_chan);

    dac_chan_enable(&dac_instance, DAC_CHANNEL_0);
}
```

define a data length variables and add to user application (typically the start of `main()`):

```
uint32_t i;
```

Add to user application initialization (typically the start of `main()`):

```
configure_rtc_count();

rtc_count_set_period(&rtc_instance,1);

configure_dac();

configure_dac_channel();

configure_event_resource();

dac_register_callback(&dac_instance, DAC_CHANNEL_0,
        dac_callback,DAC_CALLBACK_TRANSFER_COMPLETE);

dac_chan_enable_callback(&dac_instance, DAC_CHANNEL_0,
        DAC_CALLBACK_TRANSFER_COMPLETE);

for (i=0;i<DATA_LENGTH;i++) {
    dac_data[i] = 0xfff*i;
}
```

Workflow

1. Create a module software instance structure for the DAC module to store the DAC driver state while it is in use.

   ```
   struct dac_module dac_instance;
   ```

Note This should never go out of scope as long as the module is in use. In most cases, this should be global.

2. RTC module is used as the event trigger for DAC in this case, create a module software instance structure for the RTC module to store the RTC driver state.

   ```
   struct rtc_module rtc_instance;
   ```

Note This should never go out of scope as long as the module is in use. In most cases, this should be global.

3. Create a buffer for the DAC samples to be converted by the driver.

```
static uint16_t dac_data[DATA_LENGTH];
```

4. Create a callback function that will be called when DAC completes convert job.

```
void dac_callback(uint8_t channel)
{
    UNUSED(channel);

    transfer_is_done = true;
}
```

5. Configure the DAC module.

   a. Create a DAC module configuration struct, which can be filled out to adjust the configuration of a physical DAC peripheral.

```
struct dac_config config_dac;
```

   b. Initialize the DAC configuration struct with the module's default values.

```
dac_get_config_defaults(&config_dac);
```

Note

This should always be performed before using the configuration struct to ensure that all values are initialized to known default settings.

   c. Configure the DAC module with starting conversion on event.

```
dac_instance.start_on_event = true;
```

   d. Initialize the DAC module.

```
dac_init(&dac_instance, DAC, &config_dac);
```

   e. Enable DAC start on conversion mode.

```
struct dac_events events =
    { .on_event_start_conversion = true };
```

   f. Enable DAC event.

```
dac_enable_events(&dac_instance, &events);
```

   g. Enable DAC module.

```
dac_enable(&dac_instance);
```

6. Configure the DAC channel.

   a. Create a DAC channel configuration struct, which can be filled out to adjust the configuration of a physical DAC output channel.

```
struct dac_chan_config config_dac_chan;
```

b. Initialize the DAC channel configuration struct with the module's default values.

```
dac_chan_get_config_defaults(&config_dac_chan);
```

Note This should always be performed before using the configuration struct to ensure that all values are initialized to known default settings.

c. Configure the DAC channel with the desired channel settings.

```
dac_chan_set_config(&dac_instance, DAC_CHANNEL_0,
        &config_dac_chan);
```

d. Enable the DAC channel so that it can output a voltage.

```
dac_chan_enable(&dac_instance, DAC_CHANNEL_0);
```

7. Configure the RTC module.

a. Create a RTC module event struct, which can be filled out to adjust the configuration of a physical RTC peripheral.

```
struct rtc_count_events  rtc_event;
```

b. Create a RTC module configuration struct, which can be filled out to adjust the configuration of a physical RTC peripheral.

```
struct rtc_count_config config_rtc_count;
```

c. Initialize the RTC configuration struct with the module's default values.

```
rtc_count_get_config_defaults(&config_rtc_count);
```

Note This should always be performed before using the configuration struct to ensure that all values are initialized to known default settings.

d. Change the RTC module configuration to suit the application.

```
config_rtc_count.prescaler           = RTC_COUNT_PRESCALER_DIV_1;
config_rtc_count.mode                = RTC_COUNT_MODE_16BIT;
config_rtc_count.continuously_update = true;
```

e. Initialize the RTC module.

```
rtc_count_init(&rtc_instance, RTC, &config_rtc_count);
```

f. Configure the RTC module with overflow event.

```
rtc_event.generate_event_on_overflow = true;
```

g. Enable RTC module overflow event.

```
rtc_count_enable_events(&rtc_instance, &rtc_event);
```

h. Enable RTC module.

```
rtc_count_enable(&rtc_instance);
```

8. Configure the Event resource.

a. Create a event resource config struct, which can be filled out to adjust the configuration of a physical event peripheral.

```
struct events_config event_config;
```

b. Initialize the event configuration struct with the module's default values.

```
events_get_config_defaults(&event_config);
```

Note

This should always be performed before using the configuration struct to ensure that all values are initialized to known default settings.

c. Change the event module configuration to suit the application.

```
event_config.generator      = EVSYS_ID_GEN_RTC_OVF;
event_config.edge_detect    = EVENTS_EDGE_DETECT_RISING;
event_config.path           = EVENTS_PATH_ASYNCHRONOUS;
event_config.clock_source   = GCLK_GENERATOR_0;
```

d. Allocate the event resource.

```
events_allocate(&event_dac, &event_config);
```

e. Attach the event resource with user DAC start

```
events_attach_user(&event_dac, EVSYS_ID_USER_DAC_START);
```

9. Register and enable the DAC Write Buffer Complete callback handler

a. Register the user-provided Write Buffer Complete callback function with the driver, so that it will be run when an asynchronous buffer write job completes.

```
dac_register_callback(&dac_instance, DAC_CHANNEL_0,
        dac_callback,DAC_CALLBACK_TRANSFER_COMPLETE);
```

b. Enable the Read Buffer Complete callback so that it will generate callbacks.

```
dac_chan_enable_callback(&dac_instance, DAC_CHANNEL_0,
        DAC_CALLBACK_TRANSFER_COMPLETE);
```

4.8.2.2 Use Case

Code

Copy-paste the following code to your user application:

```
dac_chan_write_buffer_job(&dac_instance, DAC_CHANNEL_0,
        dac_data, DATA_LENGTH);

while (!transfer_is_done) {
    /* Wait for transfer done */
}

while (1) {
}
```

Workflow

1. Start an DAC conversion and generate a callback when complete.

```
dac_chan_write_buffer_job(&dac_instance, DAC_CHANNEL_0,
        dac_data, DATA_LENGTH);
```

2. Wait until the conversion is complete.

```
while (!transfer_is_done) {
    /* Wait for transfer done */
}
```

3. Enter an infinite loop once the conversion is complete.

```
while (1) {
}
```

4.8.3 Quick Start Guide for Using DMA with ADC/DAC

For this examples, see Quick Start Guide for Using DMA with ADC/DAC

5. SAM D20/D21 EEPROM Emulator Service (EEPROM)

This driver for SAM D20/D21 devices provides an emulated EEPROM memory space in the device's FLASH memory, for the storage and retrieval of user-application configuration data into and out of non-volatile memory.

The following peripherals are used by this module:

- NVM (Non-Volatile Memory Controller)

The outline of this documentation is as follows:

- Prerequisites
- Module Overview
- Special Considerations
- Extra Information
- Examples
- API Overview

5.1 Prerequisites

The SAM D20/D21 device fuses must be configured via an external programmer or debugger, so that an EEPROM section is allocated in the main NVM flash memory contents. If a NVM section is not allocated for the EEPROM emulator, or if insufficient space for the emulator is reserved, the module will fail to initialize.

5.2 Module Overview

As the SAM D20/D21 devices do not contain any physical EEPROM memory, the storage of non-volatile user data is instead emulated using a special section of the device's main FLASH memory. The use of FLASH memory technology over EEPROM presents several difficulties over true EEPROM memory; data must be written as a number of physical memory pages (of several bytes each) rather than being individually byte addressable, and entire rows of FLASH must be erased before new data may be stored. To help abstract these characteristics away from the user application an emulation scheme is implemented to present a more user-friendly API for data storage and retrieval.

This module provides an EEPROM emulation layer on top of the device's internal NVM controller, to provide a standard interface for the reading and writing of non-volatile configuration data. This data is placed into the EEPROM emulated section of the device's main FLASH memory storage section, the size of which is configured using the device's fuses. Emulated EEPROM is exempt from the usual device NVM region lock bits, so that it may be read from or written to at any point in the user application.

There are many different algorithms that may be employed for EEPROM emulation using FLASH memory, to tune the write and read latencies, RAM usage, wear levelling and other characteristics. As a result, multiple different emulator schemes may be implemented, so that the most appropriate scheme for a specific application's requirements may be used.

5.2.1 Implementation Details

The following information is relevant for **EEPROM Emulator scheme 1, version 1.0.0**, as implemented by this module. Other revisions or emulation schemes may vary in their implementation details and may have different wear-leveling, latency and other characteristics.

5.2.1.1 Emulator Characteristics

This emulator is designed for **best reliability, with a good balance of available storage and write-cycle limits**. It is designed to ensure that page data is atomically updated so that in the event of a failed update the previous data is not lost (when used correctly). With the exception of a system reset with data cached to the internal write-cache buffer, at most only the latest write to physical non-volatile memory will be lost in the event of a failed write.

This emulator scheme is tuned to give best write-cycle longevity when writes are confined to the same logical EEPROM page (where possible) and when writes across multiple logical EEPROM pages are made in a linear fashion through the entire emulated EEPROM space.

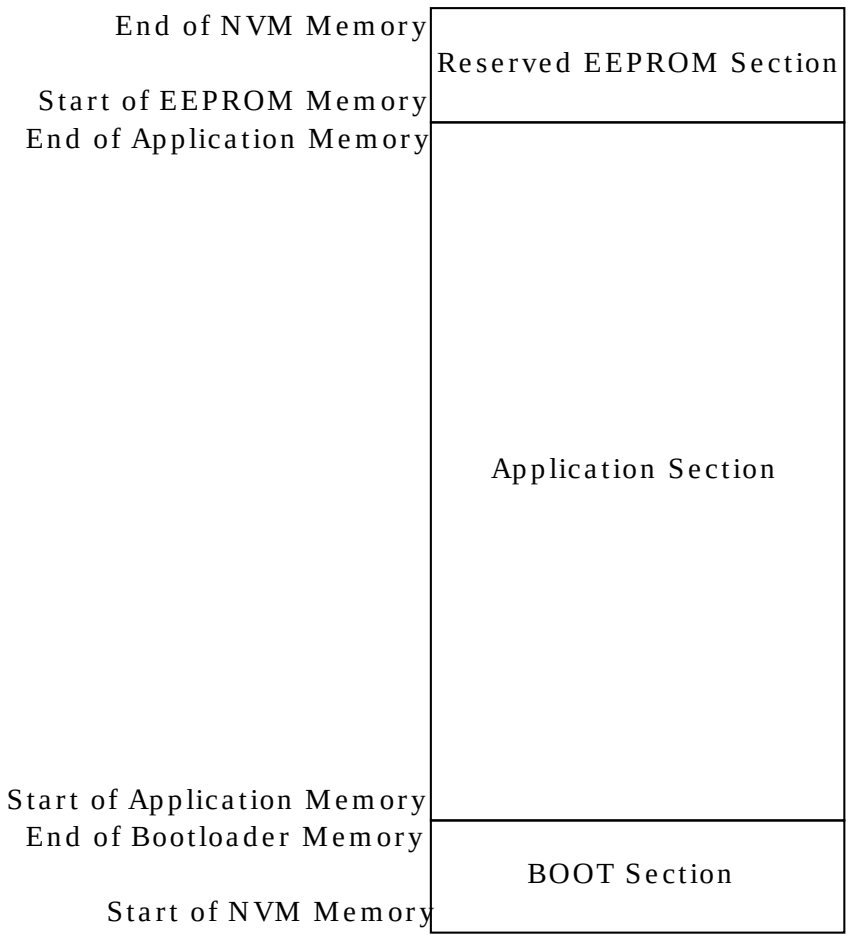
5.2.1.2 Physical Memory

The SAM D20/D21 non-volatile FLASH is divided into a number of physical rows, each containing four identically sized flash pages. Pages may be read or written to individually, however pages must be erased before being reprogrammed and the smallest granularity available for erasure is one single row.

This discrepancy results in the need for an emulator scheme that is able to handle the versioning and moving of page data to different physical rows as needed, erasing old rows ready for re-use by future page write operations.

Physically, the emulated EEPROM segment is located at the end of the physical FLASH memory space, as shown in Figure 5-1: Physical Memory on page 119.

Figure 5-1. Physical Memory



5.2.1.3 Master Row

One physical FLASH row at the end of the emulated EEPROM memory space is reserved for use by the emulator to store configuration data. The master row is not user-accessible, and is reserved solely for internal use by the emulator.

5.2.1.4 Spare Row

As data needs to be preserved between row erasures, a single FLASH row is kept unused to act as destination for copied data when a write request is made to an already full row. When the write request is made, any logical pages of data in the full row that need to be preserved are written to the spare row along with the new (updated) logical page data, before the old row is erased and marked as the new spare.

5.2.1.5 Row Contents

Each physical FLASH row initially stores the contents of two logical EEPROM memory pages. This halves the available storage space for the emulated EEPROM but reduces the overall number of row erases that are required, by reserving two pages within each row for updated versions of the logical page contents. See Figure 5-3: Initial physical layout of the emulated EEPROM memory on page 120 for a visual layout of the EEPROM Emulator physical memory.

As logical pages within a physical row are updated, the new data is filled into the remaining unused pages in the row. Once the entire row is full, a new write request will copy the logical page not being written to in the current row to the spare row with the new (updated) logical page data, before the old row is erased.

This system allows for the same logical page to be updated up to three times into physical memory before a row erasure procedure is needed. In the case of multiple versions of the same logical EEPROM page being stored in the same physical row, the right-most (highest physical FLASH memory page address) version is considered to be the most current.

5.2.1.6 Write Cache

As a typical EEPROM use case is to write to multiple sections of the same EEPROM page sequentially, the emulator is optimized with a single logical EEPROM page write cache to buffer writes before they are written to the physical backing memory store. The cache is automatically committed when a new write request to a different logical EEPROM memory page is requested, or when the user manually commits the write cache.

Without the write cache, each write request to an EEPROM memory page would require a full page write, reducing the system performance and significantly reducing the lifespan of the non-volatile memory.

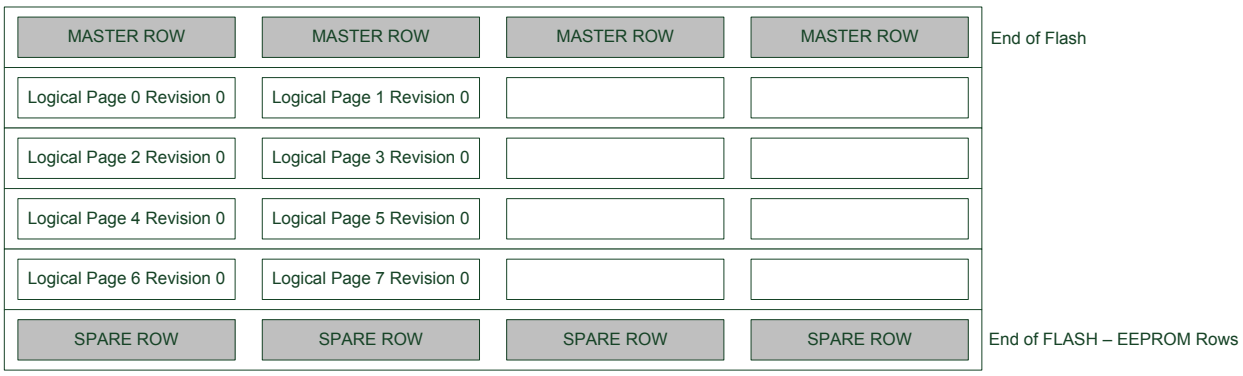
5.2.2 Memory Layout

A single logical EEPROM page is physically stored as the page contents and a header inside a single physical FLASH page, as shown in Figure 5-2: Internal layout of an emulated EEPROM page on page 120.

Figure 5-2. Internal layout of an emulated EEPROM page

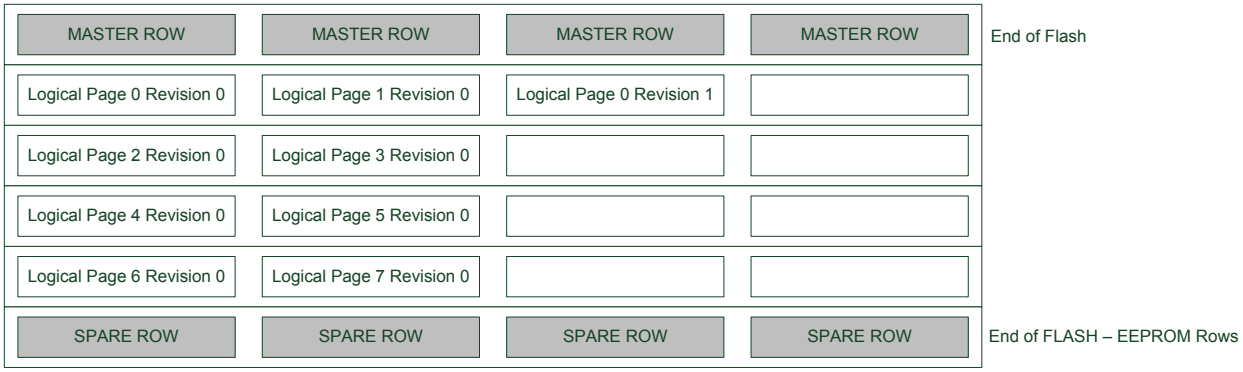
Within the EEPROM memory reservation section at the top of the NVM memory space, this emulator will produce the layout as shown in Figure 5-3: Initial physical layout of the emulated EEPROM memory on page 120 when initialized for the first time.

Figure 5-3. Initial physical layout of the emulated EEPROM memory



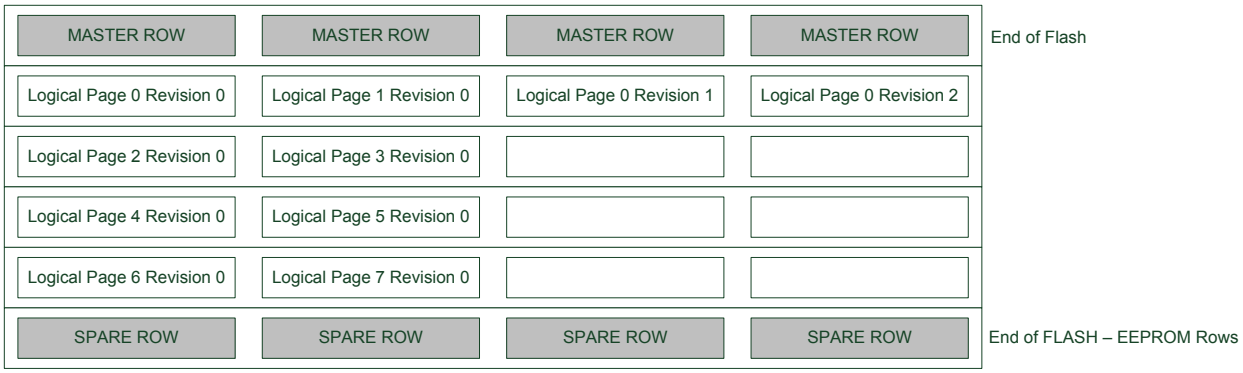
When an EEPROM page needs to be committed to physical memory, the next free FLASH page in the same row will be chosen - this makes recovery simple, as the right-most version of a logical page in a row is considered the most current. With four pages to a physical NVM row, this allows for up to three updates to the same logical page to be made before an erase is needed. Figure 5-4: First write to logical EEPROM page N-1 on page 121 shows the result of the user writing an updated version of logical EEPROM page N - 1 to the physical memory.

Figure 5-4. First write to logical EEPROM page N-1



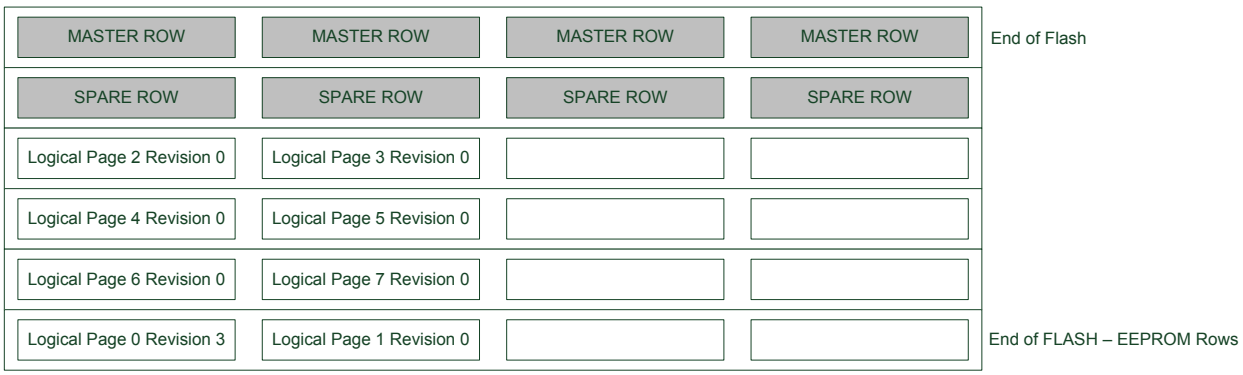
A second write of the same logical EEPROM page results in the layout shown in Figure 5-5: Second write to logical EEPROM page N-1 on page 121.

Figure 5-5. Second write to logical EEPROM page N-1



A third write of the same logical page requires that the EEPROM emulator erase the row, as it has become full. Prior to this, the contents of the unmodified page in the same row as the page being updated will be copied into the spare row, along with the new version of the page being updated. The old (full) row is then erased, resulting in the layout shown in Figure 5-6: Third write to logical EEPROM page N-1 on page 121.

Figure 5-6. Third write to logical EEPROM page N-1



5.3 Special Considerations

5.3.1 NVM Controller Configuration

The EEPROM Emulator service will initialize the NVM controller as part of its own initialization routine; the NVM controller will be placed in Manual Write mode, so that explicit write commands must be sent to the controller to commit a buffered page to physical memory. The manual write command must thus be issued to the NVM controller whenever the user application wishes to write to a NVM page for its own purposes.

5.3.2 Logical EEPROM Page Size

As a small amount of information needs to be stored in a header before the contents of a logical EEPROM page in memory (for use by the emulation service), the available data in each EEPROM page is less than the total size of a single NVM memory page by several bytes.

5.3.3 Committing of the Write Cache

A single-page write cache is used internally to buffer data written to pages in order to reduce the number of physical writes required to store the user data, and to preserve the physical memory lifespan. As a result, it is important that the write cache is committed to physical memory **as soon as possible after a BOD low power condition**, to ensure that enough power is available to guarantee a completed write so that no data is lost.

The write cache must also be manually committed to physical memory if the user application is to perform any NVM operations using the NVM controller directly.

5.4 Extra Information

For extra information see Extra Information. This includes:

- Acronyms
- Dependencies
- Errata
- Module History

5.5 Examples

For a list of examples related to this driver, see Examples for Emulated EEPROM service.

5.6 API Overview

5.6.1 Structure Definitions

5.6.1.1 Struct eeprom_emulator_parameters

Structure containing the memory layout parameters of the EEPROM emulator module.

Table 5-1. Members

Type	Name	Description
uint16_t	eeprom_number_of_pages	Number of emulated pages of EEPROM.
uint8_t	page_size	Number of bytes per emulated EEPROM page.

5.6.2 Macro Definitions

5.6.2.1 EEPROM emulator information

Macro EEPROM_EMULATOR_ID

```
#define EEPROM_EMULATOR_ID 1
```

Emulator scheme ID, identifying the scheme used to emulated EEPROM storage.

Macro EEPROM_MAJOR_VERSION

```
#define EEPROM_MAJOR_VERSION 1
```

Emulator major version number, identifying the emulator major version.

Macro EEPROM_MINOR_VERSION

```
#define EEPROM_MINOR_VERSION 0
```

Emulator minor version number, identifying the emulator minor version.

Macro EEPROM_REVISION

```
#define EEPROM_REVISION 0
```

Emulator revision version number, identifying the emulator revision.

Macro EEPROM_PAGE_SIZE

```
#define EEPROM_PAGE_SIZE (NVMCTRL_PAGE_SIZE - EEPROM_HEADER_SIZE)
```

Size of the user data portion of each logical EEPROM page, in bytes.

5.6.3 Function Definitions

5.6.3.1 Configuration and initialization

Function eeprom_emulator_init()

Initializes the EEPROM Emulator service.

```
enum status_code eeprom_emulator_init(void)
```

Initializes the emulated EEPROM memory space; if the emulated EEPROM memory has not been previously initialized, it will need to be explicitly formatted via eeprom_emulator_erase_memory(). The EEPROM memory space will **not** be automatically erased by the initialization function, so that partial data may be recovered by the user application manually if the service is unable to initialize successfully.

Returns

Status code indicating the status of the operation.

Table 5-2. Return Values

Return value	Description
STATUS_OK	EEPROM emulation service was successfully initialized

Return value	Description
STATUS_ERR_NO_MEMORY	No EEPROM section has been allocated in the device
STATUS_ERR_BAD_FORMAT	Emulated EEPROM memory is corrupt or not formatted
STATUS_ERR_IO	EEPROM data is incompatible with this version or scheme of the EEPROM emulator

Function eeprom_emulator_erase_memory()

Erases the entire emulated EEPROM memory space.

```
void eeprom_emulator_erase_memory(void)
```

Erases and re-initializes the emulated EEPROM memory space, destroying any existing data.

Function eeprom_emulator_get_parameters()

Retrieves the parameters of the EEPROM Emulator memory layout.

```
enum status_code eeprom_emulator_get_parameters(
  struct eeprom_emulator_parameters *const parameters)
```

Retrieves the configuration parameters of the EEPROM Emulator, after it has been initialized.

Table 5-3. Parameters

Data direction	Parameter name	Description
[out]	parameters	EEPROM Emulator parameter struct to fill

Returns Status of the operation.

Table 5-4. Return Values

Return value	Description
STATUS_OK	If the emulator parameters were retrieved successfully
STATUS_ERR_NOT_INITIALIZED	If the EEPROM Emulator is not initialized

5.6.3.2 Logical EEPROM page reading/writing

Function eeprom_emulator_commit_page_buffer()

Commits any cached data to physical non-volatile memory.

```
enum status_code eeprom_emulator_commit_page_buffer(void)
```

Commits the internal SRAM caches to physical non-volatile memory, to ensure that any outstanding cached data is preserved. This function should be called prior to a system reset or shutdown to prevent data loss.

Note This should be the first function executed in a BOD33 Early Warning callback to ensure that any outstanding cache data is fully written to prevent data loss.

This function should also be called before using the NVM controller directly in the user-application for any other purposes to prevent data loss.

Returns Status code indicating the status of the operation.

Function eeprom_emulator_write_page()

Writes a page of data to an emulated EEPROM memory page.

```
enum status_code eeprom_emulator_write_page(
  const uint8_t logical_page,
  const uint8_t *const data)
```

Writes an emulated EEPROM page of data to the emulated EEPROM memory space.

Note Data stored in pages may be cached in volatile RAM memory; to commit any cached data to physical non-volatile memory, the eeprom_emulator_commit_page_buffer() function should be called.

Table 5-5. Parameters

Data direction	Parameter name	Description
[in]	logical_page	Logical EEPROM page number to write to
[in]	data	Pointer to the data buffer containing source data to write

Returns Status code indicating the status of the operation.

Table 5-6. Return Values

Return value	Description
STATUS_OK	If the page was successfully read
STATUS_ERR_NOT_INITIALIZED	If the EEPROM emulator is not initialized
STATUS_ERR_BAD_ADDRESS	If an address outside the valid emulated EEPROM memory space was supplied

Function eeprom_emulator_read_page()

Reads a page of data from an emulated EEPROM memory page.

```
enum status_code eeprom_emulator_read_page(
  const uint8_t logical_page,
  uint8_t *const data)
```

Reads an emulated EEPROM page of data from the emulated EEPROM memory space.

Table 5-7. Parameters

Data direction	Parameter name	Description
[in]	logical_page	Logical EEPROM page number to read from
[out]	data	Pointer to the destination data buffer to fill

Returns Status code indicating the status of the operation.

Table 5-8. Return Values

Return value	Description
STATUS_OK	If the page was successfully read
STATUS_ERR_NOT_INITIALIZED	If the EEPROM emulator is not initialized
STATUS_ERR_BAD_ADDRESS	If an address outside the valid emulated EEPROM memory space was supplied

5.6.3.3 Buffer EEPROM reading/writing

Function eeprom_emulator_write_buffer()

Writes a buffer of data to the emulated EEPROM memory space.

```
enum status_code eeprom_emulator_write_buffer(
  const uint16_t offset,
  const uint8_t *const data,
  const uint16_t length)
```

Writes a buffer of data to a section of emulated EEPROM memory space. The source buffer may be of any size, and the destination may lie outside of an emulated EEPROM page boundary.

Note Data stored in pages may be cached in volatile RAM memory; to commit any cached data to physical non-volatile memory, the eeprom_emulator_commit_page_buffer() function should be called.

Table 5-9. Parameters

Data direction	Parameter name	Description
[in]	offset	Starting byte offset to write to, in emulated EEPROM memory space
[in]	data	Pointer to the data buffer containing source data to write
[in]	length	Length of the data to write, in bytes

Returns Status code indicating the status of the operation.

Table 5-10. Return Values

Return value	Description
STATUS_OK	If the page was successfully read

Return value	Description
STATUS_ERR_NOT_INITIALIZED	If the EEPROM emulator is not initialized
STATUS_ERR_BAD_ADDRESS	If an address outside the valid emulated EEPROM memory space was supplied

Function eeprom_emulator_read_buffer()

Reads a buffer of data from the emulated EEPROM memory space.

```
enum status_code eeprom_emulator_read_buffer(
  const uint16_t offset,
  uint8_t *const data,
  const uint16_t length)
```

Reads a buffer of data from a section of emulated EEPROM memory space. The destination buffer may be of any size, and the source may lie outside of an emulated EEPROM page boundary.

Table 5-11. Parameters

Data direction	Parameter name	Description
[in]	offset	Starting byte offset to read from, in emulated EEPROM memory space
[out]	data	Pointer to the data buffer containing source data to read
[in]	length	Length of the data to read, in bytes

Returns Status code indicating the status of the operation.

Table 5-12. Return Values

Return value	Description
STATUS_OK	If the page was successfully read
STATUS_ERR_NOT_INITIALIZED	If the EEPROM emulator is not initialized
STATUS_ERR_BAD_ADDRESS	If an address outside the valid emulated EEPROM memory space was supplied

5.7 Extra Information

5.7.1 Acronyms

Below is a table listing the acronyms used in this module, along with their intended meanings.

Acronym	Description
EEPROM	Electronically Erasable Read-Only Memory
NVM	Non-Volatile Memory

5.7.2 Dependencies

This driver has the following dependencies:

- Non-Volatile Memory Controller Driver

5.7.3 Errata

There are no errata related to this driver.

5.7.4 Module History

An overview of the module history is presented in the table below, with details on the enhancements and fixes made to the module since its first release. The current version of this corresponds to the newest version in the table.

Changelog
Fix warnings and document for SAM D21
Initial Release

5.8 Examples for Emulated EEPROM service

This is a list of the available Quick Start guides (QSGs) and example applications for SAM D20/D21 EEPROM Emulator Service (EEPROM). QSGs are simple examples with step-by-step instructions to configure and use this driver in a selection of use cases. Note that QSGs can be compiled as a standalone application or be added to the user application.

- Quick Start Guide for the Emulated EEPROM module - Basic Use Case

5.8.1 Quick Start Guide for the Emulated EEPROM module - Basic Use Case

In this use case, the EEPROM emulator module is configured and a sample page of data read and written. The first byte of the first EEPROM page is toggled, and a LED is turned on or off to reflect the new state. Each time the device is reset, the LED should toggle to a different state to indicate correct non-volatile storage and retrieval.

5.8.1.1 Prerequisites

The device's fuses must be configured to reserve a sufficient number of FLASH memory rows for use by the EEPROM emulator service, before the service can be used.

5.8.1.2 Setup

Prerequisites

There are no special setup requirements for this use-case.

Code

Copy-paste the following setup code to your user application:

```
void configure_eeprom(void)
{
    /* Setup EEPROM emulator service */
    enum status_code error_code = eeprom_emulator_init();

    if (error_code == STATUS_ERR_NO_MEMORY) {
        while (true) {
            /* No EEPROM section has been set in the device's fuses */
        }
    }
    else if (error_code != STATUS_OK) {
        /* Erase the emulated EEPROM memory (assume it is unformatted or
         * irrecoverably corrupt) */
        eeprom_emulator_erase_memory();
        eeprom_emulator_init();
```

```
    }
}
```

Add to user application initialization (typically the start of `main()`):

```
configure_eeprom();
```

Workflow

1. Attempt to initialize the EEPROM emulator service, storing the error code from the initialization function into a temporary variable.

   ```
   enum status_code error_code = eeprom_emulator_init();
   ```

2. Check if the emulator failed to initialize due to the device fuses not being configured to reserve enough of the main FLASH memory rows for emulated EEPROM usage - abort if the fuses are mis-configured.

   ```
   if (error_code == STATUS_ERR_NO_MEMORY) {
       while (true) {
           /* No EEPROM section has been set in the device's fuses */
       }
   }
   ```

3. Check if the emulator service failed to initialize for any other reason; if so assume the emulator physical memory is unformatted or corrupt and erase/re-try initialization.

   ```
   else if (error_code != STATUS_OK) {
       /* Erase the emulated EEPROM memory (assume it is unformatted or
        * irrecoverably corrupt) */
       eeprom_emulator_erase_memory();
       eeprom_emulator_init();
   }
   ```

5.8.1.3 Use Case

Code

Copy-paste the following code to your user application:

```
uint8_t page_data[EEPROM_PAGE_SIZE];
eeprom_emulator_read_page(0, page_data);

page_data[0] = !page_data[0];
port_pin_set_output_level(LED_0_PIN, page_data[0]);

eeprom_emulator_write_page(0, page_data);
eeprom_emulator_commit_page_buffer();

while (true) {

}
```

Workflow

1. Create a buffer to hold a single emulated EEPROM page of memory, and read out logical EEPROM page zero into it.

```
uint8_t page_data[EEPROM_PAGE_SIZE];
eeprom_emulator_read_page(0, page_data);
```

2. Toggle the first byte of the read page.

```
page_data[0] = !page_data[0];
```

3. Output the toggled LED state onto the board LED.

```
port_pin_set_output_level(LED_0_PIN, page_data[0]);
```

4. Write the modified page back to logical EEPROM page zero, flushing the internal emulator write cache afterwards to ensure it is immediately written to physical non-volatile memory.

```
eeprom_emulator_write_page(0, page_data);
eeprom_emulator_commit_page_buffer();
```

6. SAM D20/D21 Event System Driver (EVENTS)

This driver for SAM D20/D21 devices provides an interface for the configuration and management of the device's peripheral event resources and users within the device, including enabling and disabling of peripheral source selection and synchronization of clock domains between various modules. The following API modes is covered by this manual:

- Polled API
- Interrupt hook API

The following peripherals are used by this module:

- EVSYS (Event System Management)

The outline of this documentation is as follows:

- Prerequisites
- Module Overview
- Special Considerations
- Extra Information
- Examples
- API Overview

6.1 Prerequisites

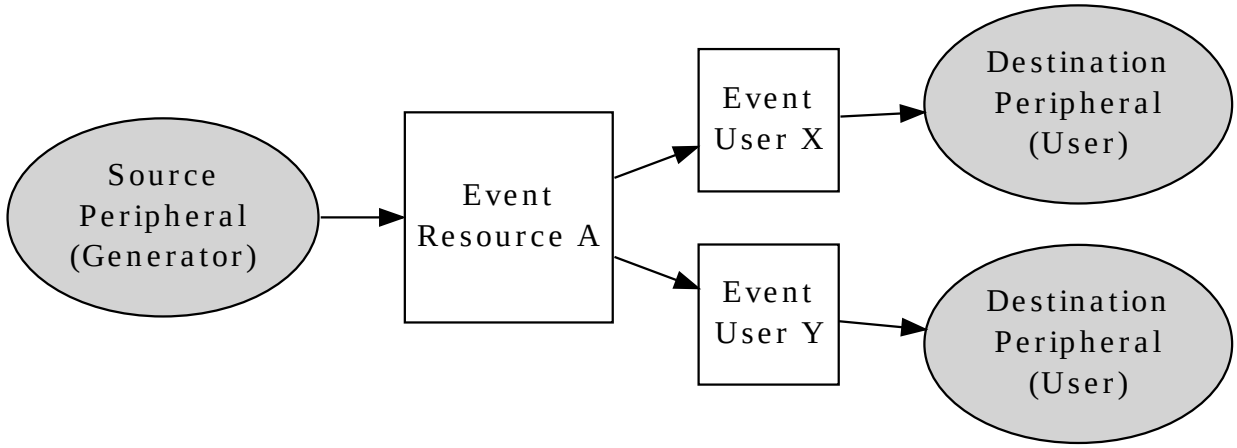
There are no prerequisites for this module.

6.2 Module Overview

Peripherals within the SAM D20/D21 devices are capable of generating two types of actions in response to given stimulus: set a register flag for later intervention by the CPU (using interrupt or polling methods), or generate event signals which can be internally routed directly to other peripherals within the device. The use of events allows for direct actions to be performed in one peripheral in response to a stimulus in another without CPU intervention. This can lower the overall power consumption of the system if the CPU is able to remain in sleep modes for longer periods (SleepWalking™), and lowers the latency of the system response.

The event system is comprised of a number of freely configurable Event resources, plus a number of fixed Event Users. Each Event resource can be configured to select the input peripheral that will generate the events signal, as well as the synchronization path and edge detection mode. The fixed-function Event Users, connected to peripherals within the device, can then subscribe to an Event resource in a one-to-many relationship in order to receive events as they are generated. An overview of the event system chain is shown in Figure 6-1: Module Overview on page 132.

Figure 6-1. Module Overview



There are many different events that can be routed in the device, which can then trigger many different actions. For example, an Analog Comparator module could be configured to generate an event when the input signal rises above the compare threshold, which then triggers a Timer Counter module to capture the current count value for later use.

6.2.1 Event Channels

The Event module in each device consists of several channels, which can be freely linked to an event generator (i.e. a peripheral within the device that is capable of generating events). Each channel can be individually configured to select the generator peripheral, signal path and edge detection applied to the input event signal, before being passed to any event user(s).

Event channels can support multiple users within the device in a standardized manner; when an Event User is linked to an Event Channel, the channel will automatically handshake with all attached users to ensure that all modules correctly receive and acknowledge the event.

6.2.2 Event Users

Event Users are able to subscribe to an Event Channel, once it has been configured. Each Event User consists of a fixed connection to one of the peripherals within the device (for example, an ADC module or Timer module) and is capable of being connected to a single Event Channel.

6.2.3 Edge Detection

For asynchronous events, edge detection on the event input is not possible, and the event signal must be passed directly between the event generator and event user. For synchronous and re-synchronous events, the input signal from the event generator must pass through an edge detection unit, so that only the rising, falling or both edges of the event signal triggers an action in the event user.

6.2.4 Path Selection

The event system in the SAM D20/D21 devices supports three signal path types from the event generator to event users: asynchronous, synchronous and re-synchronous events.

6.2.4.1 Asynchronous Paths

Asynchronous event paths allow for an asynchronous connection between the event generator and event user(s), when the source and destination peripherals share the same Generic Clock channel. In this mode the event is propagated between the source and destination directly to reduce the event latency, thus no edge detection is possible. The asynchronous event chain is shown in Figure 6-2: Asynchronous Paths on page 133.

Figure 6-2. Asynchronous Paths

Note Identically shaped borders in the diagram indicate a shared generic clock channel.

6.2.4.2 Synchronous Paths

The Synchronous event path should be used when edge detection or interrupts from the event channel are required, and the source event generator and the event channel shares the same Generic Clock channel. The synchronous event chain is shown in Figure 6-3: Synchronous Paths on page 133.

Not all peripherals support Synchronous event paths; refer to the device datasheet.

Figure 6-3. Synchronous Paths

Note Identically shaped borders in the diagram indicate a shared generic clock channel.

6.2.4.3 Re-synchronous Paths

Re-synchronous event paths are a special form of synchronous events, where when edge detection or interrupts from the event channel are required, but the event generator and the event channel use different Generic Clock channels. The re-synchronous path allows the Event System to synchronize the incoming event signal from the Event Generator to the clock of the Event System module to avoid missed events, at the cost of a higher latency due to the re-synchronization process. The re-synchronous event chain is shown in Figure 6-4: Re-synchronous Paths on page 133.

Not all peripherals support Re-synchronous event paths; refer to the device datasheet.

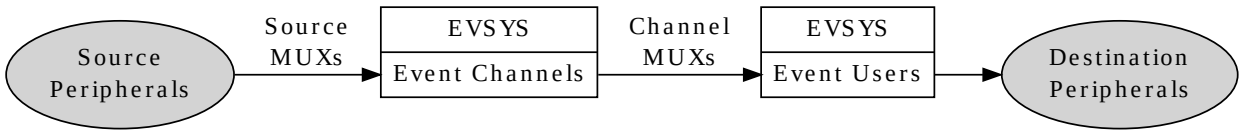
Figure 6-4. Re-synchronous Paths

Note Identically shaped borders in the diagram indicate a shared generic clock channel.

6.2.5 Physical Connection

Figure 6-5: Physical Connection on page 134 shows how this module is interconnected within the device.

Figure 6-5. Physical Connection



6.2.6 Configuring Events

For SAM D20/D21 devices, several steps are required to properly configure an event chain, so that hardware peripherals can respond to events generated by each other, listed below.

6.2.6.1 Source Peripheral

1. The source peripheral (that will generate events) must be configured and enabled.
2. The source peripheral (that will generate events) must have an output event enabled.

6.2.6.2 Event System

1. An event system channel must be allocated and configured with the correct source peripheral selected as the channel's event generator.
2. The event system user must be configured and enabled, and attached to # event channel previously allocated.

6.2.6.3 Destination Peripheral

1. The destination peripheral (that will receive events) must be configured and enabled.
2. The destination peripheral (that will receive events) must have an input event enabled.

6.3 Special Considerations

There are no special considerations for this module.

6.4 Extra Information

For extra information see Extra Information for EVENTS Driver. This includes:

- Acronyms
- Dependencies
- Errata
- Module History

6.5 Examples

For a list of examples related to this driver, see Examples for EVENTS Driver.

6.6 API Overview

6.6.1 Variable and Type Definitions

6.6.1.1 Type events_interrupt_hook

```
typedef void(* events_interrupt_hook )(struct events_resource *resource)
```

6.6.2 Structure Definitions

6.6.2.1 Struct events_config

This events configuration struct is used to configure each of the channels

Table 6-1. Members

Type	Name	Description
uint8_t	clock_source	Clock source for the event channel
enum events_edge_detect	edge_detect	Select edge detection mode
uint8_t	generator	Set event generator for the channel
enum events_path_selection	path	Select events channel path

6.6.2.2 Struct events_hook

Table 6-2. Members

Type	Name	Description
events_interrupt_hook	hook_func	
struct events_hook *	next	
struct events_resource *	resource	

6.6.2.3 Struct events_resource

Event resource structure.

Note The fields in this structure should not be altered by the user application; they are reserved for driver internals only.

6.6.3 Macro Definitions

6.6.3.1 Macro EVSYS_ID_GEN_NONE

```
#define EVSYS_ID_GEN_NONE 0
```

Use this to disable any peripheral event input to a channel. This can be usefull if you only want to use a channel for software generated events.Definition for no generator selection

6.6.3.2 Macro EVSYS_ID_USER_NONE

```
#define EVSYS_ID_USER_NONE 0
```

Definition for no user selection

6.6.4 Function Definitions

6.6.4.1 Function events_ack_interrupt()

Acknowledge an interrupt source.

```
enum status_code events_ack_interrupt(
  struct events_resource * resource,
  enum events_interrupt_source source)
```

Acknowledge an interrupt source so the interrupt state is cleared in hardware

Table 6-3. Parameters

Data direction	Parameter name	Description
[in]	resource	Pointer to an events_resource struct instance
[in]	source	One of the members in the events_interrupt_source enumerator

Returns Status of the interrupt source

Table 6-4. Return Values

Return value	Description
STATUS_OK	Interrupt source was acknowledged sucessfully

6.6.4.2 Function events_add_hook()

Insert hook into the event drivers interrupt hook queue.

```
enum status_code events_add_hook(
  struct events_resource * resource,
  struct events_hook * hook)
```

Inserts a hook into the event drivers interrupt hook queue

Table 6-5. Parameters

Data direction	Parameter name	Description
[in]	resource	Pointer to an events_resource struct instance
[in]	hook	Pointer to an events_hook struct instance

Returns Status of the insertion procedure

Table 6-6. Return Values

Return value	Description
STATUS_OK	Insertion of hook went sucessful

6.6.4.3 Function events_allocate()

Allocate an event channel and set configuration.

```
enum status_code events_allocate(
```

```
  struct events_resource * resource,
  struct events_config * config)
```

Allocates an event channel from the event channel pool and sets the channel configuration.

Table 6-7. Parameters

Data direction	Parameter name	Description
[out]	resource	Pointer to a events_resource struct instance
[in]	config	Pointer to a events_config struct

Returns Status of the configuration procedure

Table 6-8. Return Values

Return value	Description
STATUS_OK	Allocation and configuration went successful
STATUS_ERR_NOT_FOUND	No free event channel found

6.6.4.4 Function events_attach_user()

Attach user to the event channel.

```
enum status_code events_attach_user(
  struct events_resource * resource,
  uint8_t user_id)
```

Attach a user peripheral to the event channel to receive events.

Table 6-9. Parameters

Data direction	Parameter name	Description
[in]	resource	Pointer to an events_resource struct instance
[in]	user_id	A number identifying the user peripheral found in the device header file.

Returns Status of the user attach procedure

Table 6-10. Return Values

Return value	Description
STATUS_OK	No errors detected when attaching the event user

6.6.4.5 Function events_create_hook()

Initializes a interrupt hook for insertion in the event interrupt hook queue.

```
enum status_code events_create_hook(
  struct events_hook * hook,
```

```
  events_interrupt_hook hook_func)
```

Initializes a hook structure so it is ready for insertion in the interrupt hook queue

Table 6-11. Parameters

Data direction	Parameter name	Description
[out]	hook	Pointer to an events_hook struct instance
[in]	hook_func	Pointer to a function contaning the interrupt hook code

Returns Status of the hook creation procedure

Table 6-12. Return Values

Return value	Description
STATUS_OK	Creation and initialization of interrup hook went sucessful

6.6.4.6 Function events_del_hook()

Remove hook from the event drivers interrupt hook queue.

```
enum status_code events_del_hook(
  struct events_resource * resource,
  struct events_hook * hook)
```

Removes a hook from the event drivers interrupt hook queue

Table 6-13. Parameters

Data direction	Parameter name	Description
[in]	resource	Pointer to an events_resource struct instance
[in]	hook	Pointer to an events_hook struct instance

Returns Status of the removal procedure

Table 6-14. Return Values

Return value	Description
STATUS_OK	Removal of hook went sucessful
STATUS_ERR_NO_MEMORY	There is no hooks instances in the event driver interrupt hook list
STATUS_ERR_NOT_FOUND	Interrupt hook not found in the event drivers interrupt hook list

6.6.4.7 Function events_detach_user()

Detach an user peripheral from the event channel.

```
enum status_code events_detach_user(
  struct events_resource * resource,
  uint8_t user_id)
```

Deattach an user peripheral from the event channels so it does not receive any more events.

Table 6-15. Parameters

Data direction	Parameter name	Description
[in]	resource	Pointer to an event_resource struct instance
[in]	user_id	A number identifying the user peripheral found in the device header file.

Returns Status of the user detach procedure

Table 6-16. Return Values

Return value	Description
STATUS_OK	No errors detected when detaching the event user

6.6.4.8 Function events_disable_interrupt_source()

Disable interrupt source.

```
enum status_code events_disable_interrupt_source(
  struct events_resource * resource,
  enum events_interrupt_source source)
```

Disable an interrupt source so can trigger execution of an interrupt hook

Table 6-17. Parameters

Data direction	Parameter name	Description
[in]	resource	Pointer to an events_resource struct instance
[in]	source	One of the members in the events_interrupt_source enumerator

Returns Status of the interrupt source enable procedure

Table 6-18. Return Values

Return value	Description
STATUS_OK	Enabling of the interrupt source went sucessful
STATUS_ERR_INVALID_ARG	Interrupt source does not exist

6.6.4.9 Function events_enable_interrupt_source()

Enable interrupt source.

```
enum status_code events_enable_interrupt_source(
  struct events_resource * resource,
  enum events_interrupt_source source)
```

Enable an interrupt source so can trigger execution of an interrupt hook

Table 6-19. Parameters

Data direction	Parameter name	Description
[in]	resource	Pointer to an events_resource struct instance
[in]	source	One of the members in the events_interrupt_source enumerator

Returns Status of the interrupt source enable procedure

Table 6-20. Return Values

Return value	Description
STATUS_OK	Enabling of the interrupt source went sucessful
STATUS_ERR_INVALID_ARG	Interrupt source does not exist

6.6.4.10 Function events_get_config_defaults()

Initializes an event configurations struct to defaults.

```
void events_get_config_defaults(
  struct events_config * config)
```

Initailizes an event configuration struct to predefined safe default settings.

Table 6-21. Parameters

Data direction	Parameter name	Description
[in]	config	Pointer to an instance of struct events_config

6.6.4.11 Function events_get_free_channels()

Get number of free channels.

```
uint8_t events_get_free_channels(void)
```

Get number of allocatable channels in the events system resource pool

Returns The number of free channels in the event system

6.6.4.12 Function events_is_busy()

Check if a channel is busy.

```
bool events_is_busy(
  struct events_resource * resource)
```

Check if a channel is busy, a channels stays busy until all users connected to the channel has handled an event

Table 6-22. Parameters

Data direction	Parameter name	Description
[in]	resource	Pointer to a events_resource struct instance

Returns Status of the channels busy state

Table 6-23. Return Values

Return value	Description
true	One or more users connected to the channel has not handled the last event
false	All users are ready handle new events

6.6.4.13 Function events_is_detected()

Check if event is detected on event channel.

```
bool events_is_detected(
  struct events_resource * resource)
```

Check if an event has been detected on the channel

Note This function will clear the event detected interrupt flag

Table 6-24. Parameters

Data direction	Parameter name	Description
[in]	resource	Pointer to an events_resource struct

Returns Status of the event detection interrupt flag

Table 6-25. Return Values

Return value	Description
true	Event has been detected
false	Event has not been detected

6.6.4.14 Function events_is_interrupt_set()

Check if interrupt source is set.

```
bool events_is_interrupt_set(
  struct events_resource * resource,
  enum events_interrupt_source source)
```

Check if an interrupt source is set and should be processed

Table 6-26. Parameters

Data direction	Parameter name	Description
[in]	resource	Pointer to an events_resource struct instance
[in]	source	One of the memebers in the events_interrupt_source enumerator

Returns Status of the interrupt source

Table 6-27. Return Values

Return value	Description
true	Interrupt source is set
false	Interrupt source is not set

6.6.4.15 Function events_is_overrun()

Check if there has been an overrun situation on this channel.

```
bool events_is_overrun(
  struct events_resource * resource)
```

Check if there has been an overrun situation on this channel

Note This function will clear the event overrun detected interrupt flag

Table 6-28. Parameters

Data direction	Parameter name	Description
[in]	resource	Pointer to an events_resource struct

Returns Status of the event overrun interrupt flag

Table 6-29. Return Values

Return value	Description
true	Event overrun has been detected
false	Event overrun has not been detected

6.6.4.16 Function events_is_users_ready()

Check if all users connected to the channel is ready.

```
bool events_is_users_ready(
  struct events_resource * resource)
```

Check if all users connected to the channel is ready to handle incomming events

Table 6-30. Parameters

Data direction	Parameter name	Description
[in]	resource	Pointer to an events_resource struct

Returns The ready status of users connected to an event channel

Table 6-31. Return Values

Return value	Description
true	All users connect to event channel is ready handle incomming events
false	One or more users connect to event channel is not ready to handle incomming events

6.6.4.17 Function events_release()

Release allocated channel back the the resource pool.

```
enum status_code events_release(
  struct events_resource * resource)
```

Release an allocated channel back to the resource pool to make it available for other purposes.

Table 6-32. Parameters

Data direction	Parameter name	Description
[in]	resource	Pointer to an events_resource struct

Returns Status of channel release procedure

Table 6-33. Return Values

Return value	Description
STATUS_OK	No error was detected when channel was released
STATUS_BUSY	One or more event users have not processed the last event
STATUS_ERR_NOT_INITIALIZED	Channel not allocated, and can derfor not be released

6.6.4.18 Function events_trigger()

Trigger software event.

```
enum status_code events_trigger(
  struct events_resource * resource)
```

Trigger an event by software

Table 6-34. Parameters

Data direction	Parameter name	Description
[in]	resource	Pointer to an events_resource struct

Returns Status of the event software procedure

Table 6-35. Return Values

Return value	Description
STATUS_OK	No error was detected when software tigger signal was issued
STATUS_ERR_UNSUPPORTED_DEV	If the channel path is asynchronous and/or the edge detection is not set to RISING

6.6.5 Enumeration Definitions

6.6.5.1 Enum events_edge_detect

Event channel edge detect setting

Table 6-36. Members

Enum value	Description
EVENTS_EDGE_DETECT_NONE	No event output
EVENTS_EDGE_DETECT_RISING	Event on rising edge
EVENTS_EDGE_DETECT_FALLING	Event on falling edge
EVENTS_EDGE_DETECT_BOTH	Event on both edges

6.6.5.2 Enum events_interrupt_source

Interrupt source selector definitions

Table 6-37. Members

Enum value	Description
EVENTS_INTERRUPT_OVERRUN	
EVENTS_INTERRUPT_DETECT	

6.6.5.3 Enum events_path_selection

Event channel path selection

Table 6-38. Members

Enum value	Description
EVENTS_PATH_SYNCHRONOUS	Select the synchronous path for this event channel
EVENTS_PATH_RESYNCHRONIZED	Select the resynchronizer path for this event channel
EVENTS_PATH_ASYNCHRONOUS	Select the asynchronous path for this event channel

6.7 Extra Information for EVENTS Driver

6.7.1 Acronyms

Below is a table listing the acronyms used in this module, along with their intended meanings.

Acronym	Description
CPU	Central Processing Unit
MUX	Multiplexer

6.7.2 Dependencies

This driver has the following dependencies:

- System Clock Driver

6.7.3 Errata

There are no errata related to this driver.

6.7.4 Module History

An overview of the module history is presented in the table below, with details on the enhancements and fixes made to the module since its first release. The current version of this corresponds to the newest version in the table.

Changelog
Rewrite of events driver.
Initial Release

6.8 Examples for EVENTS Driver

This is a list of the available Quick Start guides (QSGs) and example applications for SAM D20/D21 Event System Driver (EVENTS). QSGs are simple examples with step-by-step instructions to configure and use this driver in a selection of use cases. Note that QSGs can be compiled as a standalone application or be added to the user application.

- Quick Start Guide for EVENTS - Basic
- Quick Start Guide for EVENTS - interrupt hooks

6.8.1 Quick Start Guide for EVENTS - Basic

In this use case, the EVENT module is configured for:

- Synchronous event path with rising edge detection on the input
- One user attached to the configured event channel
- No hardware event generator attached to the channel

This use case allocates an event channel, this channel is not connected to any hardware event generator, events are software triggered. One user is connected to the allocated and configured event channel.

6.8.1.1 Setup

Prerequisites

There are no special setup requirements for this use-case.

Code

Copy-paste the following setup code to your user application:

```
#define EXAMPLE_EVENT_GENERATOR    EVSYS_ID_GEN_TC4_MCX_0
#define EXAMPLE_EVENT_USER         EVSYS_ID_USER_TC3_EVU

static void configure_event_channel(struct events_resource *resource)
{
    struct events_config config;

    events_get_config_defaults(&config);

    config.generator      = EXAMPLE_EVENT_GENERATOR;
    config.edge_detect    = EVENTS_EDGE_DETECT_RISING;
    config.path           = EVENTS_PATH_SYNCHRONOUS;
    config.clock_source   = GCLK_GENERATOR_0;

    events_allocate(resource, &config);
}

static void configure_event_user(struct events_resource *resource)
{
    events_attach_user(resource, EXAMPLE_EVENT_USER);
}
```

Create an event resource struct and add to user application (typically the start of `main()`):

```
struct events_resource example_event;
```

Add to user application initialization (typically the start of `main()`):

```
configure_event_channel(&example_event);
configure_event_user(&example_event);
```

Workflow

1. Create an event channel configuration struct, which can be filled out to adjust the configuration of a single event channel.

   ```
   struct events_config config;
   ```

2. Initialize the event channel configuration struct with the module's default values.

```
events_get_config_defaults(&config);
```

Note This should always be performed before using the configuration struct to ensure that all values are initialized to known default settings.

3. Adjust the configuration struct to request that the channel be attached to the specified event generator, that rising edges of the event signal be detected on the channel and that the synchronous event path be used.

```
config.generator      = EXAMPLE_EVENT_GENERATOR;
config.edge_detect    = EVENTS_EDGE_DETECT_RISING;
config.path           = EVENTS_PATH_SYNCHRONOUS;
config.clock_source   = GCLK_GENERATOR_0;
```

4. Allocate and configure the channel using the configuration structure.

```
events_allocate(resource, &config);
```

Note The existing configuration struct may be re-used, as long as any values that have been altered from the default settings are taken into account by the user application.

5. Attach an user to the channel

```
events_attach_user(resource, EXAMPLE_EVENT_USER);
```

6.8.1.2 Use Case

Code

Copy-paste the following code to your user application:

```
while (events_is_busy(&example_event)) {
    /* Wait for channel */
};

events_trigger(&example_event);

while (true) {
    /* Nothing to do */
}
```

Workflow

1. Wait for the even channel to become ready to accept a new event trigger.

```
while (events_is_busy(&example_event)) {
    /* Wait for channel */
};
```

2. Perform a software event trigger on the configured event channel.

```
events_trigger(&example_event);
```

6.8.2 Quick Start Guide for EVENTS - interrupt hooks

In this use case, the EVENT module is configured for:

- Synchronous event path with rising edge detection
- TC4 as event generator on the allocated event channel
- No event channel user attached
- An event interrupt hook is used to execute some code when an event is detected

In this usecase TC4 is used as event generator, generating events on overflow. No user attached, counting events on the channel. To able to execute some code when an event is detected, an interrupt hook is used. The interrupt hook will also count the number of events detected and toggle a led on the board each time an event is detected.

Note Because this example is showing how to setup an interrupt hook there is no user attached to the user.

6.8.2.1 Setup

Prerequisites

There are no special setup requirements for this use-case.

Code

Copy-paste the following setup code to your user application:

```
#define EXAMPLE_EVENT_GENERATOR    EVSYS_ID_GEN_TC4_OVF
#define EXAMPLE_EVENT_USER         EVSYS_ID_USER_NONE

#define TC_MODULE TC4

static volatile uint32_t event_count = 0;

void event_counter(struct events_resource *resource);

static void configure_event_channel(struct events_resource *resource)
{
    struct events_config config;

    events_get_config_defaults(&config);

    config.generator      = EXAMPLE_EVENT_GENERATOR;
    config.edge_detect    = EVENTS_EDGE_DETECT_RISING;
    config.path           = EVENTS_PATH_SYNCHRONOUS;
    config.clock_source   = GCLK_GENERATOR_0;

    events_allocate(resource, &config);
}

static void configure_event_user(struct events_resource *resource)
{
    events_attach_user(resource, EXAMPLE_EVENT_USER);
}
```

```
static void configure_tc(struct tc_module *tc_instance)
{
    struct tc_config config_tc;
    struct tc_events config_events;

    tc_get_config_defaults(&config_tc);

    config_tc.counter_size    = TC_COUNTER_SIZE_8BIT;
    config_tc.wave_generation = TC_WAVE_GENERATION_NORMAL_FREQ;
    config_tc.clock_source    = GCLK_GENERATOR_1;
    config_tc.clock_prescaler = TC_CLOCK_PRESCALER_DIV64;

    tc_init(tc_instance, TC_MODULE, &config_tc);

    config_events.generate_event_on_overflow = true;
    tc_enable_events(tc_instance, &config_events);

    tc_enable(tc_instance);

}

static void configure_event_interrupt(struct events_resource *resource, struct events_hook *hook)
{
    events_create_hook(hook, event_counter);

    events_add_hook(resource, hook);
    events_enable_interrupt_source(resource, EVENTS_INTERRUPT_DETECT);
}


void event_counter(struct events_resource *resource)
{
    if(events_is_interrupt_set(resource, EVENTS_INTERRUPT_DETECT)) {
        port_pin_toggle_output_level(LED_0_PIN);

        event_count++;
        events_ack_interrupt(resource, EVENTS_INTERRUPT_DETECT);

    }
}
```

Add to user application initialization (typically the start of `main()`):

```
struct tc_module       tc_instance;
struct events_resource example_event;
struct events_hook     hook;

system_init();
system_interrupt_enable_global();

configure_event_channel(&example_event);
configure_event_user(&example_event);
configure_event_interrupt(&example_event, &hook);
configure_tc(&tc_instance);
```

Workflow

1. Create an event channel configuration structure instance which will contain the configuration for the event.

```
struct events_config config;
```

2. Initialize the event channel configuration struct with safe default values.

Note This shall always be performed before using the configuration struct to ensure that all members are initialized to known default values.

```
events_get_config_defaults(&config);
```

3. Adjust the configuration structure
   - Use EXAMPLE_EVENT_GENRATOR as event generator
   - Detect events on rising edge
   - Use the synchronous event path
   - Use GCLK Generator 0 as event channel clock source

```
config.generator      = EXAMPLE_EVENT_GENERATOR;
config.edge_detect    = EVENTS_EDGE_DETECT_RISING;
config.path           = EVENTS_PATH_SYNCHRONOUS;
config.clock_source   = GCLK_GENERATOR_0;
```

4. Allocate and configure the channel using the configuration structure.

```
events_allocate(resource, &config);
```

5. Make sure there is no user attached. To attach an user, change the value of EXAMPLE_EVENT_USER to the correct peripheral ID.

```
events_attach_user(resource, EXAMPLE_EVENT_USER);
```

6. Create config_tc and config_events configuration structure instances.

```
struct tc_config config_tc;
struct tc_events config_events;
```

7. Initialize the TC module configuration structure with safe default values.

Note This function shall always be called on new configuration structure instances to make sure that all structure members is initialized.

```
tc_get_config_defaults(&config_tc);
```

8. Adjust the config_tc structure
   - Set counter size to 8bit
   - Set wave generation mode to normal frequency generation

- Use GCLK generator 1 to as tc module clock source
- Prescale the input clock with 64

```
config_tc.counter_size    = TC_COUNTER_SIZE_8BIT;
config_tc.wave_generation = TC_WAVE_GENERATION_NORMAL_FREQ;
config_tc.clock_source    = GCLK_GENERATOR_1;
config_tc.clock_prescaler = TC_CLOCK_PRESCALER_DIV64;
```

9. Initialize, configure and assosiate the tc_instance handle with the TC hardware pointed to by TC_MODULE

```
tc_init(tc_instance, TC_MODULE, &config_tc);
```

10. Adjust the config_events structure to enable event generation on overflow in the timer and then enable the event configuration

```
config_events.generate_event_on_overflow = true;
tc_enable_events(tc_instance, &config_events);
```

11. Enable the timer/counter module

```
tc_enable(tc_instance);
```

12. Create a new interrupt hook and use the function event_counter as hook code

```
events_create_hook(hook, event_counter);
```

13. Add the newly created hook to the interrupt hook queue and enable the event detected interrupt

```
events_add_hook(resource, hook);
events_enable_interrupt_source(resource, EVENTS_INTERRUPT_DETECT);
```

14. Example interrupt hook code. If the hook was triggered by a event detected interrupt on the event channel this code will toggle the led on the Xplained PRO board and increase the value of the event_count variable. The interrupt then acknowledged.

```
void event_counter(struct events_resource *resource)
{
    if(events_is_interrupt_set(resource, EVENTS_INTERRUPT_DETECT)) {
        port_pin_toggle_output_level(LED_0_PIN);

        event_count++;
        events_ack_interrupt(resource, EVENTS_INTERRUPT_DETECT);

    }
}
```

6.8.2.2 Use Case

Code

Copy-paste the following code to your user application:

```
while (events_is_busy(&example_event)) {
```

```
    /* Wait for channel */
};

tc_start_counter(&tc_instance);

while (true) {
    /* Nothing to do */
}
```

Workflow

1. Wait for the even channel to become ready.

```
while (events_is_busy(&example_event)) {
    /* Wait for channel */
};
```

2. Start the timer/counter

```
tc_start_counter(&tc_instance);
```

7. SAM D20/D21 External Interrupt Driver (EXTINT)

This driver for SAM D20/D21 devices provides an interface for the configuration and management of external interrupts generated by the physical device pins, including edge detection. The following driver API modes are covered by this manual:

- Polled APIs
- Callback APIs

The following peripherals are used by this module:

- EIC (External Interrupt Controller)

The outline of this documentation is as follows:

7.1 Prerequisites

There are no prerequisites for this module.

7.2 Module Overview

The External Interrupt (EXTINT) module provides a method of asynchronously detecting rising edge, falling edge or specific level detection on individual I/O pins of a device. This detection can then be used to trigger a software interrupt or event, or polled for later use if required. External interrupts can also optionally be used to automatically wake up the device from sleep mode, allowing the device to conserve power while still being able to react to an external stimulus in a timely manner.

7.2.1 Logical Channels

The External Interrupt module contains a number of logical channels, each of which is capable of being individually configured for a given pin routing, detection mode and filtering/wake up characteristics.

Each individual logical external interrupt channel may be routed to a single physical device I/O pin in order to detect a particular edge or level of the incoming signal.

7.2.2 NMI Channels

One or more Non Maskable Interrupt (NMI) channels are provided within each physical External Interrupt Controller module, allowing a single physical pin of the device to fire a single NMI interrupt in response to a particular edge or level stimulus. A NMI cannot, as the name suggests, be disabled in firmware and will take precedence over any in-progress interrupt sources.

NMIs can be used to implement critical device features such as forced software reset or other functionality where the action should be executed in preference to all other running code with a minimum amount of latency.

7.2.3 Input Filtering and Detection

To reduce the possibility of noise or other transient signals causing unwanted device wake-ups, interrupts and/or events via an external interrupt channel, a hardware signal filter can be enabled on individual channels. This filter provides a Majority-of-Three voter filter on the incoming signal, so that the input state is considered to be the

majority vote of three subsequent samples of the pin input buffer. The possible sampled input and resulting filtered output when the filter is enabled is shown in Table 7-1: Sampled input and resulting filtered output on page 154.

Table 7-1. Sampled input and resulting filtered output

Input Sample 1	Input Sample 2	Input Sample 3	Filtered Output
0	0	0	0
0	0	1	0
0	1	0	0
0	1	1	1
1	0	0	0
1	0	1	1
1	1	0	1
1	1	1	1

7.2.4 Events and Interrupts

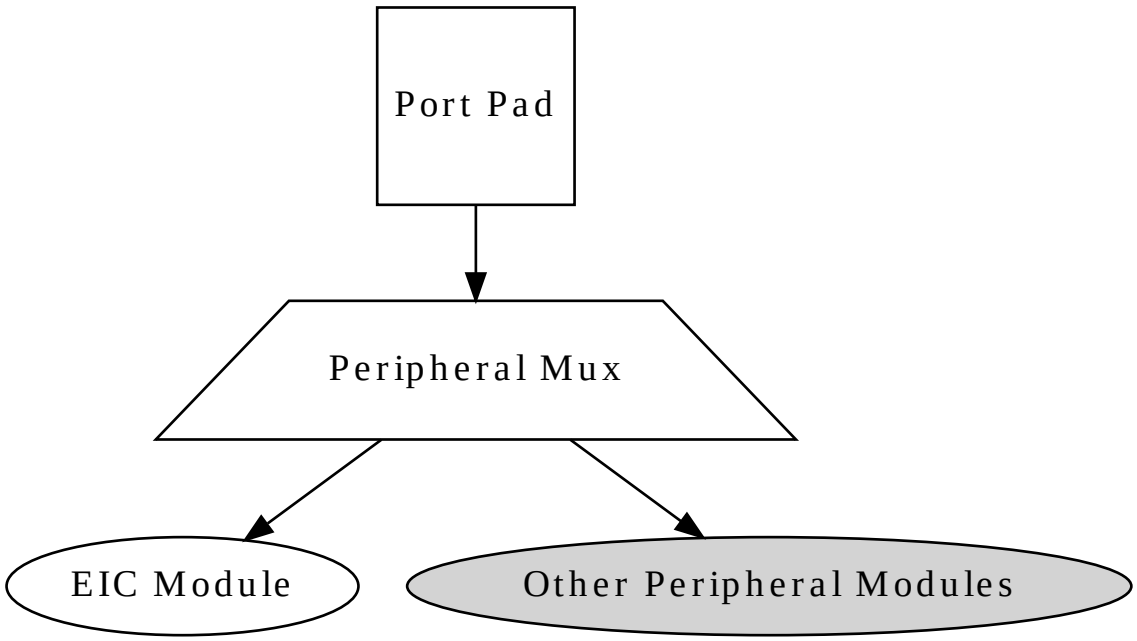
Channel detection states may be polled inside the application for synchronous detection, or events and interrupts may be used for asynchronous behavior. Each channel can be configured to give an asynchronous hardware event (which may in turn trigger actions in other hardware modules) or an asynchronous software interrupt.

Note The connection of events between modules requires the use of the SAM D20/D21 Event System Driver (EVENTS) to route output event of one module to the input event of another. For more information on event routing, refer to the event driver documentation.

7.2.5 Physical Connection

Figure 7-1: Physical Connection on page 154 shows how this module is interconnected within the device.

Figure 7-1. Physical Connection



7.3 Special Considerations

Not all devices support disabling of the NMI channel(s) detection mode - see your device datasheet.

7.4 Extra Information

For extra information see Extra Information for EXTINT Driver. This includes:

- Acronyms
- Dependencies
- Errata
- Module History

7.5 Examples

For a list of examples related to this driver, see Examples for EXTINT Driver.

7.6 API Overview

7.6.1 Variable and Type Definitions

7.6.1.1 Callback configuration and initialization

Type extint_callback_t

```
typedef void(* extint_callback_t )(void)
```

Type definition for an EXTINT module callback function.

7.6.2 Structure Definitions

7.6.2.1 Struct extint_chan_conf

Configuration structure for the edge detection mode of an external interrupt channel.

Table 7-2. Members

Type	Name	Description
enum extint_detect	detection_criteria	Edge detection mode to use.
bool	filter_input_signal	Filter the raw input signal to prevent noise from triggering an interrupt accidentally, using a 3 sample majority filter.
uint32_t	gpio_pin	GPIO pin the NMI should be connected to.
uint32_t	gpio_pin_mux	MUX position the GPIO pin should be configured to.
enum extint_pull	gpio_pin_pull	Internal pull to enable on the input pin.
bool	wake_if_sleeping	Wake up the device if the channel interrupt fires during sleep mode.

7.6.2.2 Struct extint_events

Event flags for the extint_enable_events() and extint_disable_events().

Table 7-3. Members

Type	Name	Description
bool	generate_event_on_detect[]	If true, an event will be generated when an external interrupt channel detection state changes.

7.6.2.3 Struct extint_nmi_conf

Configuration structure for the edge detection mode of an external interrupt NMI channel.

Table 7-4. Members

Type	Name	Description
enum extint_detect	detection_criteria	Edge detection mode to use. Not all devices support all possible detection modes for NMIs.
bool	filter_input_signal	Filter the raw input signal to prevent noise from triggering an interrupt accidentally, using a 3 sample majority filter.
uint32_t	gpio_pin	GPIO pin the NMI should be connected to.
uint32_t	gpio_pin_mux	MUX position the GPIO pin should be configured to.
enum extint_pull	gpio_pin_pull	Internal pull to enable on the input pin.

7.6.3 Macro Definitions

7.6.3.1 Macro EXTINT_CLOCK_SOURCE

```
#define EXTINT_CLOCK_SOURCE GCLK_GENERATOR_0
```

Configuration option, setting the EIC clock source which can be used for EIC edge detection or filtering. This option may be overridden in the module configuration header file `conf_extint.h`.

7.6.4 Function Definitions

7.6.4.1 Configuration and initialization

Function extint_is_syncing()

Determines if the hardware module(s) are currently synchronizing to the bus.

```
bool extint_is_syncing(void)
```

Checks to see if the underlying hardware peripheral module(s) are currently synchronizing across multiple clock domains to the hardware bus, This function can be used to delay further operations on a module until such time that it is ready, to prevent blocking delays for synchronization in the user application.

Returns Synchronization status of the underlying hardware module(s).

Table 7-5. Return Values

Return value	Description
true	If the module has completed synchronization
false	If the module synchronization is ongoing

7.6.4.2 Event management

Function extint_enable_events()

Enables an External Interrupt event output.

```
void extint_enable_events(
  struct extint_events *const events)
```

Enables one or more output events from the External Interrupt module. See here for a list of events this module supports.

Note Events cannot be altered while the module is enabled.

Table 7-6. Parameters

Data direction	Parameter name	Description
[in]	events	Struct containing flags of events to enable

Function extint_disable_events()

Disables an External Interrupt event output.

```
void extint_disable_events(
  struct extint_events *const events)
```

Disables one or more output events from the External Interrupt module. See here for a list of events this module supports.

Note Events cannot be altered while the module is enabled.

Table 7-7. Parameters

Data direction	Parameter name	Description
[in]	events	Struct containing flags of events to disable

7.6.4.3 Configuration and initialization (channel)

Function extint_chan_get_config_defaults()

Initializes an External Interrupt channel configuration structure to defaults.

```
void extint_chan_get_config_defaults(
  struct extint_chan_conf *const config)
```

Initializes a given External Interrupt channel configuration structure to a set of known default values. This function should be called on all new instances of these configuration structures before being modified by the user application.

The default configuration is as follows:

- Wake the device if an edge detection occurs whilst in sleep
- Input filtering disabled
- Internal pull-up enabled
- Detect falling edges of a signal

Table 7-8. Parameters

Data direction	Parameter name	Description
[out]	config	Configuration structure to initialize to default values

Function extint_chan_set_config()

Writes an External Interrupt channel configuration to the hardware module.

```
void extint_chan_set_config(
  const uint8_t channel,
  const struct extint_chan_conf *const config)
```

Writes out a given configuration of an External Interrupt channel configuration to the hardware module. If the channel is already configured, the new configuration will replace the existing one.

Table 7-9. Parameters

Data direction	Parameter name	Description
[in]	channel	External Interrupt channel to configure
[in]	config	Configuration settings for the channel

7.6.4.4 Configuration and initialization (NMI)

Function extint_nmi_get_config_defaults()

Initializes an External Interrupt NMI channel configuration structure to defaults.

```
void extint_nmi_get_config_defaults(
```

```
  struct extint_nmi_conf *const config)
```

Initializes a given External Interrupt NMI channel configuration structure to a set of known default values. This function should be called on all new instances of these configuration structures before being modified by the user application.

The default configuration is as follows:

- Input filtering disabled
- Detect falling edges of a signal

Table 7-10. Parameters

Data direction	Parameter name	Description
[out]	config	Configuration structure to initialize to default values

Function extint_nmi_set_config()

Writes an External Interrupt NMI channel configuration to the hardware module.

```
enum status_code extint_nmi_set_config(
  const uint8_t nmi_channel,
  const struct extint_nmi_conf *const config)
```

Writes out a given configuration of an External Interrupt NMI channel configuration to the hardware module. If the channel is already configured, the new configuration will replace the existing one.

Table 7-11. Parameters

Data direction	Parameter name	Description
[in]	nmi_channel	External Interrupt NMI channel to configure
[in]	config	Configuration settings for the channel

Returns Status code indicating the success or failure of the request.

Table 7-12. Return Values

Return value	Description
STATUS_OK	Configuration succeeded
STATUS_ERR_PIN_MUX_INVALID	An invalid pin mux value was supplied
STATUS_ERR_BAD_FORMAT	An invalid detection mode was requested

7.6.4.5 Detection testing and clearing (channel)

Function extint_chan_is_detected()

Retrieves the edge detection state of a configured channel.

```
bool extint_chan_is_detected(
```

```
  const uint8_t channel)
```

Reads the current state of a configured channel, and determines if the detection criteria of the channel has been met.

Table 7-13. Parameters

Data direction	Parameter name	Description
[in]	channel	External Interrupt channel index to check.

Returns Status of the requested channel's edge detection state.

Table 7-14. Return Values

Return value	Description
true	If the channel's edge/level detection criteria was met
false	If the channel has not detected its configured criteria

Function extint_chan_clear_detected()

Clears the edge detection state of a configured channel.

```
void extint_chan_clear_detected(
  const uint8_t channel)
```

Clears the current state of a configured channel, readying it for the next level or edge detection.

Table 7-15. Parameters

Data direction	Parameter name	Description
[in]	channel	External Interrupt channel index to check.

7.6.4.6 Detection testing and clearing (NMI)

Function extint_nmi_is_detected()

Retrieves the edge detection state of a configured NMI channel.

```
bool extint_nmi_is_detected(
  const uint8_t nmi_channel)
```

Reads the current state of a configured NMI channel, and determines if the detection criteria of the NMI channel has been met.

Table 7-16. Parameters

Data direction	Parameter name	Description
[in]	nmi_channel	External Interrupt NMI channel index to check.

Returns Status of the requested NMI channel's edge detection state.

Table 7-17. Return Values

Return value	Description
true	If the NMI channel's edge/level detection criteria was met
false	If the NMI channel has not detected its configured criteria

Function extint_nmi_clear_detected()

Clears the edge detection state of a configured NMI channel.

```
void extint_nmi_clear_detected(
  const uint8_t nmi_channel)
```

Clears the current state of a configured NMI channel, readying it for the next level or edge detection.

Table 7-18. Parameters

Data direction	Parameter name	Description
[in]	nmi_channel	External Interrupt NMI channel index to check.

7.6.4.7 Callback configuration and initialization

Function extint_register_callback()

Registers an asynchronous callback function with the driver.

```
enum status_code extint_register_callback(
  const extint_callback_t callback,
  const uint8_t channel,
  const enum extint_callback_type type)
```

Registers an asynchronous callback with the EXTINT driver, fired when a channel detects the configured channel detection criteria (e.g. edge or level). Callbacks are fired once for each detected channel.

Note NMI channel callbacks cannot be registered via this function; the device's NMI interrupt should be hooked directly in the user application and the NMI flags manually cleared via extint_nmi_clear_detected().

Table 7-19. Parameters

Data direction	Parameter name	Description
[in]	callback	Pointer to the callback function to register
[in]	channel	Logical channel to register callback for

Data direction	Parameter name	Description
[in]	type	Type of callback function to register

Returns Status of the registration operation.

Table 7-20. Return Values

Return value	Description
STATUS_OK	The callback was registered successfully.
STATUS_ERR_INVALID_ARG	If an invalid callback type was supplied.
STATUS_ERR_ALREADY_INITIALIZED	Callback function has been registered, need unregister first.

Function extint_unregister_callback()

Unregisters an asynchronous callback function with the driver.

```
enum status_code extint_unregister_callback(
  const extint_callback_t callback,
  const uint8_t channel,
  const enum extint_callback_type type)
```

Unregisters an asynchronous callback with the EXTINT driver, removing it from the internal callback registration table.

Table 7-21. Parameters

Data direction	Parameter name	Description
[in]	callback	Pointer to the callback function to unregister
[in]	channel	Logical channel to unregister callback for
[in]	type	Type of callback function to unregister

Returns Status of the de-registration operation.

Table 7-22. Return Values

Return value	Description
STATUS_OK	The callback was Unregistered successfully.
STATUS_ERR_INVALID_ARG	If an invalid callback type was supplied.
STATUS_ERR_BAD_ADDRESS	No matching entry was found in the registration table.

Function extint_get_current_channel()

Find what channel caused the callback.

```
uint8_t extint_get_current_channel(void)
```

Can be used in an EXTINT callback function to find what channel caused the callback in case same callback is used by multiple channels.

Returns Channel number.

7.6.4.8 Callback enabling and disabling (channel)

Function extint_chan_enable_callback()

Enables asynchronous callback generation for a given channel and type.

```
enum status_code extint_chan_enable_callback(
  const uint8_t channel,
  const enum extint_callback_type type)
```

Enables asynchronous callbacks for a given logical external interrupt channel and type. This must be called before an external interrupt channel will generate callback events.

Table 7-23. Parameters

Data direction	Parameter name	Description
[in]	channel	Logical channel to enable callback generation for
[in]	type	Type of callback function callbacks to enable

Returns Status of the callback enable operation.

Table 7-24. Return Values

Return value	Description
STATUS_OK	The callback was enabled successfully.
STATUS_ERR_INVALID_ARG	If an invalid callback type was supplied.

Function extint_chan_disable_callback()

Disables asynchronous callback generation for a given channel and type.

```
enum status_code extint_chan_disable_callback(
  const uint8_t channel,
  const enum extint_callback_type type)
```

Disables asynchronous callbacks for a given logical external interrupt channel and type.

Table 7-25. Parameters

Data direction	Parameter name	Description
[in]	channel	Logical channel to disable callback generation for
[in]	type	Type of callback function callbacks to disable

Returns Status of the callback disable operation.

Table 7-26. Return Values

Return value	Description
STATUS_OK	The callback was disabled successfully.
STATUS_ERR_INVALID_ARG	If an invalid callback type was supplied.

7.6.5 Enumeration Definitions

7.6.5.1 Callback configuration and initialization

Enum extint_callback_type

Enum for the possible callback types for the EXTINT module.

Table 7-27. Members

Enum value	Description
EXTINT_CALLBACK_TYPE_DETECT	Callback type for when an external interrupt detects the configured channel criteria (i.e. edge or level detection)

7.6.5.2 Enum extint_detect

Enum for the possible signal edge detection modes of the External Interrupt Controller module.

Table 7-28. Members

Enum value	Description
EXTINT_DETECT_NONE	No edge detection. Not allowed as a NMI detection mode on some devices.
EXTINT_DETECT_RISING	Detect rising signal edges.
EXTINT_DETECT_FALLING	Detect falling signal edges.
EXTINT_DETECT_BOTH	Detect both signal edges.
EXTINT_DETECT_HIGH	Detect high signal levels.
EXTINT_DETECT_LOW	Detect low signal levels.

7.6.5.3 Enum extint_pull

Enum for the possible pin internal pull configurations.

Note Disabling the internal pull resistor is not recommended if the driver is used in interrupt (callback) mode, due the possibility of floating inputs generating continuous interrupts.

Table 7-29. Members

Enum value	Description
EXTINT_PULL_UP	Internal pull-up resistor is enabled on the pin.

Enum value	Description
EXTINT_PULL_DOWN	Internal pull-down resistor is enabled on the pin.
EXTINT_PULL_NONE	Internal pull resistor is disconnected from the pin.

7.7 Extra Information for EXTINT Driver

7.7.1 Acronyms

The table below presents the acronyms used in this module:

Acronym	Description
EIC	External Interrupt Controller
MUX	Multiplexer
NMI	Non-Maskable Interrupt

7.7.2 Dependencies

This driver has the following dependencies:

- System Pin Multiplexer Driver

7.7.3 Errata

There are no errata related to this driver.

7.7.4 Module History

An overview of the module history is presented in the table below, with details on the enhancements and fixes made to the module since its first release. The current version of this corresponds to the newest version in the table.

Changelog
• Driver updated to follow driver type convention. • Removed `extint_reset()`, `extint_disable()` and `extint_enable()` functions. Added internal function `_system_extint_init()`. • Added configuration EXTINT_CLOCK_SOURCE in conf_extint.h. • Removed configuration EXTINT_CALLBACKS_MAX in conf_extint.h, and added channel parameter in the register functions `extint_register_callback()` and `extint_unregister_callback()`.
Updated interrupt handler to clear interrupt flag before calling callback function.
Updated initialization function to also enable the digital interface clock to the module if it is disabled.
Initial Release

7.8 Examples for EXTINT Driver

This is a list of the available Quick Start guides (QSGs) and example applications for SAM D20/D21 External Interrupt Driver (EXTINT). QSGs are simple examples with step-by-step instructions to configure and use this driver in a selection of use cases. Note that QSGs can be compiled as a standalone application or be added to the user application.

- Quick Start Guide for EXTINT - Basic

- Quick Start Guide for EXTINT - Callback

7.8.1 Quick Start Guide for EXTINT - Basic

In this use case, the EXTINT module is configured for:

- External interrupt channel connected to the board LED is used
- External interrupt channel is configured to detect both input signal edges

This use case configures a physical I/O pin of the device so that it is routed to a logical External Interrupt Controller channel to detect rising and falling edges of the incoming signal.

When the board button is pressed, the board LED will light up. When the board button is released, the LED will turn off.

7.8.1.1 Setup

Prerequisites

There are no special setup requirements for this use-case.

Code

Copy-paste the following setup code to your user application:

```
void configure_extint_channel(void)
{
    struct extint_chan_conf config_extint_chan;
    extint_chan_get_config_defaults(&config_extint_chan);

    config_extint_chan.gpio_pin           = BUTTON_0_EIC_PIN;
    config_extint_chan.gpio_pin_mux       = BUTTON_0_EIC_MUX;
    config_extint_chan.gpio_pin_pull      = EXTINT_PULL_UP;
    config_extint_chan.detection_criteria = EXTINT_DETECT_BOTH;
    extint_chan_set_config(BUTTON_0_EIC_LINE, &config_extint_chan);
}
```

Add to user application initialization (typically the start of `main()`):

```
configure_extint_channel();
```

Workflow

1. Create an EXTINT module channel configuration struct, which can be filled out to adjust the configuration of a single external interrupt channel.

   ```
   struct extint_chan_conf config_extint_chan;
   ```

2. Initialize the channel configuration struct with the module's default values.

   ```
   extint_chan_get_config_defaults(&config_extint_chan);
   ```

Note This should always be performed before using the configuration struct to ensure that all values are initialized to known default settings.

3. Adjust the configuration struct to configure the pin MUX (to route the desired physical pin to the logical channel) to the board button, and to configure the channel to detect both rising and falling edges.

```
config_extint_chan.gpio_pin           = BUTTON_0_EIC_PIN;
config_extint_chan.gpio_pin_mux       = BUTTON_0_EIC_MUX;
config_extint_chan.gpio_pin_pull      = EXTINT_PULL_UP;
config_extint_chan.detection_criteria = EXTINT_DETECT_BOTH;
```

4. Configure external interrupt channel with the desired channel settings.

```
extint_chan_set_config(BUTTON_0_EIC_LINE, &config_extint_chan);
```

7.8.1.2 Use Case

Code

Copy-paste the following code to your user application:

```
while (true) {
    if (extint_chan_is_detected(BUTTON_0_EIC_LINE)) {

        // Do something in response to EXTINT edge detection
        bool button_pin_state = port_pin_get_input_level(BUTTON_0_PIN);
        port_pin_set_output_level(LED_0_PIN, button_pin_state);

        extint_chan_clear_detected(BUTTON_0_EIC_LINE);
    }
}
```

Workflow

1. Read in the current external interrupt channel state to see if an edge has been detected.

```
if (extint_chan_is_detected(BUTTON_0_EIC_LINE)) {
```

2. Read in the new physical button state and mirror it on the board LED.

```
// Do something in response to EXTINT edge detection
bool button_pin_state = port_pin_get_input_level(BUTTON_0_PIN);
port_pin_set_output_level(LED_0_PIN, button_pin_state);
```

3. Clear the detection state of the external interrupt channel so that it is ready to detect a future falling edge.

```
extint_chan_clear_detected(BUTTON_0_EIC_LINE);
```

7.8.2 Quick Start Guide for EXTINT - Callback

In this use case, the EXTINT module is configured for:

- External interrupt channel connected to the board LED is used
- External interrupt channel is configured to detect both input signal edges
- Callbacks are used to handle detections from the External Interrupt

This use case configures a physical I/O pin of the device so that it is routed to a logical External Interrupt Controller channel to detect rising and falling edges of the incoming signal. A callback function is used to handle detection events from the External Interrupt module asynchronously.

When the board button is pressed, the board LED will light up. When the board button is released, the LED will turn off.

7.8.2.1 Setup

Prerequisites

There are no special setup requirements for this use-case.

Code

Copy-paste the following setup code to your user application:

```
void configure_extint_channel(void)
{
    struct extint_chan_conf config_extint_chan;
    extint_chan_get_config_defaults(&config_extint_chan);

    config_extint_chan.gpio_pin           = BUTTON_0_EIC_PIN;
    config_extint_chan.gpio_pin_mux       = BUTTON_0_EIC_MUX;
    config_extint_chan.gpio_pin_pull      = EXTINT_PULL_UP;
    config_extint_chan.detection_criteria = EXTINT_DETECT_BOTH;
    extint_chan_set_config(BUTTON_0_EIC_LINE, &config_extint_chan);
}

void configure_extint_callbacks(void)
{
    extint_register_callback(extint_detection_callback,
            BUTTON_0_EIC_LINE,
            EXTINT_CALLBACK_TYPE_DETECT);
    extint_chan_enable_callback(BUTTON_0_EIC_LINE,
            EXTINT_CALLBACK_TYPE_DETECT);
}

void extint_detection_callback(void)
{
    bool pin_state = port_pin_get_input_level(BUTTON_0_PIN);
    port_pin_set_output_level(LED_0_PIN, pin_state);
}
```

Add to user application initialization (typically the start of `main()`):

```
configure_extint_channel();
configure_extint_callbacks();

system_interrupt_enable_global();
```

Workflow

1. Create an EXTINT module channel configuration struct, which can be filled out to adjust the configuration of a single external interrupt channel.

   ```
   struct extint_chan_conf config_extint_chan;
   ```

2. Initialize the channel configuration struct with the module's default values.

   ```
   extint_chan_get_config_defaults(&config_extint_chan);
   ```

Note This should always be performed before using the configuration struct to ensure that all values are initialized to known default settings.

3. Adjust the configuration struct to configure the pin MUX (to route the desired physical pin to the logical channel) to the board button, and to configure the channel to detect both rising and falling edges.

```
config_extint_chan.gpio_pin           = BUTTON_0_EIC_PIN;
config_extint_chan.gpio_pin_mux       = BUTTON_0_EIC_MUX;
config_extint_chan.gpio_pin_pull      = EXTINT_PULL_UP;
config_extint_chan.detection_criteria = EXTINT_DETECT_BOTH;
```

4. Configure external interrupt channel with the desired channel settings.

```
extint_chan_set_config(BUTTON_0_EIC_LINE, &config_extint_chan);
```

5. Register a callback function `extint_handler()` to handle detections from the External Interrupt controller.

```
extint_register_callback(extint_detection_callback,
        BUTTON_0_EIC_LINE,
        EXTINT_CALLBACK_TYPE_DETECT);
```

6. Enable the registered callback function for the configured External Interrupt channel, so that it will be called by the module when the channel detects an edge.

```
extint_chan_enable_callback(BUTTON_0_EIC_LINE,
        EXTINT_CALLBACK_TYPE_DETECT);
```

7. Define the EXTINT callback that will be fired when a detection event occurs. For this example, a LED will mirror the new button state on each detection edge.

```
void extint_detection_callback(void)
{
    bool pin_state = port_pin_get_input_level(BUTTON_0_PIN);
    port_pin_set_output_level(LED_0_PIN, pin_state);
}
```

7.8.2.2 Use Case

Code

Copy-paste the following code to your user application:

```
while (true) {
    /* Do nothing - EXTINT will fire callback asynchronously */
}
```

Workflow

1. External interrupt events from the driver are detected asynchronously; no special application `main()` code is required.

8. SAM D20/D21 I2C Driver (SERCOM I2C)

This driver for SAM D20/D21 devices provides an interface for the configuration and management of the device's SERCOM I^2C module, for the transfer of data via an I^2C bus. The following driver API modes are covered by this manual:

- Master Mode Polled APIs
- Master Mode Callback APIs
- Slave Mode Polled APIs
- Slave Mode Callback APIs

The following peripheral is used by this module:

- SERCOM (Serial Communication Interface)

The outline of this documentation is as follows:

8.1 Prerequisites

There are no prerequisites.

8.2 Module Overview

The outline of this section is as follows:

8.2.1 Driver Feature Macro Definition

Driver Feature Macro	Supported devices
FEATURE_I2C_FAST_MODE_PLUS_AND_HIGH_SPE	SAMD21

Driver Feature Macro	Supported devices
FEATURE_I2C_10_BIT_ADDRESS	SAMD21
FEATURE_I2C_SCL_STRETCH_MODE	SAMD21
FEATURE_I2C_SCL_EXTEND_TIMEOUT	SAMD21

Note The specific features are only available in the driver when the selected device supports those features.

8.2.2 Functional Description

The I^2C provides a simple two-wire bidirectional bus consisting of a wired-AND type serial clock line (SCL) and a wired-AND type serial data line (SDA).

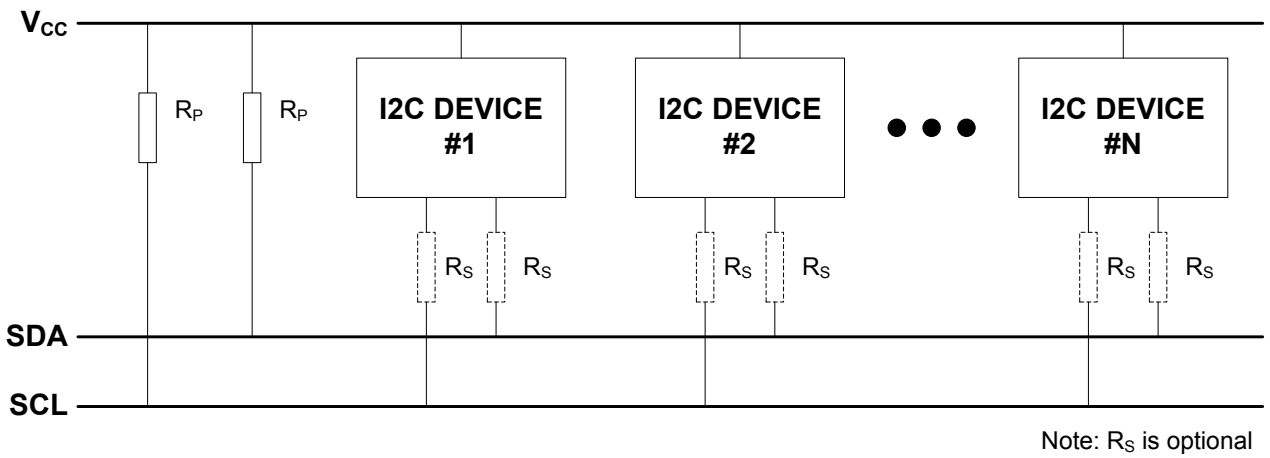
The I^2C bus provides a simple, but efficient method of interconnecting multiple master and slave devices. An arbitration mechanism is provided for resolving bus ownership between masters, as only one master device may own the bus at any given time. The arbitration mechanism relies on the wired-AND connections to avoid bus drivers short-circuiting.

A unique address is assigned to all slave devices connected to the bus. A device can contain both master and slave logic, and can emulate multiple slave devices by responding to more than one address.

8.2.3 Bus Topology

The I^2C bus topology is illustrated in Figure 8-1: I2C bus topology on page 171. The pull-up resistors (Rs) will provide a high level on the bus lines when none of the I^2C devices are driving the bus. These are optional, and can be replaced with a constant current source.

Figure 8-1. I2C bus topology



Note: R_S is optional

8.2.4 Transactions

The I^2C standard defines three fundamental transaction formats:

- Master Write
  - The master transmits data packets to the slave after addressing it
- Master Read
  - The slave transmits data packets to the master after being addressed

- Combined Read/Write
  - A combined transaction consists of several write and read transactions

A data transfer starts with the master issuing a **Start** condition on the bus, followed by the address of the slave together with a bit to indicate whether the master wants to read from or write to the slave. The addressed slave must respond to this by sending an **ACK** back to the master.

After this, data packets are sent from the master or slave, according to the read/write bit. Each packet must be acknowledged (ACK) or not acknowledged (NACK) by the receiver.

If a slave responds with a NACK, the master must assume that the slave cannot receive any more data and cancel the write operation.

The master completes a transaction by issuing a **Stop** condition.

A master can issue multiple **Start** conditions during a transaction; this is then called a **Repeated Start** condition.

8.2.4.1 Address Packets

The slave address consists of seven bits. The 8th bit in the transfer determines the data direction (read or write). An address packet always succeeds a **Start** or **Repeated Start** condition. The 8th bit is handled in the driver, and the user will only have to provide the 7 bit address.

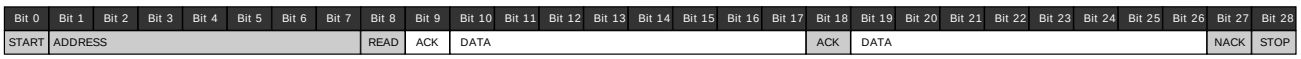
8.2.4.2 Data Packets

Data packets are nine bits long, consisting of one 8-bit data byte, and an acknowledgement bit. Data packets follow either an address packet or another data packet on the bus.

8.2.4.3 Transaction Examples

The gray bits in the following examples are sent from master to slave, and the white bits are sent from slave to master. Example of a read transaction is shown in Figure 8-2: I2C Packet Read on page 172. Here, the master first issues a **Start** condition and gets ownership of the bus. An address packet with the direction flag set to read is then sent and acknowledged by the slave. Then the slave sends one data packet which is acknowledged by the master. The slave sends another packet, which is not acknowledged by the master and indicates that the master will terminate the transaction. In the end, the transaction is terminated by the master issuing a **Stop** condition.

Figure 8-2. I2C Packet Read



Example of a write transaction is shown in Figure 8-3: I2C Packet Write on page 172. Here, the master first issues a **Start** condition and gets ownership of the bus. An address packet with the dir flag set to write is then sent and acknowledged by the slave. Then the master sends two data packets, each acknowledged by the slave. In the end, the transaction is terminated by the master issuing a **Stop** condition.

Figure 8-3. I2C Packet Write

8.2.4.4 Packet Timeout

When a master sends an I^2C packet, there is no way of being sure that a slave will acknowledge the packet. To avoid stalling the device forever while waiting for an acknowledge, a user selectable timeout is provided in the i2c_master_config struct which lets the driver exit a read or write operation after the specified time. The function will then return the STATUS_ERR_TIMEOUT flag.

This is also the case for the slave when using the functions postfixed `_wait`.

The time before the timeout occurs, will be the same as for unknown bus state timeout.

8.2.4.5 Repeated Start

To issue a **Repeated Start**, the functions postfixed `_no_stop` must be used. These functions will not send a **Stop** condition when the transfer is done, thus the next transfer will start with a **Repeated Start**. To end the transaction, the functions without the `_no_stop` postfix must be used for the last read/write.

8.2.5 Multi Master

In a multi master environment, arbitration of the bus is important, as only one master can own the bus at any point.

8.2.5.1 Arbitration

Clock stretching

The serial clock line is always driven by a master device. However, all devices connected to the bus are allowed stretch the low period of the clock to slow down the overall clock frequency or to insert wait states while processing data. Both master and slave can randomly stretch the clock, which will force the other device into a wait-state until the clock line goes high again.

Arbitration on the data line

If two masters start transmitting at the same time, they will both transmit until one master detects that the other master is pulling the data line low. When this is detected, the master not pulling the line low, will stop the transmission and wait until the bus is idle. As it is the master trying to contact the slave with the lowest address that will get the bus ownership, this will create an arbitration scheme always prioritizing the slaves with the lowest address in case of a bus collision.

8.2.5.2 Clock Synchronization

In situations where more than one master is trying to control the bus clock line at the same time, a clock synchronization algorithm based on the same principles used for clock stretching is necessary.

8.2.6 Bus States

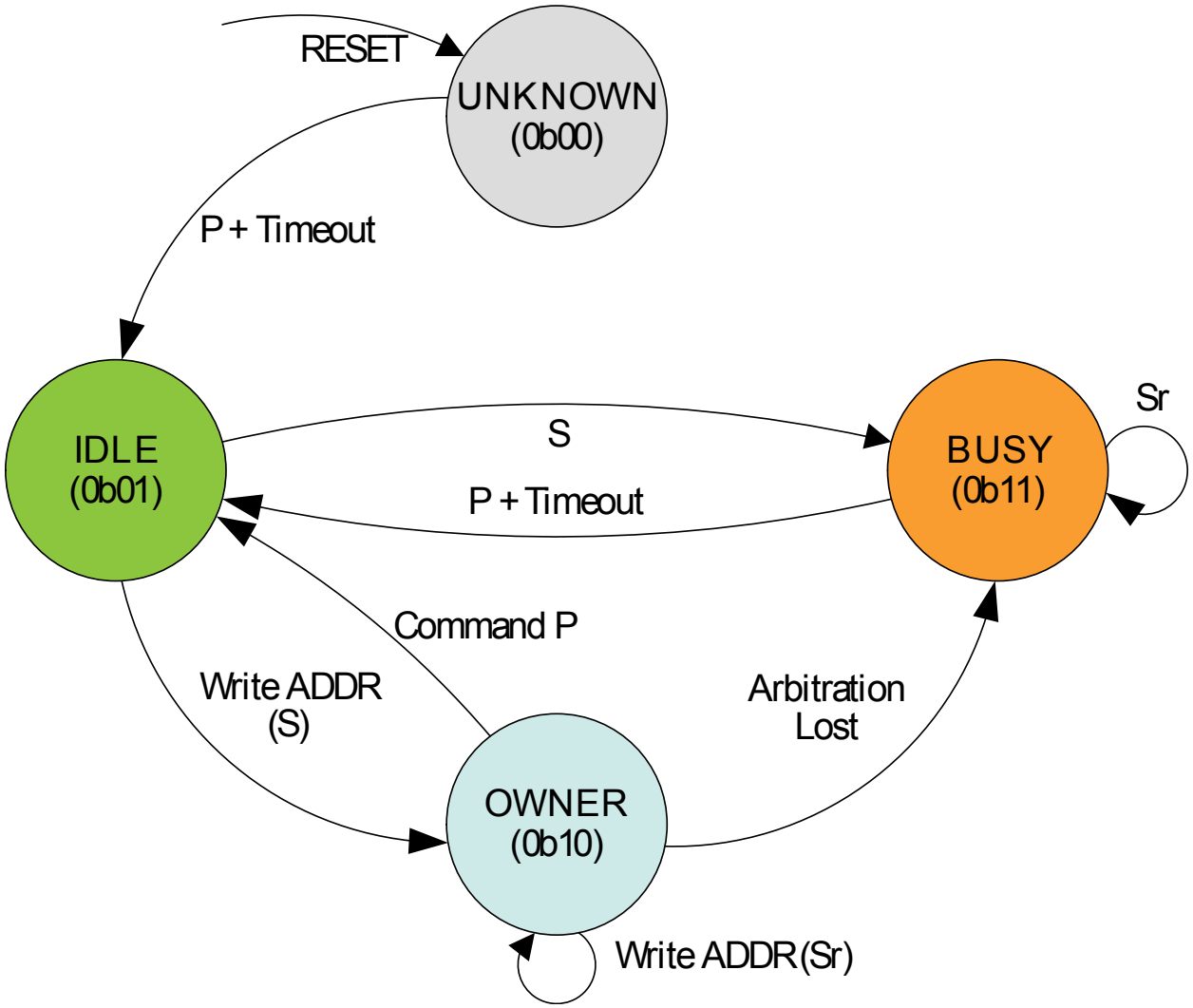
As the I^2C bus is limited to one transaction at the time, a master that wants to perform a bus transaction must wait until the bus is free. Because of this, it is necessary for all masters in a multi-master system to know the current status of the bus to be able to avoid conflicts and to ensure data integrity.

- **IDLE** No activity on the bus (between a **Stop** and a new **Start** condition)
- **OWNER** If the master initiates a transaction successfully
- **BUSY** If another master is driving the bus
- **UNKNOWN** If the master has recently been enabled or connected to the bus. Is forced to **IDLE** after given timeout when the master module is enabled.

The bus state diagram can be seen in Figure 8-4: I2C bus state diagram on page 174.

- S: Start condition
- P: Stop condition
- Sr: Repeated start condition

Figure 8-4. I2C bus state diagram



8.2.7 Bus Timing

Inactive bus timeout for the master and SDA hold time is configurable in the drivers.

8.2.7.1 Unknown Bus State Timeout

When a master is enabled or connected to the bus, the bus state will be unknown until either a given timeout or a stop command has occurred. The timeout is configurable in the i2c_master_config struct. The timeout time will depend on toolchain and optimization level used, as the timeout is a loop incrementing a value until it reaches the specified timeout value.

8.2.7.2 SDA Hold Timeout

When using the I^2C in slave mode, it will be important to set a SDA hold time which assures that the master will be able to pick up the bit sent from the slave. The SDA hold time makes sure that this is the case by holding the data line low for a given period after the negative edge on the clock.

The SDA hold time is also available for the master driver, but is not a necessity.

8.2.8 Operation in Sleep Modes

The I^2C module can operate in all sleep modes by setting the run_in_standby boolean in the i2c_master_config or i2c_slave_config struct. The operation in slave and master mode is shown in Table 8-1: I2C standby operations on page 175.

Table 8-1. I2C standby operations

Run in standby	Slave	Master
false	Disabled, all reception is dropped	GCLK disabled when master is idle
true	Wake on address match when enabled	GCLK enabled while in sleep modes

8.3 Special Considerations

8.3.1 Interrupt-Driven Operation

While an interrupt-driven operation is in progress, subsequent calls to a write or read operation will return the STATUS_BUSY flag, indicating that only one operation is allowed at any given time.

To check if another transmission can be initiated, the user can either call another transfer operation, or use the i2c_master_get_job_status/i2c_slave_get_job_status functions depending on mode.

If the user would like to get callback from operations while using the interrupt-driven driver, the callback must be registered and then enabled using the "register_callback" and "enable_callback" functions.

8.4 Extra Information

For extra information see Extra Information for SERCOM I2C Driver. This includes:

- Acronyms
- Dependencies
- Errata
- Module History

8.5 Examples

For a list of examples related to this driver, see Examples for SERCOM I2C Driver.

8.6 API Overview

8.6.1 Structure Definitions

8.6.1.1 Struct i2c_master_config

This is the configuration structure for the I^2C Master device. It is used as an argument for i2c_master_init to provide the desired configurations for the module. The structure should be initialized using the i2c_master_get_config_defaults .

Table 8-2. Members

Type	Name	Description
uint32_t	baud_rate	Baud rate (in KHZ) for I2C operations in standard-mode, Fast-mode and Fast-mode Plus Transfers, i2c_master_baud_rate
uint16_t	buffer_timeout	Timeout for packet write to wait for slave
enum gclk_generator	generator_source	GCLK generator to use as clock source
enum i2c_master_inactive_timeout	inactive_timeout	Inactive bus time out
uint32_t	pinmux_pad0	PAD0 (SDA) pinmux
uint32_t	pinmux_pad1	PAD1 (SCL) pinmux

Type	Name	Description
bool	run_in_standby	Set to keep module active in sleep modes
bool	scl_low_timeout	Set to enable SCL low time-out
enum i2c_master_start_hold_time	start_hold_time	Bus hold time after start signal on data line
uint16_t	unknown_bus_state_timeout	Unknown bus state timeout

8.6.1.2 Struct i2c_master_module

SERCOM I^2C Master driver software instance structure, used to retain software state information of an associated hardware module instance.

Note The fields of this structure should not be altered by the user application; they are reserved for module-internal use only.

8.6.1.3 Struct i2c_master_packet

Structure to be used when transferring I^2C master packets.

Table 8-3. Members

Type	Name	Description
uint16_t	address	Address to slave device
uint8_t *	data	Data array containing all data to be transferred
uint16_t	data_length	Length of data array
bool	high_speed	Use high speed transfer. Set to false if the feature is not supported by the device
uint8_t	hs_master_code	High speed mode master code (0000 1XXX), valid when high_speed is true
bool	ten_bit_address	Use 10 bit addressing. Set to false if the feature is not supported by the device

8.6.1.4 Struct i2c_slave_config

This is the configuration structure for the I2C Slave device. It is used as an argument for i2c_slave_init to provide the desired configurations for the module. The structure should be initialized using the i2c_slave_get_config_defaults.

Table 8-4. Members

Type	Name	Description
uint16_t	address	Address or upper limit of address range
uint16_t	address_mask	Address mask, second address or lower limit of address range
enum i2c_slave_address_mode	address_mode	Addressing mode

Type	Name	Description
uint16_t	buffer_timeout	Timeout to wait for master in polled functions
bool	enable_general_call_address	Enable general call address recognition (general call address is defined as 0000000 with direction bit 0)
bool	enable_nack_on_address	Enable NACK on address match (this can be changed after initialization via the i2c_slave_enable_nack_on_address and i2c_slave_disable_nack_on_address functions)
bool	enable_scl_low_timeout	Set to enable the SCL low timeout
enum gclk_generator	generator_source	GCLK generator to use as clock source
uint32_t	pinmux_pad0	PAD0 (SDA) pinmux
uint32_t	pinmux_pad1	PAD1 (SCL) pinmux
bool	run_in_standby	Set to keep module active in sleep modes
bool	scl_low_timeout	Set to enable SCL low time-out
enum i2c_slave_sda_hold_time	sda_hold_time	SDA hold time with respect to the negative edge of SCL

8.6.1.5 Struct i2c_slave_module

SERCOM I^2C Slave driver software instance structure, used to retain software state information of an associated hardware module instance.

Note The fields of this structure should not be altered by the user application; they are reserved for module-internal use only.

8.6.1.6 Struct i2c_slave_packet

Structure to be used when transferring I^2C slave packets.

Table 8-5. Members

Type	Name	Description
uint8_t *	data	Data array containing all data to be transferred
uint16_t	data_length	Length of data array

8.6.2 Macro Definitions

8.6.2.1 I2C slave status flags

I2C slave status flags, returned by i2c_slave_get_status() and cleared by i2c_slave_clear_status().

Macro I2C_SLAVE_STATUS_ADDRESS_MATCH

```
#define I2C_SLAVE_STATUS_ADDRESS_MATCH (1UL << 0)
```

Address Match

Note Should only be cleared internally by driver.

Macro I2C_SLAVE_STATUS_DATA_READY

```
#define I2C_SLAVE_STATUS_DATA_READY (1UL << 1)
```

Data Ready

Macro I2C_SLAVE_STATUS_STOP_RECEIVED

```
#define I2C_SLAVE_STATUS_STOP_RECEIVED (1UL << 2)
```

Stop Received

Macro I2C_SLAVE_STATUS_CLOCK_HOLD

```
#define I2C_SLAVE_STATUS_CLOCK_HOLD (1UL << 3)
```

Clock Hold

Note Cannot be cleared, only valid when I2C_SLAVE_STATUS_ADDRESS_MATCH is set

Macro I2C_SLAVE_STATUS_SCL_LOW_TIMEOUT

```
#define I2C_SLAVE_STATUS_SCL_LOW_TIMEOUT (1UL << 4)
```

SCL Low Timeout

Macro I2C_SLAVE_STATUS_REPEATED_START

```
#define I2C_SLAVE_STATUS_REPEATED_START (1UL << 5)
```

Repeated Start

Note Cannot be cleared, only valid when I2C_SLAVE_STATUS_ADDRESS_MATCH is set

Macro I2C_SLAVE_STATUS_RECEIVED_NACK

```
#define I2C_SLAVE_STATUS_RECEIVED_NACK (1UL << 6)
```

Received not acknowledge

Note Cannot be cleared

Macro I2C_SLAVE_STATUS_COLLISION

```
#define I2C_SLAVE_STATUS_COLLISION (1UL << 7)
```

Transmit Collision

Macro I2C_SLAVE_STATUS_BUS_ERROR

```
#define I2C_SLAVE_STATUS_BUS_ERROR (1UL << 8)
```

Bus error

8.6.3 Function Definitions

8.6.3.1 Lock/Unlock

Function i2c_master_lock()

Attempt to get lock on driver instance.

```
enum status_code i2c_master_lock(
  struct i2c_master_module *const module)
```

This function checks the instance's lock, which indicates whether or not it is currently in use, and sets the lock if it was not already set.

The purpose of this is to enable exclusive access to driver instances, so that, e.g., transactions by different services will not interfere with each other.

Table 8-6. Parameters

Data direction	Parameter name	Description
[in, out]	module	Pointer to the driver instance to lock.

Table 8-7. Return Values

Return value	Description
STATUS_OK	if the module was locked.
STATUS_BUSY	if the module was already locked.

Function i2c_master_unlock()

Unlock driver instance.

```
void i2c_master_unlock(
  struct i2c_master_module *const module)
```

This function clears the instance lock, indicating that it is available for use.

Table 8-8. Parameters

Data direction	Parameter name	Description
[in, out]	module	Pointer to the driver instance to lock.

Table 8-9. Return Values

Return value	Description
STATUS_OK	if the module was locked.
STATUS_BUSY	if the module was already locked.

8.6.3.2 Configuration and Initialization

Function i2c_master_is_syncing()

Returns the synchronization status of the module.

```
bool i2c_master_is_syncing(
  const struct i2c_master_module *const module)
```

Returns the synchronization status of the module.

Table 8-10. Parameters

Data direction	Parameter name	Description
[in]	module	Pointer to software module structure

Returns Status of the synchronization.

Table 8-11. Return Values

Return value	Description
true	Module is busy synchronizing
false	Module is not synchronizing

Function i2c_master_get_config_defaults()

Gets the I2C master default configurations.

```
void i2c_master_get_config_defaults(
```

```
  struct i2c_master_config *const config)
```

Use to initialize the configuration structure to known default values.

The default configuration is as follows:

- Baudrate 100kHz
- GCLK generator 0
- Do not run in standby
- Start bit hold time 300ns-600ns
- Buffer timeout = 65535
- Unknown bus status timeout = 65535
- Do not run in standby
- PINMUX_DEFAULT for SERCOM pads

Those default configuration only availale if the device supports it:

- High speed baudrate 3.4MHz
- Standard-mode and Fast-mode transfer speed
- SCL stretch disabled
- slave SCL low extend time-out disabled
- maser SCL low extend time-out disabled

Table 8-12. Parameters

Data direction	Parameter name	Description
[out]	config	Pointer to configuration structure to be initiated

Function i2c_master_init()

Initializes the requested I2C hardware module.

```
enum status_code i2c_master_init(
  struct i2c_master_module *const module,
  Sercom *const hw,
  const struct i2c_master_config *const config)
```

Initializes the SERCOM I^2C master device requested and sets the provided software module struct. Run this function before any further use of the driver.

Table 8-13. Parameters

Data direction	Parameter name	Description
[out]	module	Pointer to software module struct
[in]	hw	Pointer to the hardware instance
[in]	config	Pointer to the configuration struct

Returns Status of initialization.

Table 8-14. Return Values

Return value	Description
STATUS_OK	Module initiated correctly
STATUS_ERR_DENIED	If module is enabled
STATUS_BUSY	If module is busy resetting
STATUS_ERR_ALREADY_INITIALIZED	If setting other GCLK generator than previously set
STATUS_ERR_BAUDRATE_UNAVAILABLE	If given baudrate is not compatible with set GCLK frequency

Function i2c_master_enable()

Enables the I2C module.

```
void i2c_master_enable(
  const struct i2c_master_module *const module)
```

Enables the requested I^{2}C module and set the bus state to IDLE after the specified timeout period if no stop bit is detected.

Table 8-15. Parameters

Data direction	Parameter name	Description
[in]	module	Pointer to the software module struct

Function i2c_master_disable()

Disable the I2C module.

```
void i2c_master_disable(
  const struct i2c_master_module *const module)
```

Disables the requested I^{2}C module.

Table 8-16. Parameters

Data direction	Parameter name	Description
[in]	module	Pointer to the software module struct

Function i2c_master_reset()

Resets the hardware module.

```
void i2c_master_reset(
  struct i2c_master_module *const module)
```

Reset the module to hardware defaults.

Table 8-17. Parameters

Data direction	Parameter name	Description
[in, out]	module	Pointer to software module structure

8.6.3.3 Read and Write

Function i2c_master_read_packet_wait()

Reads data packet from slave.

```
enum status_code i2c_master_read_packet_wait(
  struct i2c_master_module *const module,
  struct i2c_master_packet *const packet)
```

Reads a data packet from the specified slave address on the I^2C bus and sends a stop condition when finished.

Note This will stall the device from any other operation. For interrupt-driven operation, see i2c_master_read_packet_job.

Table 8-18. Parameters

Data direction	Parameter name	Description
[in, out]	module	Pointer to software module struct
[in, out]	packet	Pointer to I^2C packet to transfer

Returns Status of reading packet.

Table 8-19. Return Values

Return value	Description
STATUS_OK	The packet was read successfully
STATUS_ERR_TIMEOUT	If no response was given within specified timeout period
STATUS_ERR_DENIED	If error on bus
STATUS_ERR_PACKET_COLLISION	If arbitration is lost
STATUS_ERR_BAD_ADDRESS	If slave is busy, or no slave acknowledged the address

Function i2c_master_read_packet_wait_no_stop()

Reads data packet from slave without sending a stop condition when done.

```
enum status_code i2c_master_read_packet_wait_no_stop(
  struct i2c_master_module *const module,
  struct i2c_master_packet *const packet)
```

Reads a data packet from the specified slave address on the I^2C bus without sending a stop condition when done, thus retaining ownership of the bus when done. To end the transaction, a read or write with stop condition must be performed.

Note This will stall the device from any other operation. For interrupt-driven operation, see i2c_master_read_packet_job.

Table 8-20. Parameters

Data direction	Parameter name	Description
[in, out]	module	Pointer to software module struct
[in, out]	packet	Pointer to I^2C packet to transfer

Returns Status of reading packet.

Table 8-21. Return Values

Return value	Description
STATUS_OK	The packet was read successfully
STATUS_ERR_TIMEOUT	If no response was given within specified timeout period
STATUS_ERR_DENIED	If error on bus
STATUS_ERR_PACKET_COLLISION	If arbitration is lost
STATUS_ERR_BAD_ADDRESS	If slave is busy, or no slave acknowledged the address

Function i2c_master_write_packet_wait()

Writes data packet to slave.

```
enum status_code i2c_master_write_packet_wait(
  struct i2c_master_module *const module,
  struct i2c_master_packet *const packet)
```

Writes a data packet to the specified slave address on the I^2C bus and sends a stop condition when finished.

Note This will stall the device from any other operation. For interrupt-driven operation, see i2c_master_read_packet_job.

Table 8-22. Parameters

Data direction	Parameter name	Description
[in, out]	module	Pointer to software module struct
[in, out]	packet	Pointer to I^2C packet to transfer

Returns Status of reading packet.

Table 8-23. Return Values

Return value	Description
STATUS_OK	If packet was read
STATUS_BUSY	If master module is busy with a job

Return value	Description
STATUS_ERR_DENIED	If error on bus
STATUS_ERR_PACKET_COLLISION	If arbitration is lost
STATUS_ERR_BAD_ADDRESS	If slave is busy, or no slave acknowledged the address
STATUS_ERR_TIMEOUT	If timeout occurred
STATUS_ERR_OVERFLOW	If slave did not acknowledge last sent data, indicating that slave does not want more data and was not able to read last data sent

Function i2c_master_write_packet_wait_no_stop()

Writes data packet to slave without sending a stop condition when done.

```
enum status_code i2c_master_write_packet_wait_no_stop(
  struct i2c_master_module *const module,
  struct i2c_master_packet *const packet)
```

Writes a data packet to the specified slave address on the I^2C bus without sending a stop condition, thus retaining ownership of the bus when done. To end the transaction, a read or write with stop condition or sending a stop with the i2c_master_send_stop function must be performed.

Note This will stall the device from any other operation. For interrupt-driven operation, see i2c_master_read_packet_job.

Table 8-24. Parameters

Data direction	Parameter name	Description
[in, out]	module	Pointer to software module struct
[in, out]	packet	Pointer to I^2C packet to transfer

Returns Status of reading packet.

Table 8-25. Return Values

Return value	Description
STATUS_OK	If packet was read
STATUS_BUSY	If master module is busy
STATUS_ERR_DENIED	If error on bus
STATUS_ERR_PACKET_COLLISION	If arbitration is lost
STATUS_ERR_BAD_ADDRESS	If slave is busy, or no slave acknowledged the address
STATUS_ERR_TIMEOUT	If timeout occurred
STATUS_ERR_OVERFLOW	If slave did not acknowledge last sent data, indicating that slave do not want more data

Function i2c_master_send_stop()

Sends stop condition on bus.

```
void i2c_master_send_stop(
  struct i2c_master_module *const module)
```

Sends a stop condition on bus.

Note This function can only be used after the i2c_master_write_packet_wait_no_stop function. If a stop condition is to be sent after a read, the i2c_master_read_packet_wait function must be used.

Table 8-26. Parameters

Data direction	Parameter name	Description
[in]	module	Pointer to the software instance struct

8.6.3.4 Callbacks

Function i2c_master_register_callback()

Registers callback for the specified callback type.

```
void i2c_master_register_callback(
  struct i2c_master_module *const module,
  i2c_master_callback_t callback,
  enum i2c_master_callback callback_type)
```

Associates the given callback function with the specified callback type.

To enable the callback, the i2c_master_enable_callback function must be used.

Table 8-27. Parameters

Data direction	Parameter name	Description
[in, out]	module	Pointer to the software module struct
[in]	callback	Pointer to the function desired for the specified callback
[in]	callback_type	Callback type to register

Function i2c_master_unregister_callback()

Unregisters callback for the specified callback type.

```
void i2c_master_unregister_callback(
  struct i2c_master_module *const module,
  enum i2c_master_callback callback_type)
```

When called, the currently registered callback for the given callback type will be removed.

Table 8-28. Parameters

Data direction	Parameter name	Description
[in, out]	module	Pointer to the software module struct

Data direction	Parameter name	Description
[in]	callback_type	Specifies the callback type to unregister

Function i2c_master_enable_callback()

Enables callback.

```
void i2c_master_enable_callback(
  struct i2c_master_module *const module,
  enum i2c_master_callback callback_type)
```

Enables the callback specified by the callback_type.

Table 8-29. Parameters

Data direction	Parameter name	Description
[in, out]	module	Pointer to the software module struct
[in]	callback_type	Callback type to enable

Function i2c_master_disable_callback()

Disables callback.

```
void i2c_master_disable_callback(
  struct i2c_master_module *const module,
  enum i2c_master_callback callback_type)
```

Disables the callback specified by the callback_type.

Table 8-30. Parameters

Data direction	Parameter name	Description
[in, out]	module	Pointer to the software module struct
[in]	callback_type	Callback type to disable

8.6.3.5 Read and Write, Interrupt-Driven

Function i2c_master_read_packet_job()

Initiates a read packet operation.

```
enum status_code i2c_master_read_packet_job(
  struct i2c_master_module *const module,
  struct i2c_master_packet *const packet)
```

Reads a data packet from the specified slave address on the I^2C bus. This is the non-blocking equivalent of i2c_master_read_packet_wait.

Table 8-31. Parameters

Data direction	Parameter name	Description
[in, out]	module	Pointer to software module struct
[in, out]	packet	Pointer to I^{2}C packet to transfer

Returns Status of starting reading I^{2}C packet.

Table 8-32. Return Values

Return value	Description
STATUS_OK	If reading was started successfully
STATUS_BUSY	If module is currently busy with another transfer

Function i2c_master_read_packet_job_no_stop()

Initiates a read packet operation without sending a STOP condition when done.

```
enum status_code i2c_master_read_packet_job_no_stop(
  struct i2c_master_module *const module,
  struct i2c_master_packet *const packet)
```

Reads a data packet from the specified slave address on the I^{2}C bus without sending a stop condition, thus retaining ownership of the bus when done. To end the transaction, a read or write with stop condition must be performed.

This is the non-blocking equivalent of i2c_master_read_packet_wait_no_stop.

Table 8-33. Parameters

Data direction	Parameter name	Description
[in, out]	module	Pointer to software module struct
[in, out]	packet	Pointer to I^{2}C packet to transfer

Returns Status of starting reading I^{2}C packet.

Table 8-34. Return Values

Return value	Description
STATUS_OK	If reading was started successfully
STATUS_BUSY	If module is currently busy with another operation

Function i2c_master_write_packet_job()

Initiates a write packet operation.

```
enum status_code i2c_master_write_packet_job(
  struct i2c_master_module *const module,
  struct i2c_master_packet *const packet)
```

Writes a data packet to the specified slave address on the I2C bus. This is the non-blocking equivalent of i2c_master_write_packet_wait.

Table 8-35. Parameters

Data direction	Parameter name	Description
[in, out]	module	Pointer to software module struct
[in, out]	packet	Pointer to I2C packet to transfer

Returns Status of starting writing I2C packet job.

Table 8-36. Return Values

Return value	Description
STATUS_OK	If writing was started successfully
STATUS_BUSY	If module is currently busy with another transfer

Function i2c_master_write_packet_job_no_stop()

Initiates a write packet operation without sending a STOP condition when done.

```
enum status_code i2c_master_write_packet_job_no_stop(
  struct i2c_master_module *const module,
  struct i2c_master_packet *const packet)
```

Writes a data packet to the specified slave address on the I2C bus without sending a stop condition, thus retaining ownership of the bus when done. To end the transaction, a read or write with stop condition or sending a stop with the i2c_master_send_stop function must be performed.

This is the non-blocking equivalent of i2c_master_write_packet_wait_no_stop.

Table 8-37. Parameters

Data direction	Parameter name	Description
[in, out]	module	Pointer to software module struct
[in, out]	packet	Pointer to I2C packet to transfer

Returns Status of starting writing I2C packet job.

Table 8-38. Return Values

Return value	Description
STATUS_OK	If writing was started successfully
STATUS_BUSY	If module is currently busy with another

Function i2c_master_cancel_job()

Cancel any currently ongoing operation.

```
void i2c_master_cancel_job(
```

```
  struct i2c_master_module *const module)
```

Terminates the running transfer operation.

Table 8-39. Parameters

Data direction	Parameter name	Description
[in, out]	module	Pointer to software module structure

Function i2c_master_get_job_status()

Get status from ongoing job.

```
enum status_code i2c_master_get_job_status(
  struct i2c_master_module *const module)
```

Will return the status of a transfer operation.

Table 8-40. Parameters

Data direction	Parameter name	Description
[in]	module	Pointer to software module structure

Returns Last status code from transfer operation.

Table 8-41. Return Values

Return value	Description
STATUS_OK	No error has occurred
STATUS_BUSY	If transfer is in progress
STATUS_BUSY	If master module is busy
STATUS_ERR_DENIED	If error on bus
STATUS_ERR_PACKET_COLLISION	If arbitration is lost
STATUS_ERR_BAD_ADDRESS	If slave is busy, or no slave acknowledged the address
STATUS_ERR_TIMEOUT	If timeout occurred
STATUS_ERR_OVERFLOW	If slave did not acknowledge last sent data, indicating that slave does not want more data and was not able to read

8.6.3.6 Lock/Unlock

Function i2c_slave_lock()

Attempt to get lock on driver instance.

```
enum status_code i2c_slave_lock(
  struct i2c_slave_module *const module)
```

This function checks the instance's lock, which indicates whether or not it is currently in use, and sets the lock if it was not already set.

The purpose of this is to enable exclusive access to driver instances, so that, e.g., transactions by different services will not interfere with each other.

Table 8-42. Parameters

Data direction	Parameter name	Description
[in, out]	module	Pointer to the driver instance to lock.

Table 8-43. Return Values

Return value	Description
STATUS_OK	if the module was locked.
STATUS_BUSY	if the module was already locked.

Function i2c_slave_unlock()

Unlock driver instance.

```
void i2c_slave_unlock(
  struct i2c_slave_module *const module)
```

This function clears the instance lock, indicating that it is available for use.

Table 8-44. Parameters

Data direction	Parameter name	Description
[in, out]	module	Pointer to the driver instance to lock.

Table 8-45. Return Values

Return value	Description
STATUS_OK	if the module was locked.
STATUS_BUSY	if the module was already locked.

8.6.3.7 Configuration and Initialization

Function i2c_slave_is_syncing()

Returns the synchronization status of the module.

```
bool i2c_slave_is_syncing(
  const struct i2c_slave_module *const module)
```

Returns the synchronization status of the module.

Table 8-46. Parameters

Data direction	Parameter name	Description
[out]	module	Pointer to software module structure

Returns Status of the synchronization.

Table 8-47. Return Values

Return value	Description
true	Module is busy synchronizing
false	Module is not synchronizing

Function i2c_slave_get_config_defaults()

Gets the I2C slave default configurations.

```
void i2c_slave_get_config_defaults(
  struct i2c_slave_config *const config)
```

This will initialize the configuration structure to known default values.

The default configuration is as follows:

- Disable SCL low timeout
- 300ns - 600ns SDA hold time
- Buffer timeout = 65535
- Address with mask
- Address = 0
- Address mask = 0 (one single address)
- General call address disabled
- Address nack disabled if the interrupt driver is used
- GCLK generator 0
- Do not run in standby
- PINMUX_DEFAULT for SERCOM pads

Those default configuration only availale if the device supports it:

- Not using 10 bit addressing
- Standard-mode and Fast-mode transfer speed
- SCL stretch disabled
- slave SCL low extend time-out disabled

Table 8-48. Parameters

Data direction	Parameter name	Description
[out]	config	Pointer to configuration structure to be initialized

Function i2c_slave_init()

Initializes the requested I2C hardware module.

```
enum status_code i2c_slave_init(
  struct i2c_slave_module *const module,
  Sercom *const hw,
  const struct i2c_slave_config *const config)
```

Initializes the SERCOM I2C Slave device requested and sets the provided software module struct. Run this function before any further use of the driver.

Table 8-49. Parameters

Data direction	Parameter name	Description
[out]	module	Pointer to software module struct
[in]	hw	Pointer to the hardware instance
[in]	config	Pointer to the configuration struct

Returns Status of initialization.

Table 8-50. Return Values

Return value	Description
STATUS_OK	Module initiated correctly
STATUS_ERR_DENIED	If module is enabled
STATUS_BUSY	If module is busy resetting
STATUS_ERR_ALREADY_INITIALIZED	If setting other GCLK generator than previously set

Function i2c_slave_enable()

Enables the I2C module.

```
void i2c_slave_enable(
  const struct i2c_slave_module *const module)
```

This will enable the requested I2C module.

Table 8-51. Parameters

Data direction	Parameter name	Description
[in]	module	Pointer to the software module struct

Function i2c_slave_disable()

Disables the I2C module.

```
void i2c_slave_disable(
  const struct i2c_slave_module *const module)
```

This will disable the I2C module specified in the provided software module structure.

Table 8-52. Parameters

Data direction	Parameter name	Description
[in]	module	Pointer to the software module struct

Function i2c_slave_reset()

Resets the hardware module.

```
void i2c_slave_reset(
  struct i2c_slave_module *const module)
```

This will reset the module to hardware defaults.

Table 8-53. Parameters

Data direction	Parameter name	Description
[in, out]	module	Pointer to software module structure

8.6.3.8 Read and Write

Function i2c_slave_write_packet_wait()

Writes a packet to the master.

```
enum status_code i2c_slave_write_packet_wait(
  struct i2c_slave_module *const module,
  struct i2c_slave_packet *const packet)
```

Writes a packet to the master. This will wait for the master to issue a request.

Table 8-54. Parameters

Data direction	Parameter name	Description
[in]	module	Pointer to software module structure
[in]	packet	Packet to write to master

Returns Status of packet write.

Table 8-55. Return Values

Return value	Description
STATUS_OK	Packet was written successfully
STATUS_ERR_DENIED	Start condition not received, another interrupt flag is set
STATUS_ERR_IO	There was an error in the previous transfer
STATUS_ERR_BAD_FORMAT	Master wants to write data

Return value	Description
STATUS_ERR_INVALID_ARG	Invalid argument(s) was provided
STATUS_ERR_BUSY	The I^2C module is busy with a job.
STATUS_ERR_ERR_OVERFLOW	Master NACKed before entire packet was transferred
STATUS_ERR_TIMEOUT	No response was given within the timeout period

Function i2c_slave_read_packet_wait()

Reads a packet from the master.

```
enum status_code i2c_slave_read_packet_wait(
  struct i2c_slave_module *const module,
  struct i2c_slave_packet *const packet)
```

Reads a packet from the master. This will wait for the master to issue a request.

Table 8-56. Parameters

Data direction	Parameter name	Description
[in]	module	Pointer to software module structure
[out]	packet	Packet to read from master

Returns Status of packet read.

Table 8-57. Return Values

Return value	Description
STATUS_OK	Packet was read successfully
STATUS_ABORTED	Master sent stop condition or repeated start before specified length of bytes was received
STATUS_ERR_IO	There was an error in the previous transfer
STATUS_ERR_DENIED	Start condition not received, another interrupt flag is set
STATUS_ERR_INVALID_ARG	Invalid argument(s) was provided
STATUS_ERR_BUSY	The I^2C module is busy with a job
STATUS_ERR_BAD_FORMAT	Master wants to read data
STATUS_ERR_ERR_OVERFLOW	Last byte received overflows buffer

Function i2c_slave_get_direction_wait()

Waits for a start condition on the bus.

```
enum i2c_slave_direction i2c_slave_get_direction_wait(
  struct i2c_slave_module *const module)
```

Waits for the master to issue a start condition on the bus. Note that this function does not check for errors in the last transfer, this will be discovered when reading or writing.

Table 8-58. Parameters

Data direction	Parameter name	Description
[in]	module	Pointer to software module structure

Returns Direction of the current transfer, when in slave mode.

Table 8-59. Return Values

Return value	Description
I2C_SLAVE_DIRECTION_NONE	No request from master within timeout period
I2C_SLAVE_DIRECTION_READ	Write request from master
I2C_SLAVE_DIRECTION_WRITE	Read request from master

Note This function is only available for 7-bit slave addressing.

Waits for the master to issue a start condition on the bus. Note that this function does not check for errors in the last transfer, this will be discovered when reading or writing.

Table 8-60. Parameters

Data direction	Parameter name	Description
[in]	module	Pointer to software module structure

Returns Direction of the current transfer, when in slave mode.

Table 8-61. Return Values

Return value	Description
I2C_SLAVE_DIRECTION_NONE	No request from master within timeout period
I2C_SLAVE_DIRECTION_READ	Write request from master
I2C_SLAVE_DIRECTION_WRITE	Read request from master

8.6.3.9 Status Management

Function i2c_slave_get_status()

Retrieves the current module status.

```
uint32_t i2c_slave_get_status(
  struct i2c_slave_module *const module)
```

Checks the status of the module and returns it as a bitmask of status flags

Table 8-62. Parameters

Data direction	Parameter name	Description
[in]	module	Pointer to the I2C slave software device struct

Returns Bitmask of status flags

Table 8-63. Return Values

Return value	Description
I2C_SLAVE_STATUS_ADDRESS_MATCH	A valid address has been received
I2C_SLAVE_STATUS_DATA_READY	A I2C slave byte transmission is successfully completed
I2C_SLAVE_STATUS_STOP_RECEIVED	A stop condition is detected for a transaction being processed
I2C_SLAVE_STATUS_CLOCK_HOLD	The slave is holding the SCL line low
I2C_SLAVE_STATUS_SCL_LOW_TIMEOUT	An SCL low time-out has occurred
I2C_SLAVE_STATUS_REPEATED_START	Indicates a repeated start, only valid if I2C_SLAVE_STATUS_ADDRESS_MATCH is set
I2C_SLAVE_STATUS_RECEIVED_NACK	The last data packet sent was not acknowledged
I2C_SLAVE_STATUS_COLLISION	The I2C slave was not able to transmit a high data or NACK bit
I2C_SLAVE_STATUS_BUS_ERROR	An illegal bus condition has occurred on the bus

Function i2c_slave_clear_status()

Clears a module status flag.

```
void i2c_slave_clear_status(
  struct i2c_slave_module *const module,
  uint32_t status_flags)
```

Clears the given status flag of the module.

Note Not all status flags can be cleared.

Table 8-64. Parameters

Data direction	Parameter name	Description
[in]	module	Pointer to the I2C software device struct
[in]	status_flags	Bit mask of status flags to clear

8.6.3.10 Address Match Functionality

Function i2c_slave_enable_nack_on_address()

Enables sending of NACK on address match.

```
void i2c_slave_enable_nack_on_address(
  struct i2c_slave_module *const module)
```

Enables sending of NACK on address match, thus discarding any incoming transaction.

Table 8-65. Parameters

Data direction	Parameter name	Description
[in, out]	module	Pointer to software module structure

Function i2c_slave_disable_nack_on_address()

Disables sending NACK on address match.

```
void i2c_slave_disable_nack_on_address(
  struct i2c_slave_module *const module)
```

Disables sending of NACK on address match, thus acknowledging incoming transactions.

Table 8-66. Parameters

Data direction	Parameter name	Description
[in, out]	module	Pointer to software module structure

8.6.3.11 Callbacks

Function i2c_slave_register_callback()

Registers callback for the specified callback type.

```
void i2c_slave_register_callback(
  struct i2c_slave_module *const module,
  i2c_slave_callback_t callback,
  enum i2c_slave_callback callback_type)
```

Associates the given callback function with the specified callback type. To enable the callback, the i2c_slave_enable_callback function must be used.

Table 8-67. Parameters

Data direction	Parameter name	Description
[in, out]	module	Pointer to the software module struct
[in]	callback	Pointer to the function desired for the specified callback
[in]	callback_type	Callback type to register

Function i2c_slave_unregister_callback()

Unregisters callback for the specified callback type.

```
void i2c_slave_unregister_callback(
  struct i2c_slave_module *const module,
  enum i2c_slave_callback callback_type)
```

Removes the currently registered callback for the given callback type.

Table 8-68. Parameters

Data direction	Parameter name	Description
[in, out]	module	Pointer to the software module struct
[in]	callback_type	Callback type to unregister

Function i2c_slave_enable_callback()

Enables callback.

```
void i2c_slave_enable_callback(
  struct i2c_slave_module *const module,
  enum i2c_slave_callback callback_type)
```

Enables the callback specified by the callback_type.

Table 8-69. Parameters

Data direction	Parameter name	Description
[in, out]	module	Pointer to the software module struct
[in]	callback_type	Callback type to enable

Function i2c_slave_disable_callback()

Disables callback.

```
void i2c_slave_disable_callback(
  struct i2c_slave_module *const module,
  enum i2c_slave_callback callback_type)
```

Disables the callback specified by the callback_type.

Table 8-70. Parameters

Data direction	Parameter name	Description
[in, out]	module	Pointer to the software module struct
[in]	callback_type	Callback type to disable

8.6.3.12 Read and Write, Interrupt-Driven

Function i2c_slave_read_packet_job()

Initiates a reads packet operation.

```
enum status_code i2c_slave_read_packet_job(
  struct i2c_slave_module *const module,
  struct i2c_slave_packet *const packet)
```

Reads a data packet from the master. A write request must be initiated by the master before the packet can be read.

The I2C_SLAVE_CALLBACK_WRITE_REQUEST on page 203 callback can be used to call this function.

Table 8-71. Parameters

Data direction	Parameter name	Description
[in, out]	module	Pointer to software module struct
[in, out]	packet	Pointer to I^2C packet to transfer

Returns Status of starting asynchronously reading I^2C packet.

Table 8-72. Return Values

Return value	Description
STATUS_OK	If reading was started successfully
STATUS_BUSY	If module is currently busy with another transfer

Function i2c_slave_write_packet_job()

Initiates a write packet operation.

```
enum status_code i2c_slave_write_packet_job(
  struct i2c_slave_module *const module,
  struct i2c_slave_packet *const packet)
```

Writes a data packet to the master. A read request must be initiated by the master before the packet can be written.

The I2C_SLAVE_CALLBACK_READ_REQUEST on page 203 callback can be used to call this function.

Table 8-73. Parameters

Data direction	Parameter name	Description
[in, out]	module	Pointer to software module struct
[in, out]	packet	Pointer to I^2C packet to transfer

Returns Status of starting writing I^2C packet.

Table 8-74. Return Values

Return value	Description
STATUS_OK	If writing was started successfully
STATUS_BUSY	If module is currently busy with another transfer

Function i2c_slave_cancel_job()

Cancels any currently ongoing operation.

```
void i2c_slave_cancel_job(
```

```
  struct i2c_slave_module *const module)
```

Terminates the running transfer operation.

Table 8-75. Parameters

Data direction	Parameter name	Description
[in, out]	module	Pointer to software module structure

Function i2c_slave_get_job_status()

Gets status of ongoing job.

```
enum status_code i2c_slave_get_job_status(
  struct i2c_slave_module *const module)
```

Will return the status of the ongoing job, or the error that occurred in the last transfer operation. The status will be cleared when starting a new job.

Table 8-76. Parameters

Data direction	Parameter name	Description
[in, out]	module	Pointer to software module structure

Returns Status of job.

Table 8-77. Return Values

Return value	Description
STATUS_OK	No error has occurred
STATUS_BUSY	Transfer is in progress
STATUS_ERR_IO	A collision, timeout or bus error happened in the last transfer
STATUS_ERR_TIMEOUT	A timeout occurred
STATUS_ERR_OVERFLOW	Data from master overflows receive buffer

8.6.4 Enumeration Definitions

8.6.4.1 Enum i2c_master_baud_rate

Values for I^2C speeds supported by the module. The driver will also support setting any other value, in which case set the value in the i2c_master_config at desired value divided by 1000.

Example: If 10kHz operation is required, give baud_rate in the configuration structure the value 10.

Table 8-78. Members

Enum value	Description
I2C_MASTER_BAUD_RATE_100KHZ	Baud rate at 100kHz (Standard-mode)
I2C_MASTER_BAUD_RATE_400KHZ	Baud rate at 400kHz (Fast-mode)

8.6.4.2 Enum i2c_master_callback

The available callback types for the I^{2}C master module.

Table 8-79. Members

Enum value	Description
I2C_MASTER_CALLBACK_WRITE_COMPLETE	Callback for packet write complete
I2C_MASTER_CALLBACK_READ_COMPLETE	Callback for packet read complete
I2C_MASTER_CALLBACK_ERROR	Callback for error

8.6.4.3 Enum i2c_master_inactive_timeout

\ brief Values for inactive bus time-out.

If the inactive bus time-out is enabled and the bus is inactive for longer than the time-out setting, the bus state logic will be set to idle.

Table 8-80. Members

Enum value	Description
I2C_MASTER_INACTIVE_TIMEOUT_DISABLED	Inactive bus time-out disabled
I2C_MASTER_INACTIVE_TIMEOUT_55US	Inactive bus time-out 5-6 SCL cycle time-out (50-60us)
I2C_MASTER_INACTIVE_TIMEOUT_105US	Inactive bus time-out 10-11 SCL cycle time-out (100-110us)
I2C_MASTER_INACTIVE_TIMEOUT_205US	Inactive bus time-out 20-21 SCL cycle time-out (200-210us)

8.6.4.4 Enum i2c_master_interrupt_flag

Flags used when reading or setting interrupt flags.

Table 8-81. Members

Enum value	Description
I2C_MASTER_INTERRUPT_WRITE	Interrupt flag used for write
I2C_MASTER_INTERRUPT_READ	Interrupt flag used for read

8.6.4.5 Enum i2c_master_start_hold_time

Values for the possible I^{2}C master mode SDA internal hold times after start bit has been sent.

Table 8-82. Members

Enum value	Description
I2C_MASTER_START_HOLD_TIME_DISABLED	Internal SDA hold time disabled
I2C_MASTER_START_HOLD_TIME_50NS_100NS	Internal SDA hold time 50ns-100ns
I2C_MASTER_START_HOLD_TIME_300NS_600NS	Internal SDA hold time 300ns-600ns
I2C_MASTER_START_HOLD_TIME_400NS_800NS	Internal SDA hold time 400ns-800ns

8.6.4.6 Enum i2c_slave_address_mode

Enum for the possible address modes.

Table 8-83. Members

Enum value	Description
I2C_SLAVE_ADDRESS_MODE_MASK	Address match on address_mask used as a mask to address
I2C_SLAVE_ADDRESS_MODE_TWO_ADDRESSES	Address math on both address and address_mask
I2C_SLAVE_ADDRESS_MODE_RANGE	Address match on range of addresses between and including address and address_mask

8.6.4.7 Enum i2c_slave_callback

The available callback types for the I2C slave.

Table 8-84. Members

Enum value	Description
I2C_SLAVE_CALLBACK_WRITE_COMPLETE	Callback for packet write complete
I2C_SLAVE_CALLBACK_READ_COMPLETE	Callback for packet read complete
I2C_SLAVE_CALLBACK_READ_REQUEST	Callback for read request from master - can be used to issue a write
I2C_SLAVE_CALLBACK_WRITE_REQUEST	Callback for write request from master - can be used to issue a read
I2C_SLAVE_CALLBACK_ERROR	Callback for error
I2C_SLAVE_CALLBACK_ERROR_LAST_TRANSFER	Callback for error in last transfer. Discovered on a new address interrupt

8.6.4.8 Enum i2c_slave_direction

Enum for the direction of a request.

Table 8-85. Members

Enum value	Description
I2C_SLAVE_DIRECTION_READ	Read
I2C_SLAVE_DIRECTION_WRITE	Write
I2C_SLAVE_DIRECTION_NONE	No direction

8.6.4.9 Enum i2c_slave_sda_hold_time

Enum for the possible SDA hold times with respect to the negative edge of SCL.

Table 8-86. Members

Enum value	Description
I2C_SLAVE_SDA_HOLD_TIME_DISABLED	SDA hold time disabled
I2C_SLAVE_SDA_HOLD_TIME_50NS_100NS	SDA hold time 50ns-100ns
I2C_SLAVE_SDA_HOLD_TIME_300NS_600NS	SDA hold time 300ns-600ns

Enum value	Description
I2C_SLAVE_SDA_HOLD_TIME_400NS_800NS	SDA hold time 400ns-800ns

8.6.4.10 Enum i2c_transfer_direction

For master: transfer direction or setting direction bit in address. For slave: direction of request from master.

Table 8-87. Members

Enum value	Description
I2C_TRANSFER_WRITE	
I2C_TRANSFER_READ	

8.7 Extra Information for SERCOM I2C Driver

8.7.1 Acronyms

Table 8-88: Acronyms on page 204 is a table listing the acronyms used in this module, along with their intended meanings.

Table 8-88. Acronyms

Acronym	Description
SDA	Serial Data Line
SCL	Serial Clock Line
SERCOM	Serial Communication Interface
DMA	Direct Memory Access

8.7.2 Dependencies

The I^2C driver has the following dependencies:

- System Pin Multiplexer Driver

8.7.3 Errata

There are no errata related to this driver.

8.7.4 Module History

Table 8-89: Module History on page 204 is an overview of the module history, detailing enhancements and fixes made to the module since its first release. The current version of this corresponds to the newest version listed in Table 8-89: Module History on page 204.

Table 8-89. Module History

Changelog
• Added 10-bit addressing and high speed support in SAM D21. • Seperate structure i2c_packet into i2c_master_packet and i2c_slave packet.
• Added support for SCL stretch and extended timeout hardware features in SAM D21. • Added fast mode plus support in SAM D21.
Fixed incorrect logical mask for determining if a bus error has occurred in I2C Slave mode.
Initial Release

8.8 Examples for SERCOM I2C Driver

This is a list of the available Quick Start guides (QSGs) and example applications for SAM D20/D21 I2C Driver (SERCOM I2C). QSGs are simple examples with step-by-step instructions to configure and use this driver in a selection of use cases. Note that QSGs can be compiled as a standalone application or be added to the user application.

- Quick Start Guide for the I2C Master module - Basic Use Case
- Quick Start Guide for the I2C Master module - Callback Use Case
- Quick Start Guide for the I2C Master module - DMA Use Case
- Quick Start Guide for the I2C Slave module - Basic Use Case
- Quick Start Guide for the I2C Slave module - Callback Use Case
- Quick Start Guide for the I2C Slave module - DMA Use Case

8.8.1 Quick Start Guide for SERCOM I2C Master - Basic

In this use case, the I^2C will used and set up as follows:

- Master mode
- 100kHz operation speed
- Not operational in standby
- 10000 packet timeout value
- 65535 unknown bus state timeout value

8.8.1.1 Prerequisites

The device must be connected to an I^2C slave.

8.8.1.2 Setup

Code

The following must be added to the user application:

- A sample buffer to send, a sample buffer to read:

```
#define DATA_LENGTH 10
static uint8_t write_buffer[DATA_LENGTH] = {
        0x00, 0x01, 0x02, 0x03, 0x04, 0x05, 0x06, 0x07, 0x08, 0x09,
};

static uint8_t read_buffer[DATA_LENGTH];
```

- Slave address to access:

```
#define SLAVE_ADDRESS 0x12
```

- Number of times to try to send packet if it fails:

```
#define TIMEOUT 1000
```

- Globally accessible module structure:

```
struct i2c_master_module i2c_master_instance;
```

- Function for setting up the module:

```
void configure_i2c_master(void)
{
    /* Initialize config structure and software module. */
    struct i2c_master_config config_i2c_master;
    i2c_master_get_config_defaults(&config_i2c_master);

    /* Change buffer timeout to something longer. */
    config_i2c_master.buffer_timeout = 10000;

    /* Initialize and enable device with config. */
    i2c_master_init(&i2c_master_instance, SERCOM2, &config_i2c_master);

    i2c_master_enable(&i2c_master_instance);
}
```

- Add to user application `main()`:

```
/* Configure device and enable. */
configure_i2c_master();

/* Timeout counter. */
uint16_t timeout = 0;

/* Init i2c packet. */
struct i2c_master_packet packet = {
    .address     = SLAVE_ADDRESS,
    .data_length = DATA_LENGTH,
    .data        = write_buffer,
    .ten_bit_address = false,
    .high_speed      = false,
    .hs_master_code  = 0x0,
};
```

Workflow

1. Configure and enable module:

```
void configure_i2c_master(void)
{
    /* Initialize config structure and software module. */
    struct i2c_master_config config_i2c_master;
    i2c_master_get_config_defaults(&config_i2c_master);

    /* Change buffer timeout to something longer. */
    config_i2c_master.buffer_timeout = 10000;

    /* Initialize and enable device with config. */
    i2c_master_init(&i2c_master_instance, SERCOM2, &config_i2c_master);

    i2c_master_enable(&i2c_master_instance);
}
```

a. Create and initialize configuration structure.

```
struct i2c_master_config config_i2c_master;
i2c_master_get_config_defaults(&config_i2c_master);
```

b. Change settings in the configuration.

```
config_i2c_master.buffer_timeout = 10000;
```

c. Initialize the module with the set configurations.

```
i2c_master_init(&i2c_master_instance, SERCOM2, &config_i2c_master);
```

d. Enable the module.

```
i2c_master_enable(&i2c_master_instance);
```

2. Create a variable to see when we should stop trying to send packet.

```
uint16_t timeout = 0;
```

3. Create a packet to send:

```
struct i2c_master_packet packet = {
    .address     = SLAVE_ADDRESS,
    .data_length = DATA_LENGTH,
    .data        = write_buffer,
    .ten_bit_address = false,
    .high_speed      = false,
    .hs_master_code  = 0x0,
};
```

8.8.1.3 Implementation

Code

Add to user application `main()`:

```
/* Write buffer to slave until success. */
while (i2c_master_write_packet_wait(&i2c_master_instance, &packet) !=
        STATUS_OK) {
    /* Increment timeout counter and check if timed out. */
    if (timeout++ == TIMEOUT) {
        break;
    }
}

/* Read from slave until success. */
packet.data = read_buffer;
while (i2c_master_read_packet_wait(&i2c_master_instance, &packet) !=
        STATUS_OK) {
    /* Increment timeout counter and check if timed out. */
    if (timeout++ == TIMEOUT) {
        break;
    }
```

```
}
```

Workflow

1. Write packet to slave.

```
while (i2c_master_write_packet_wait(&i2c_master_instance, &packet) !=
        STATUS_OK) {
    /* Increment timeout counter and check if timed out. */
    if (timeout++ == TIMEOUT) {
        break;
    }
}
```

   The module will try to send the packet TIMEOUT number of times or until it is successfully sent.

2. Read packet from slave.

```
packet.data = read_buffer;
while (i2c_master_read_packet_wait(&i2c_master_instance, &packet) !=
        STATUS_OK) {
    /* Increment timeout counter and check if timed out. */
    if (timeout++ == TIMEOUT) {
        break;
    }
}
```

   The module will try to read the packet TIMEOUT number of times or until it is successfully read.

8.8.2 Quick Start Guide for SERCOM I2C Master - Callback

In this use case, the I^2C will used and set up as follows:

- Master mode
- 100kHz operation speed
- Not operational in standby
- 65535 unknown bus state timeout value

8.8.2.1 Prerequisites

The device must be connected to an I^2C slave.

8.8.2.2 Setup

Code

The following must be added to the user application:

A sample buffer to write from, a reversed buffer to write from and length of buffers.

```
#define DATA_LENGTH 8

static uint8_t buffer[DATA_LENGTH] = {
    0x00, 0x01, 0x02, 0x03, 0x04, 0x05, 0x06, 0x07
};

static uint8_t buffer_reversed[DATA_LENGTH] = {
    0x07, 0x06, 0x05, 0x04, 0x03, 0x02, 0x01, 0x00
```

```
};
```

Address of slave:

```
#define SLAVE_ADDRESS 0x12
```

Globally accessible module structure:

```
struct i2c_master_module i2c_master_instance;
```

Globally accessible packet:

```
struct i2c_master_packet packet;
```

Function for setting up module:

```
void configure_i2c(void)
{
    /* Initialize config structure and software module */
    struct i2c_master_config config_i2c_master;
    i2c_master_get_config_defaults(&config_i2c_master);

    /* Change buffer timeout to something longer */
    config_i2c_master.buffer_timeout = 65535;

    /* Initialize and enable device with config */
    while(i2c_master_init(&i2c_master_instance, SERCOM2, &config_i2c_master) != STATUS_OK);

    i2c_master_enable(&i2c_master_instance);
}
```

Callback function for write complete:

```
void i2c_write_complete_callback(
        struct i2c_master_module *const module)
{
    /* Send every other packet with reversed data */
    if (packet.data[0] == 0x00) {
        packet.data = &buffer_reversed[0];
    } else {
        packet.data = &buffer[0];
    }

    /* Initiate new packet write */
    i2c_master_write_packet_job(module, &packet);
}
```

Function for setting up the callback functionality of the driver:

```
void configure_i2c_callbacks(void)
{
    /* Register callback function. */
    i2c_master_register_callback(&i2c_master_instance, i2c_write_complete_callback,
            I2C_MASTER_CALLBACK_WRITE_COMPLETE);
    i2c_master_enable_callback(&i2c_master_instance,
            I2C_MASTER_CALLBACK_WRITE_COMPLETE);
```

```
}
```

Add to user application main():

```
/* Configure device and enable. */
configure_i2c();
/* Configure callbacks and enable. */
configure_i2c_callbacks();
```

Workflow

1. Configure and enable module.

   ```
   configure_i2c();
   ```

   a. Create and initialize configuration structure.

      ```
      struct i2c_master_config config_i2c_master;
      i2c_master_get_config_defaults(&config_i2c_master);
      ```

   b. Change settings in the configuration.

      ```
      config_i2c_master.buffer_timeout = 65535;
      ```

   c. Initialize the module with the set configurations.

      ```
      while(i2c_master_init(&i2c_master_instance, SERCOM2, &config_i2c_master) != STATUS_OK);
      ```

   d. Enable the module.

      ```
      i2c_master_enable(&i2c_master_instance);
      ```

2. Configure callback functionality.

   ```
   configure_i2c_callbacks();
   ```

   a. Register write complete callback.

      ```
      i2c_master_register_callback(&i2c_master_instance, i2c_write_complete_callback,
              I2C_MASTER_CALLBACK_WRITE_COMPLETE);
      ```

   b. Enable write complete callback.

      ```
      i2c_master_enable_callback(&i2c_master_instance,
              I2C_MASTER_CALLBACK_WRITE_COMPLETE);
      ```

3. Create a packet to send to slave.

   ```
   packet.address     = SLAVE_ADDRESS;
   packet.data_length = DATA_LENGTH;
   packet.data        = buffer;
   ```

8.8.2.3 Implementation

Code

Add to user application main:

```
while (true) {
    /* Infinite loop */
}
```

Workflow

1. Write packet to slave.

```
i2c_master_write_packet_job(&i2c_master_instance, &packet);
```

2. Infinite while loop, while waiting for interaction with slave.

```
while (true) {
    /* Infinite loop */
}
```

8.8.2.4 Callback

Each time a packet is sent, the callback function will be called.

Workflow

- Write complete callback:

  1. Send every other packet in reversed order.

```
if (packet.data[0] == 0x00) {
    packet.data = &buffer_reversed[0];
} else {
    packet.data = &buffer[0];
}
```

  2. Write new packet to slave.

```
i2c_master_write_packet_job(module, &packet);
```

8.8.3 Quick Start Guide for Using DMA with SERCOM I2C Master

The supported device list:

- SAMD21

In this use case, the I^2C will used and set up as follows:

- Master mode
- 100kHz operation speed
- Not operational in standby
- 10000 packet timeout value
- 65535 unknown bus state timeout value

8.8.3.1 Prerequisites

The device must be connected to an I^2C slave.

8.8.3.2 Setup

Code

The following must be added to the user application:

- A sample buffer to send, number of entries to send and address of slave:

```
#define DATA_LENGTH 10
static uint8_t buffer[DATA_LENGTH] = {
        0x00, 0x01, 0x02, 0x03, 0x04, 0x05, 0x06, 0x07, 0x08, 0x09,
};

#define SLAVE_ADDRESS 0x12
```

  Number of times to try to send packet if it fails:

```
#define TIMEOUT 1000
```

- Globally accessible module structure:

```
struct i2c_master_module i2c_master_instance;
```

- Function for setting up the module:

```
static void configure_i2c_master(void)
{
    /* Initialize config structure and software module. */
    struct i2c_master_config config_i2c_master;
    i2c_master_get_config_defaults(&config_i2c_master);

    /* Change buffer timeout to something longer. */
    config_i2c_master.buffer_timeout = 10000;

    /* Initialize and enable device with config. */
    i2c_master_init(&i2c_master_instance, SERCOM2, &config_i2c_master);

    i2c_master_enable(&i2c_master_instance);
}
```

- Globally accessible DMA module structure:

```
struct dma_resource example_resource;
```

- Globally transfer done flag:

```
static volatile bool transfer_is_done = false;
```

- Globally accessible DMA transfer descriptor:

```
COMPILER_ALIGNED(16)
DmacDescriptor example_descriptor;
```

- Function for transfer done callback:

```
static void transfer_done( const struct dma_resource* const resource )
{
    UNUSED(resource);

    transfer_is_done = true;
}
```

- Function for setting up the DMA resource:

```
static void configure_dma_resource(struct dma_resource *resource)
{
    struct dma_resource_config config;

    dma_get_config_defaults(&config);

    config.peripheral_trigger = SERCOM2_DMAC_ID_TX;
    config.trigger_action = DMA_TRIGGER_ACTON_BEAT;

    dma_allocate(resource, &config);
}
```

- Function for setting up the DMA transfer descriptor:

```
static void setup_dma_descriptor(DmacDescriptor *descriptor)
{
    struct dma_descriptor_config descriptor_config;

    dma_descriptor_get_config_defaults(&descriptor_config);

    descriptor_config.beat_size = DMA_BEAT_SIZE_BYTE;
    descriptor_config.dst_increment_enable = false;
    descriptor_config.block_transfer_count = DATA_LENGTH;
    descriptor_config.source_address = (uint32_t)buffer + DATA_LENGTH;
    descriptor_config.destination_address = (uint32_t)(&i2c_master_instance.hw->I2CM.DATA.reg

    dma_descriptor_create(descriptor, &descriptor_config);
}
```

- Add to user application `main()`:

```
configure_i2c_master();

configure_dma_resource(&example_resource);
setup_dma_descriptor(&example_descriptor);
dma_add_descriptor(&example_resource, &example_descriptor);
dma_register_callback(&example_resource, transfer_done,
        DMA_CALLBACK_TRANSFER_DONE);
dma_enable_callback(&example_resource, DMA_CALLBACK_TRANSFER_DONE);
```

Workflow

Configure and enable SERCOM:

```
configure_i2c_master();
```

1. Create and initialize configuration structure.

```
struct i2c_master_config config_i2c_master;
i2c_master_get_config_defaults(&config_i2c_master);
```

2. Change settings in the configuration.

```
config_i2c_master.buffer_timeout = 10000;
```

3. Initialize the module with the set configurations.

```
i2c_master_init(&i2c_master_instance, SERCOM2, &config_i2c_master);
```

4. Enable the module.

```
i2c_master_enable(&i2c_master_instance);
```

Configure DMA

1. Create a DMA resource configuration structure, which can be filled out to adjust the configuration of a single DMA transfer.

```
struct dma_resource_config config;
```

2. Initialize the DMA resource configuration struct with the module's default values.

```
dma_get_config_defaults(&config);
```

Note This should always be performed before using the configuration struct to ensure that all values are initialized to known default settings.

3. Set extra configurations for the DMA resource. It is using peripheral trigger, SERCOM Tx trigger and trigger causes a transaction transfer in this example.

```
config.peripheral_trigger = SERCOM2_DMAC_ID_TX;
config.trigger_action = DMA_TRIGGER_ACTON_BEAT;
```

4. Allocate a DMA resource with the configurations.

```
dma_allocate(resource, &config);
```

5. Create a DMA transfer descriptor configuration structure, which can be filled out to adjust the configuration of a single DMA transfer.

```
struct dma_descriptor_config descriptor_config;
```

6. Initialize the DMA transfer descriptor configuration struct with the module's default values.

```
dma_descriptor_get_config_defaults(&descriptor_config);
```

Note This should always be performed before using the configuration struct to ensure that all values are initialized to known default settings.

7. Set the specific parameters for a DMA transfer with transfer size, source address, destination address.

```
descriptor_config.beat_size = DMA_BEAT_SIZE_BYTE;
descriptor_config.dst_increment_enable = false;
descriptor_config.block_transfer_count = DATA_LENGTH;
descriptor_config.source_address = (uint32_t)buffer + DATA_LENGTH;
descriptor_config.destination_address = (uint32_t)(&i2c_master_instance.hw->I2CM.DATA.reg);
```

8. Create the DMA transfer descriptor.

```
dma_descriptor_create(descriptor, &descriptor_config);
```

8.8.3.3 Implementation

Code

Add to user application `main()`:

```
dma_start_transfer_job(&example_resource);

i2c_master_dma_set_transfer(&i2c_master_instance, SLAVE_ADDRESS,
        DATA_LENGTH, I2C_TRANSFER_WRITE);

while (!transfer_is_done) {
    /* Wait for transfer done */
}

while (true) {
}
```

Workflow

1. Start the DMA transfer job.

```
dma_start_transfer_job(&example_resource);
```

2. Set the auto address length and enable flag.

```
i2c_master_dma_set_transfer(&i2c_master_instance, SLAVE_ADDRESS,
        DATA_LENGTH, I2C_TRANSFER_WRITE);
```

3. Waiting for transfer complete

```
while (!transfer_is_done) {
    /* Wait for transfer done */
}
```

4. Enter an infinite loop once transfer complete.

```
while (true) {
```

```
}
```

8.8.4 Quick Start Guide for SERCOM I2C Slave - Basic

In this use case, the I²C will used and set up as follows:

- Slave mode
- 100kHz operation speed
- Not operational in standby
- 10000 packet timeout value

8.8.4.1 Prerequisites

The device must be connected to an I²C master.

8.8.4.2 Setup

Code

The following must be added to the user application:

A sample buffer to write from, a sample buffer to read to and length of buffers:

```
#define DATA_LENGTH 10

uint8_t write_buffer[DATA_LENGTH] = {
    0x00, 0x01, 0x02, 0x03, 0x04, 0x05, 0x06, 0x07, 0x08, 0x09
};
uint8_t read_buffer[DATA_LENGTH];
```

Address to respond to:

```
#define SLAVE_ADDRESS 0x12
```

Globally accessible module structure:

```
struct i2c_slave_module i2c_slave_instance;
```

Function for setting up the module.

```
void configure_i2c_slave(void)
{
    /* Create and initialize config_i2c_slave structure */
    struct i2c_slave_config config_i2c_slave;
    i2c_slave_get_config_defaults(&config_i2c_slave);

    /* Change address and address_mode */
    config_i2c_slave.address        = SLAVE_ADDRESS;
    config_i2c_slave.address_mode   = I2C_SLAVE_ADDRESS_MODE_MASK;
    config_i2c_slave.buffer_timeout = 1000;

    /* Initialize and enable device with config_i2c_slave */
    i2c_slave_init(&i2c_slave_instance, SERCOM2, &config_i2c_slave);

    i2c_slave_enable(&i2c_slave_instance);
```

```
}
```

Add to user application main():

```
configure_i2c_slave();

enum i2c_slave_direction dir;
struct i2c_slave_packet packet = {
    .data_length = DATA_LENGTH,
    .data        = write_buffer,
};
```

Workflow

1. Configure and enable module:

   ```
   configure_i2c_slave();
   ```

   a. Create and initialize configuration structure.

      ```
      struct i2c_slave_config config_i2c_slave;
      i2c_slave_get_config_defaults(&config_i2c_slave);
      ```

   b. Change address and address mode settings in the configuration.

      ```
      config_i2c_slave.address        = SLAVE_ADDRESS;
      config_i2c_slave.address_mode   = I2C_SLAVE_ADDRESS_MODE_MASK;
      config_i2c_slave.buffer_timeout = 1000;
      ```

   c. Initialize the module with the set configurations.

      ```
      i2c_slave_init(&i2c_slave_instance, SERCOM2, &config_i2c_slave);
      ```

   d. Enable the module.

      ```
      i2c_slave_enable(&i2c_slave_instance);
      ```

2. Create variable to hold transfer direction

   ```
   enum i2c_slave_direction dir;
   ```

3. Create packet variable to transfer

   ```
   struct i2c_slave_packet packet = {
       .data_length = DATA_LENGTH,
       .data        = write_buffer,
   };
   ```

8.8.4.3 Implementation

Code

Add to user application main:

```
while (true) {
    /* Wait for direction from master */
    dir = i2c_slave_get_direction_wait(&i2c_slave_instance);

    /* Transfer packet in direction requested by master */
    if (dir == I2C_SLAVE_DIRECTION_READ) {
        packet.data = read_buffer;
        i2c_slave_read_packet_wait(&i2c_slave_instance, &packet);
    } else if (dir == I2C_SLAVE_DIRECTION_WRITE) {
        packet.data = write_buffer;
        i2c_slave_write_packet_wait(&i2c_slave_instance, &packet);
    }
}
```

Workflow

1. Wait for start condition from master and get transfer direction.

```
dir = i2c_slave_get_direction_wait(&i2c_slave_instance);
```

2. Depending on transfer direction, set up buffer to read to or write from, and write or read from master.

```
if (dir == I2C_SLAVE_DIRECTION_READ) {
    packet.data = read_buffer;
    i2c_slave_read_packet_wait(&i2c_slave_instance, &packet);
} else if (dir == I2C_SLAVE_DIRECTION_WRITE) {
    packet.data = write_buffer;
    i2c_slave_write_packet_wait(&i2c_slave_instance, &packet);
}
```

8.8.5 Quick Start Guide for SERCOM I2C Slave - Callback

In this use case, the I^2C will used and set up as follows:

- Slave mode
- 100kHz operation speed
- Not operational in standby
- 10000 packet timeout value

8.8.5.1 Prerequisites

The device must be connected to an I^2C master.

8.8.5.2 Setup

Code

The following must be added to the user application:

A sample buffer to write from, a sample buffer to read to and length of buffers:

```
#define DATA_LENGTH 10
static uint8_t write_buffer[DATA_LENGTH] = {
        0x00, 0x01, 0x02, 0x03, 0x04, 0x05, 0x06, 0x07, 0x08, 0x09,
};
```

```
static uint8_t read_buffer [DATA_LENGTH];
```

Address to respond to:

```
#define SLAVE_ADDRESS 0x12
```

Globally accessible module structure:

```
struct i2c_slave_module i2c_slave_instance;
```

Globally accessible packet:

```
static struct i2c_slave_packet packet;
```

Function for setting up the module.

```
void configure_i2c_slave(void)
{
    /* Initialize config structure and module instance. */
    struct i2c_slave_config config_i2c_slave;
    i2c_slave_get_config_defaults(&config_i2c_slave);
    /* Change address and address_mode. */
    config_i2c_slave.address      = SLAVE_ADDRESS;
    config_i2c_slave.address_mode = I2C_SLAVE_ADDRESS_MODE_MASK;
    /* Initialize and enable device with config. */
    i2c_slave_init(&i2c_slave_instance, SERCOM2, &config_i2c_slave);

    i2c_slave_enable(&i2c_slave_instance);
}
```

Callback function for read request from a master:

```
void i2c_read_request_callback(
        struct i2c_slave_module *const module)
{
    /* Init i2c packet. */
    packet.data_length = DATA_LENGTH;
    packet.data        = write_buffer;

    /* Write buffer to master */
    i2c_slave_write_packet_job(module, &packet);
}
```

Callback function for write request from a master:

```
void i2c_write_request_callback(
        struct i2c_slave_module *const module)
{
    /* Init i2c packet. */
    packet.data_length = DATA_LENGTH;
    packet.data        = read_buffer;

    /* Read buffer from master */
    if (i2c_slave_read_packet_job(module, &packet) != STATUS_OK) {
    }
}
```

Function for setting up the callback functionality of the driver:

```
void configure_i2c_slave_callbacks(void)
{
    /* Register and enable callback functions */
    i2c_slave_register_callback(&i2c_slave_instance, i2c_read_request_callback,
            I2C_SLAVE_CALLBACK_READ_REQUEST);
    i2c_slave_enable_callback(&i2c_slave_instance,
            I2C_SLAVE_CALLBACK_READ_REQUEST);

    i2c_slave_register_callback(&i2c_slave_instance, i2c_write_request_callback,
            I2C_SLAVE_CALLBACK_WRITE_REQUEST);
    i2c_slave_enable_callback(&i2c_slave_instance,
            I2C_SLAVE_CALLBACK_WRITE_REQUEST);
}
```

Add to user application main():

```
/* Configure device and enable. */
configure_i2c_slave();
configure_i2c_slave_callbacks();
```

Workflow

1. Configure and enable module:

   ```
   configure_i2c_slave();
   ```

   a. Create and initialize configuration structure.

      ```
      struct i2c_slave_config config_i2c_slave;
      i2c_slave_get_config_defaults(&config_i2c_slave);
      ```

   b. Change address and address mode settings in the configuration.

      ```
      config_i2c_slave.address      = SLAVE_ADDRESS;
      config_i2c_slave.address_mode = I2C_SLAVE_ADDRESS_MODE_MASK;
      ```

   c. Initialize the module with the set configurations.

      ```
      i2c_slave_init(&i2c_slave_instance, SERCOM2, &config_i2c_slave);
      ```

   d. Enable the module.

      ```
      i2c_slave_enable(&i2c_slave_instance);
      ```

2. Register and enable callback functions.

   ```
   configure_i2c_slave_callbacks();
   ```

   a. Register and enable callbacks for read and write requests from master.

      ```
      i2c_slave_register_callback(&i2c_slave_instance, i2c_read_request_callback,
      ```

```
        I2C_SLAVE_CALLBACK_READ_REQUEST);
i2c_slave_enable_callback(&i2c_slave_instance,
        I2C_SLAVE_CALLBACK_READ_REQUEST);

i2c_slave_register_callback(&i2c_slave_instance, i2c_write_request_callback,
        I2C_SLAVE_CALLBACK_WRITE_REQUEST);
i2c_slave_enable_callback(&i2c_slave_instance,
        I2C_SLAVE_CALLBACK_WRITE_REQUEST);
```

8.8.5.3 Implementation

Code

Add to user application main:

```
while (true) {
    /* Infinite loop while waiting for I2C master interaction */
}
```

Workflow

1. Infinite while loop, while waiting for interaction from master.

```
while (true) {
    /* Infinite loop while waiting for I2C master interaction */
}
```

8.8.5.4 Callback

When an address packet is received, one of the callback functions will be called, depending on the DIR bit in the received packet.

Workflow

- Read request callback:
  1. Length of buffer and buffer to be sent to master is initialized.

```
packet.data_length = DATA_LENGTH;
packet.data        = write_buffer;
```

  2. Write packet to master.

```
i2c_slave_write_packet_job(module, &packet);
```

- Write request callback:
  1. Length of buffer and buffer to be read from master is initialized.

```
packet.data_length = DATA_LENGTH;
packet.data        = read_buffer;
```

  2. Read packet from master.

```
if (i2c_slave_read_packet_job(module, &packet) != STATUS_OK) {
}
```

8.8.6 Quick Start Guide for Using DMA with SERCOM I2C Slave

The supported device list:

- SAMD21

In this use case, the I^2C will used and set up as follows:

- Slave mode
- 100kHz operation speed
- Not operational in standby
- 65535 unknown bus state timeout value

8.8.6.1 Prerequisites

The device must be connected to an I^2C slave.

8.8.6.2 Setup

Code

The following must be added to the user application:

- Address to respond to:

```
#define SLAVE_ADDRESS 0x12
```

- A sample buffer to send, number of entries to send and address of slave:

```
#define DATA_LENGTH 10
uint8_t read_buffer[DATA_LENGTH];
```

- Globally accessible module structure:

```
struct i2c_slave_module i2c_slave_instance;
```

- Function for setting up the module:

```
void configure_i2c_slave(void)
{
    /* Create and initialize config_i2c_slave structure */
    struct i2c_slave_config config_i2c_slave;
    i2c_slave_get_config_defaults(&config_i2c_slave);

    /* Change address and address_mode */
    config_i2c_slave.address        = SLAVE_ADDRESS;
    config_i2c_slave.address_mode   = I2C_SLAVE_ADDRESS_MODE_MASK;
    config_i2c_slave.buffer_timeout = 1000;

    /* Initialize and enable device with config_i2c_slave */
    i2c_slave_init(&i2c_slave_instance, SERCOM2, &config_i2c_slave);

    i2c_slave_enable(&i2c_slave_instance);
}
```

- Globally accessible DMA module structure:

```
struct dma_resource i2c_dma_resource;
```

- Globally accessible DMA transfer descriptor:

```
COMPILER_ALIGNED(16)
DmacDescriptor i2c_dma_descriptor;
```

- Function for setting up the DMA resource:

```
void configure_dma_resource(struct dma_resource *resource)
{
    struct dma_resource_config config;

    dma_get_config_defaults(&config);

    config.peripheral_trigger = SERCOM2_DMAC_ID_RX;
    config.trigger_action = DMA_TRIGGER_ACTON_BEAT;

    dma_allocate(resource, &config);
}
```

- Function for setting up the DMA transfer descriptor:

```
void setup_dma_descriptor(DmacDescriptor *descriptor)
{
    struct dma_descriptor_config descriptor_config;

    dma_descriptor_get_config_defaults(&descriptor_config);

    descriptor_config.beat_size = DMA_BEAT_SIZE_BYTE;
    descriptor_config.src_increment_enable = false;
    descriptor_config.block_transfer_count = DATA_LENGTH;
    descriptor_config.destination_address = (uint32_t)read_buffer + DATA_LENGTH;
    descriptor_config.source_address = (uint32_t)(&i2c_slave_instance.hw->I2CS.DATA.reg);

    dma_descriptor_create(descriptor, &descriptor_config);
}
```

- Add to user application `main()`:

```
configure_i2c_slave();

configure_dma_resource(&i2c_dma_resource);
setup_dma_descriptor(&i2c_dma_descriptor);
dma_add_descriptor(&i2c_dma_resource, &i2c_dma_descriptor);
```

Workflow

Configure and enable SERCOM:

```
void configure_i2c_slave(void)
{
    /* Create and initialize config_i2c_slave structure */
    struct i2c_slave_config config_i2c_slave;
    i2c_slave_get_config_defaults(&config_i2c_slave);
```

```
    /* Change address and address_mode */
    config_i2c_slave.address        = SLAVE_ADDRESS;
    config_i2c_slave.address_mode   = I2C_SLAVE_ADDRESS_MODE_MASK;
    config_i2c_slave.buffer_timeout = 1000;

    /* Initialize and enable device with config_i2c_slave */
    i2c_slave_init(&i2c_slave_instance, SERCOM2, &config_i2c_slave);

    i2c_slave_enable(&i2c_slave_instance);
}
```

1. Create and initialize configuration structure.

```
struct i2c_slave_config config_i2c_slave;
i2c_slave_get_config_defaults(&config_i2c_slave);
```

2. Change settings in the configuration.

```
config_i2c_slave.address        = SLAVE_ADDRESS;
config_i2c_slave.address_mode   = I2C_SLAVE_ADDRESS_MODE_MASK;
config_i2c_slave.buffer_timeout = 1000;
```

3. Initialize the module with the set configurations.

```
i2c_slave_init(&i2c_slave_instance, SERCOM2, &config_i2c_slave);
```

4. Enable the module.

```
i2c_slave_enable(&i2c_slave_instance);
```

Configure DMA

1. Create a DMA resource configuration structure, which can be filled out to adjust the configuration of a single DMA transfer.

```
struct dma_resource_config config;
```

2. Initialize the DMA resource configuration struct with the module's default values.

```
dma_get_config_defaults(&config);
```

Note This should always be performed before using the configuration struct to ensure that all values are initialized to known default settings.

3. Set extra configurations for the DMA resource. It is using peripheral trigger, SERCOM RX trigger and trigger causes a beat transfer in this example.

```
config.peripheral_trigger = SERCOM2_DMAC_ID_RX;
config.trigger_action = DMA_TRIGGER_ACTON_BEAT;
```

4. Allocate a DMA resource with the configurations.

```
dma_allocate(resource, &config);
```

5. Create a DMA transfer descriptor configuration structure, which can be filled out to adjust the configuration of a single DMA transfer.

```
struct dma_descriptor_config descriptor_config;
```

6. Initialize the DMA transfer descriptor configuration struct with the module's default values.

```
dma_descriptor_get_config_defaults(&descriptor_config);
```

Note This should always be performed before using the configuration struct to ensure that all values are initialized to known default settings.

7. Set the specific parameters for a DMA transfer with transfer size, source address, destination address.

```
descriptor_config.beat_size = DMA_BEAT_SIZE_BYTE;
descriptor_config.src_increment_enable = false;
descriptor_config.block_transfer_count = DATA_LENGTH;
descriptor_config.destination_address = (uint32_t)read_buffer + DATA_LENGTH;
descriptor_config.source_address = (uint32_t)(&i2c_slave_instance.hw->I2CS.DATA.reg);
```

8. Create the DMA transfer descriptor.

```
dma_descriptor_create(descriptor, &descriptor_config);
```

8.8.6.3 Implementation

Code

Add to user application `main()`:

```
dma_start_transfer_job(&i2c_dma_resource);

while (true) {
    if (i2c_slave_dma_read_interrupt_status(&i2c_slave_instance) &
                SERCOM_I2CS_INTFLAG_AMATCH) {
        i2c_slave_dma_write_interrupt_status(&i2c_slave_instance,
                SERCOM_I2CS_INTFLAG_AMATCH);
    }
}
```

Workflow

1. Start to wait a packet from master.

```
dma_start_transfer_job(&i2c_dma_resource);
```

2. Once data ready, clear the address match status.

```
while (true) {
    if (i2c_slave_dma_read_interrupt_status(&i2c_slave_instance) &
```

```
                SERCOM_I2CS_INTFLAG_AMATCH) {
        i2c_slave_dma_write_interrupt_status(&i2c_slave_instance,
                SERCOM_I2CS_INTFLAG_AMATCH);
    }
}
```

9. SAM D20/D21 Non-Volatile Memory Driver (NVM)

This driver for SAM D20/D21 devices provides an interface for the configuration and management of non-volatile memories within the device, for partitioning, erasing, reading and writing of data.

The following peripherals are used by this module:

- NVM (Non-Volatile Memory)

The outline of this documentation is as follows:

9.1 Prerequisites

There are no prerequisites for this module.

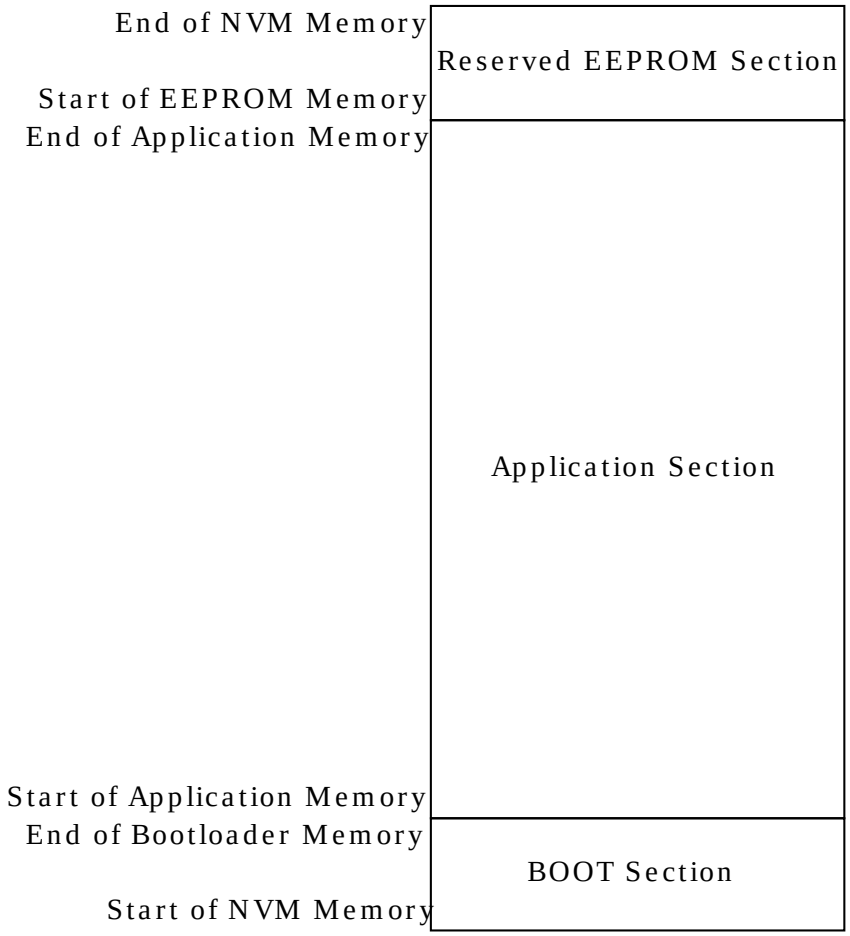
9.2 Module Overview

The Non-Volatile Memory (NVM) module provides an interface to the device's Non-Volatile Memory controller, so that memory pages can be written, read, erased and reconfigured in a standardized manner.

9.2.1 Memory Regions

The NVM memory space of the SAM D20/D21 devices is divided into two sections: a Main Array section, and an Auxiliary space section. The Main Array space can be configured to have an (emulated) EEPROM and/or boot loader section. The memory layout with the EEPROM and bootloader partitions is shown in Figure 9-1: Memory Regions on page 228.

Figure 9-1. Memory Regions



The Main Array is divided into rows and pages, where each row contains four pages. The size of each page may vary from 8-1024 bytes dependent of the device. Device specific parameters such as the page size and total number of pages in the NVM memory space are available via the nvm_get_parameters() function.

A NVM page number and address can be computed via the following equations:

$$PageNum = (RowNum \times 4) + PagePosInRow \tag{9.1}$$

$$PageAddr = PageNum \times PageSize \tag{9.2}$$

Figure 9-2: Memory Regions on page 228 shows an example of the memory page and address values associated with logical row 7 of the NVM memory space.

Figure 9-2. Memory Regions

Row 0x07	Page 0x1F	Page 0x1E	Page 0x1D	Page 0x1C
Address	0x7C0	0x780	0x740	0x700

9.2.2 Region Lock Bits

As mentioned in Memory Regions, the main block of the NVM memory is divided into a number of individually addressable pages. These pages are grouped into 16 equal sized regions, where each region can be locked separately issuing an NVM_COMMAND_LOCK_REGION on page 239 command or by writing the LOCK bits in the User Row. Rows reserved for the EEPROM section are not affected by the lock bits or commands.

Note

By using the NVM_COMMAND_LOCK_REGION on page 239 or NVM_COMMAND_UNLOCK_REGION on page 239 commands the settings will remain in effect until the next device reset. By changing the default lock setting for the regions, the auxiliary space must to be written, however the adjusted configuration will not take effect until the next device reset.

If the Security Bit is set, the auxiliary space cannot be written to. Clearing of the security bit can only be performed by a full chip erase.

9.2.3 Read/Write

Reading from the NVM memory can be performed using direct addressing into the NVM memory space, or by calling the nvm_read_buffer() function.

Writing to the NVM memory must be performed by the nvm_write_buffer() function - additionally, a manual page program command must be issued if the NVM controller is configured in manual page writing mode, or a buffer of data less than a full page is passed to the buffer write function.

Before a page can be updated, the associated NVM memory row must be erased first via the nvm_erase_row() function. Writing to a non-erased page will result in corrupt data being stored in the NVM memory space.

9.3 Special Considerations

9.3.1 Page Erasure

The granularity of an erase is per row, while the granularity of a write is per page. Thus, if the user application is modifying only one page of a row, the remaining pages in the row must be buffered and the row erased, as an erase is mandatory before writing to a page.

9.3.2 Clocks

The user must ensure that the driver is configured with a proper number of wait states when the CPU is running at high frequencies.

9.3.3 Security Bit

The User Row in the Auxiliary Space Cannot be read or written when the Security Bit is set. The Security Bit can be set by using passing NVM_COMMAND_SET_SECURITY_BIT on page 239 to the nvm_execute_command() function, or it will be set if one tries to access a locked region. See Region Lock Bits.

The Security Bit can only be cleared by performing a chip erase.

9.4 Extra Information

For extra information see Extra Information for NVM Driver. This includes:

- Acronyms
- Dependencies
- Errata
- Module History

9.5 Examples

For a list of examples related to this driver, see Examples for NVM Driver.

9.6 API Overview

9.6.1 Structure Definitions

9.6.1.1 Struct nvm_config

Configuration structure for the NVM controller within the device.

Table 9-1. Members

Type	Name	Description
enum nvm_cache_readmode	cache_readmode	Select the mode for how the cache will pre-fetch data from the flash.
bool	disable_cache	Setting this to true will disable the pre-fetch cache in front of the nvm controller.
bool	manual_page_write	Manual write mode; if enabled, pages loaded into the NVM buffer will not be written until a separate write command is issued. If disabled, writing to the last byte in the NVM page buffer will trigger an automatic write.[1]
enum nvm_sleep_power_mode	sleep_power_mode	Power reduction mode during device sleep.
uint8_t	wait_states	Number of wait states to insert when reading from flash, to prevent invalid data from being read at high clock frequencies.

Notes: [1]If a partial page is to be written, a manual write command must be executed in either mode.

9.6.1.2 Struct nvm_fusebits

This structure contain the layout of the first 64 bits of the user row which contain the fuse settings.

Table 9-2. Members

Type	Name	Description
enum nvm_bod33_action	bod33_action	BOD33 Action at power on
bool	bod33_enable	BOD33 Enable at power on
uint8_t	bod33_level	BOD33 Threshold level at power on
enum nvm_bootloader_size	bootloader_size	Bootloader size.
enum nvm_eeprom_emulator_size	eeprom_size	EEPROM emulation area size
uint16_t	lockbits	NVM Lock bits
bool	wdt_always_on	WDT Always-on at power on
enum nvm_wdt_early_warning_offset	wdt_early_warning_offset	WDT Early warning interrupt time offset at power on
bool	wdt_enable	WDT Enable at power on
uint8_t	wdt_timeout_period	WDT Period at power on
bool	wdt_window_mode_enable_at_powe	WDT Window mode enabled at power on
enum nvm_wdt_window_timeout	wdt_window_timeout	WDT Window mode time-out at power on

9.6.1.3 Struct nvm_parameters

Structure containing the memory layout parameters of the NVM module.

Table 9-3. Members

Type	Name	Description
uint32_t	bootloader_number_of_pages	Size of the Bootloader memory section configured in the NVM auxiliary memory space.
uint32_t	eeprom_number_of_pages	Size of the emulated EEPROM memory section configured in the NVM auxiliary memory space.
uint16_t	nvm_number_of_pages	Number of pages in the main array.
uint8_t	page_size	Number of bytes per page.

9.6.2 Function Definitions

9.6.2.1 Configuration and Initialization

Function nvm_get_config_defaults()

Initializes an NVM controller configuration structure to defaults.

```
void nvm_get_config_defaults(
  struct nvm_config *const config)
```

Initializes a given NVM controller configuration structure to a set of known default values. This function should be called on all new instances of these configuration structures before being modified by the user application.

The default configuration is as follows:

- Power reduction mode enabled after sleep until first NVM access
- Automatic page commit when full pages are written to
- Number of FLASH wait states left unchanged

Table 9-4. Parameters

Data direction	Parameter name	Description
[out]	config	Configuration structure to initialize to default values

Function nvm_set_config()

Sets the up the NVM hardware module based on the configuration.

```
enum status_code nvm_set_config(
  const struct nvm_config *const config)
```

Writes a given configuration of a NVM controller configuration to the hardware module, and initializes the internal device struct

Table 9-5. Parameters

Data direction	Parameter name	Description
[in]	config	Configuration settings for the NVM controller

Note The security bit must be cleared in order successfully use this function. This can only be done by a chip erase.

Returns Status of the configuration procedure.

Table 9-6. Return Values

Return value	Description
STATUS_OK	If the initialization was a success
STATUS_BUSY	If the module was busy when the operation was attempted
STATUS_ERR_IO	If the security bit has been set, preventing the EEPROM and/or auxiliary space configuration from being altered

Function nvm_is_ready()

Checks if the NVM controller is ready to accept a new command.

```
bool nvm_is_ready(void)
```

Checks the NVM controller to determine if it is currently busy execution an operation, or ready for a new command.

Returns Busy state of the NVM controller.

Table 9-7. Return Values

Return value	Description
true	If the hardware module is ready for a new command
false	If the hardware module is busy executing a command

9.6.2.2 NVM Access Management

Function nvm_get_parameters()

Reads the parameters of the NVM controller.

```
void nvm_get_parameters(
  struct nvm_parameters *const parameters)
```

Retrieves the page size, number of pages and other configuration settings of the NVM region.

Table 9-8. Parameters

Data direction	Parameter name	Description
[out]	parameters	Parameter structure, which holds page size and number of pages in the NVM memory

Function nvm_write_buffer()

Writes a number of bytes to a page in the NVM memory region.

```
enum status_code nvm_write_buffer(
  const uint32_t destination_address,
  const uint8_t * buffer,
  uint16_t length)
```

Writes from a buffer to a given page address in the NVM memory.

Table 9-9. Parameters

Data direction	Parameter name	Description
[in]	destination_address	Destination page address to write to
[in]	buffer	Pointer to buffer where the data to write is stored
[in]	length	Number of bytes in the page to write

Note If writing to a page that has previously been written to, the page's row should be erased (via nvm_erase_row()) before attempting to write new data to the page.

Returns Status of the attempt to write a page.

Table 9-10. Return Values

Return value	Description
STATUS_OK	Requested NVM memory page was successfully read
STATUS_BUSY	NVM controller was busy when the operation was attempted
STATUS_ERR_BAD_ADDRESS	The requested address was outside the acceptable range of the NVM memory region or not aligned to the start of a page
STATUS_ERR_INVALID_ARG	The supplied write length was invalid

Function nvm_read_buffer()

Reads a number of bytes from a page in the NVM memory region.

```
enum status_code nvm_read_buffer(
  const uint32_t source_address,
  uint8_t *const buffer,
  uint16_t length)
```

Reads a given number of bytes from a given page address in the NVM memory space into a buffer.

Table 9-11. Parameters

Data direction	Parameter name	Description
[in]	source_address	Source page address to read from
[out]	buffer	Pointer to a buffer where the content of the read page will be stored
[in]	length	Number of bytes in the page to read

Returns

Status of the page read attempt.

Table 9-12. Return Values

Return value	Description
STATUS_OK	Requested NVM memory page was successfully read
STATUS_BUSY	NVM controller was busy when the operation was attempted
STATUS_ERR_BAD_ADDRESS	The requested address was outside the acceptable range of the NVM memory region or not aligned to the start of a page
STATUS_ERR_INVALID_ARG	The supplied read length was invalid

Function nvm_update_buffer()

Updates an arbitrary section of a page with new data.

```
enum status_code nvm_update_buffer(
  const uint32_t destination_address,
  uint8_t *const buffer,
  uint16_t offset,
  uint16_t length)
```

Writes from a buffer to a given page in the NVM memory, retaining any unmodified data already stored in the page.

Warning

This routine is unsafe if data integrity is critical; a system reset during the update process will result in up to one row of data being lost. If corruption must be avoided in all circumstances (including power loss or system reset) this function should not be used.

Table 9-13. Parameters

Data direction	Parameter name	Description
[in]	destination_address	Destination page address to write to
[in]	buffer	Pointer to buffer where the data to write is stored
[in]	offset	Number of bytes to offset the data write in the page
[in]	length	Number of bytes in the page to update

Returns Status of the attempt to update a page.

Table 9-14. Return Values

Return value	Description
STATUS_OK	Requested NVM memory page was successfully read
STATUS_BUSY	NVM controller was busy when the operation was attempted
STATUS_ERR_BAD_ADDRESS	The requested address was outside the acceptable range of the NVM memory region
STATUS_ERR_INVALID_ARG	The supplied length and offset was invalid

Function nvm_erase_row()

Erases a row in the NVM memory space.

```
enum status_code nvm_erase_row(
  const uint32_t row_address)
```

Erases a given row in the NVM memory region.

Table 9-15. Parameters

Data direction	Parameter name	Description
[in]	row_address	Address of the row to erase

Returns Status of the NVM row erase attempt.

Table 9-16. Return Values

Return value	Description
STATUS_OK	Requested NVM memory row was successfully erased
STATUS_BUSY	NVM controller was busy when the operation was attempted
STATUS_ERR_BAD_ADDRESS	The requested row address was outside the acceptable range of the NVM memory region or not aligned to the start of a row

Function nvm_execute_command()

Executes a command on the NVM controller.

```
enum status_code nvm_execute_command(
  const enum nvm_command command,
  const uint32_t address,
  const uint32_t parameter)
```

Executes an asynchronous command on the NVM controller, to perform a requested action such as a NVM page read or write operation.

Note The function will return before the execution of the given command is completed.

Table 9-17. Parameters

Data direction	Parameter name	Description
[in]	command	Command to issue to the NVM controller
[in]	address	Address to pass to the NVM controller in NVM memory space
[in]	parameter	Parameter to pass to the NVM controller, not used for this driver

Returns Status of the attempt to execute a command.

Table 9-18. Return Values

Return value	Description
STATUS_OK	If the command was accepted and execution is now in progress
STATUS_BUSY	If the NVM controller was already busy executing a command when the new command was issued
STATUS_ERR_IO	If the command was invalid due to memory or security locking
STATUS_ERR_INVALID_ARG	If the given command was invalid or unsupported
STATUS_ERR_BAD_ADDRESS	If the given address was invalid

Function nvm_get_fuses()

Get fuses from user row.

```
enum status_code nvm_get_fuses(
  struct nvm_fusebits * fusebits)
```

Read out the fuse settings from the user row

Table 9-19. Parameters

Data direction	Parameter name	Description
[in]	fusebits	Pointer to a 64bit wide memory buffer of type struct nvm_fusebits

Returns Status of read fuses attempt

Table 9-20. Return Values

Return value	Description
STATUS_OK	This function will always return STATUS_OK

Function nvm_is_page_locked()

Checks whether the page region is locked.

```
bool nvm_is_page_locked(
  uint16_t page_number)
```

Extracts the region to which the given page belongs and checks whether that region is locked.

Table 9-21. Parameters

Data direction	Parameter name	Description
[in]	page_number	Page number to be checked

Returns

Page lock status

Table 9-22. Return Values

Return value	Description
true	Page is locked
false	Page is not locked

Function nvm_get_error()

Retrieves the error code of the last issued NVM operation.

```
enum nvm_error nvm_get_error(void)
```

Retrieves the error code from the last executed NVM operation. Once retrieved, any error state flags in the controller are cleared.

Note

The nvm_is_ready() function is an exception. Thus, errors retrieved after running this function should be valid for the function executed before nvm_is_ready().

Returns

Error caused by the last NVM operation.

Table 9-23. Return Values

Return value	Description
NVM_ERROR_NONE	No error occurred in the last NVM operation
NVM_ERROR_LOCK	The last NVM operation attempted to access a locked region
NVM_ERROR_PROG	An invalid NVM command was issued

9.6.3 Enumeration Definitions

9.6.3.1 Enum nvm_bod33_action

What action should be triggered when BOD33 is detected.

Table 9-24. Members

Enum value	Description
NVM_BOD33_ACTION_NONE	
NVM_BOD33_ACTION_RESET	
NVM_BOD33_ACTION_INTERRUPT	

9.6.3.2 Enum nvm_bootloader_size

Available bootloader protection sizes in kilobytes.

Table 9-25. Members

Enum value	Description
NVM_BOOTLOADER_SIZE_128	
NVM_BOOTLOADER_SIZE_64	
NVM_BOOTLOADER_SIZE_32	
NVM_BOOTLOADER_SIZE_16	
NVM_BOOTLOADER_SIZE_8	
NVM_BOOTLOADER_SIZE_4	
NVM_BOOTLOADER_SIZE_2	
NVM_BOOTLOADER_SIZE_0	

9.6.3.3 Enum nvm_cache_readmode

Control how the NVM cache prefetch data from flash

Table 9-26. Members

Enum value	Description
NVM_CACHE_READMODE_NO_MISS_PENALTY	The NVM Controller (cache system) does not insert wait states on a cache miss. Gives the best system performance.
NVM_CACHE_READMODE_LOW_POWER	Reduces power consumption of the cache system, but inserts a wait state each time there is a cache miss
NVM_CACHE_READMODE_DETERMINISTIC	The cache system ensures that a cache hit or miss takes the same amount of time, determined by the number of programmed flash wait states.

9.6.3.4 Enum nvm_command

Table 9-27. Members

Enum value	Description
NVM_COMMAND_ERASE_ROW	Erases the addressed memory row.
NVM_COMMAND_WRITE_PAGE	Write the contents of the page buffer to the addressed memory page.

Enum value	Description
NVM_COMMAND_ERASE_AUX_ROW	Erases the addressed auxiliary memory row. **Note** This command can only be given when the security bit is not set.
NVM_COMMAND_WRITE_AUX_ROW	Write the contents of the page buffer to the addressed auxiliary memory row. **Note** This command can only be given when the security bit is not set.
NVM_COMMAND_LOCK_REGION	Locks the addressed memory region, preventing further modifications until the region is unlocked or the device is erased.
NVM_COMMAND_UNLOCK_REGION	Unlocks the addressed memory region, allowing the region contents to be modified.
NVM_COMMAND_PAGE_BUFFER_CLEAR	Clears the page buffer of the NVM controller, resetting the contents to all zero values.
NVM_COMMAND_SET_SECURITY_BIT	Sets the device security bit, disallowing the changing of lock bits and auxiliary row data until a chip erase has been performed.
NVM_COMMAND_ENTER_LOW_POWER_MODE	Enter power reduction mode in the NVM controller to reduce the power consumption of the system. When in low power mode, all commands other than NVM_COMMAND_EXIT_LOW_POWER_MODE on page 23 will fail.
NVM_COMMAND_EXIT_LOW_POWER_MODE	Exit power reduction mode in the NVM controller to allow other NVM commands to be issued.

9.6.3.5 Enum nvm_eeprom_emulator_size

Available space in flash dedicated for EEPROM emulator in bytes.

Table 9-28. Members

Enum value	Description
NVM_EEPROM_EMULATOR_SIZE_16384	
NVM_EEPROM_EMULATOR_SIZE_8192	
NVM_EEPROM_EMULATOR_SIZE_4096	
NVM_EEPROM_EMULATOR_SIZE_2048	
NVM_EEPROM_EMULATOR_SIZE_1024	
NVM_EEPROM_EMULATOR_SIZE_512	
NVM_EEPROM_EMULATOR_SIZE_256	
NVM_EEPROM_EMULATOR_SIZE_0	

9.6.3.6 Enum nvm_error

Possible NVM controller error codes, which can be returned by the NVM controller after a command is issued.

Table 9-29. Members

Enum value	Description
NVM_ERROR_NONE	No errors
NVM_ERROR_LOCK	Lock error, a locked region was attempted accessed.
NVM_ERROR_PROG	Program error, invalid command was executed.

9.6.3.7 Enum nvm_sleep_power_mode

Power reduction modes of the NVM controller, to conserve power while the device is in sleep.

Table 9-30. Members

Enum value	Description
NVM_SLEEP_POWER_MODE_WAKEONACCESS	NVM controller exits low power mode on first access after sleep.
NVM_SLEEP_POWER_MODE_WAKEUPINSTANT	NVM controller exits low power mode when the device exits sleep mode.
NVM_SLEEP_POWER_MODE_ALWAYS_AWAKE	Power reduction mode in the NVM controller disabled.

9.6.3.8 Enum nvm_wdt_early_warning_offset

This setting determine how many GCLK_WDT cycles before a watchdog time-out period an early warning interrupt should be triggered.

Table 9-31. Members

Enum value	Description
NVM_WDT_EARLY_WARNING_OFFSET_8	
NVM_WDT_EARLY_WARNING_OFFSET_16	
NVM_WDT_EARLY_WARNING_OFFSET_32	
NVM_WDT_EARLY_WARNING_OFFSET_64	
NVM_WDT_EARLY_WARNING_OFFSET_128	
NVM_WDT_EARLY_WARNING_OFFSET_256	
NVM_WDT_EARLY_WARNING_OFFSET_512	
NVM_WDT_EARLY_WARNING_OFFSET_1024	
NVM_WDT_EARLY_WARNING_OFFSET_2048	
NVM_WDT_EARLY_WARNING_OFFSET_4096	
NVM_WDT_EARLY_WARNING_OFFSET_8192	
NVM_WDT_EARLY_WARNING_OFFSET_16384	

9.6.3.9 Enum nvm_wdt_window_timeout

Windows mode time-out period in clock cycles.

Table 9-32. Members

Enum value	Description
NVM_WDT_WINDOW_TIMEOUT_PERIOD_8	
NVM_WDT_WINDOW_TIMEOUT_PERIOD_16	
NVM_WDT_WINDOW_TIMEOUT_PERIOD_32	
NVM_WDT_WINDOW_TIMEOUT_PERIOD_64	
NVM_WDT_WINDOW_TIMEOUT_PERIOD_128	
NVM_WDT_WINDOW_TIMEOUT_PERIOD_256	
NVM_WDT_WINDOW_TIMEOUT_PERIOD_512	
NVM_WDT_WINDOW_TIMEOUT_PERIOD_1024	
NVM_WDT_WINDOW_TIMEOUT_PERIOD_2048	
NVM_WDT_WINDOW_TIMEOUT_PERIOD_4096	
NVM_WDT_WINDOW_TIMEOUT_PERIOD_8192	
NVM_WDT_WINDOW_TIMEOUT_PERIOD_16384	

9.7 Extra Information for NVM Driver

9.7.1 Acronyms

The table below presents the acronyms used in this module:

Acronym	Description
NVM	Non-Volatile Memory
EEPROM	Electrically Erasable Programmable Read-Only Memory

9.7.2 Dependencies

This driver has the following dependencies:

- None

9.7.3 Errata

There are no errata related to this driver.

9.7.4 Module History

An overview of the module history is presented in the table below, with details on the enhancements and fixes made to the module since its first release. The current version of this corresponds to the newest version in the table.

Changelog
Added support for SAMD21, removed BOD12 reference, removed nvm_set_fuses() API.
Added functions to read/write fuse settings
Added support for nvm cache configuration
Updated initialization function to also enable the digital interface clock to the module if it is disabled.
Initial Release

9.8 Examples for NVM Driver

This is a list of the available Quick Start guides (QSGs) and example applications for SAM D20/D21 Non-Volatile Memory Driver (NVM). QSGs are simple examples with step-by-step instructions to configure and use this driver in a selection of use cases. Note that QSGs can be compiled as a standalone application or be added to the user application.

- Quick Start Guide for NVM - Basic

9.8.1 Quick Start Guide for NVM - Basic

In this use case, the NVM module is configured for:

- Power reduction mode enabled after sleep until first NVM access
- Automatic page write commands issued to commit data as pages are written to the internal buffer
- Zero wait states when reading FLASH memory
- No memory space for the EEPROM
- No protected bootloader section

This use case sets up the NVM controller to write a page of data to flash, and the read it back into the same buffer.

9.8.1.1 Setup

Prerequisites

There are no special setup requirements for this use-case.

Code

Copy-paste the following setup code to your user application:

```
void configure_nvm(void)
{
    struct nvm_config config_nvm;

    nvm_get_config_defaults(&config_nvm);

    nvm_set_config(&config_nvm);
}
```

Add to user application initialization (typically the start of `main()`):

```
configure_nvm();
```

Workflow

1. Create an NVM module configuration struct, which can be filled out to adjust the configuration of the NVM controller.

   ```
   struct nvm_config config_nvm;
   ```

2. Initialize the NVM configuration struct with the module's default values.

   ```
   nvm_get_config_defaults(&config_nvm);
   ```

Note This should always be performed before using the configuration struct to ensure that all values are initialized to known default settings.

3. Configure NVM controller with the created configuration struct settings.

```
nvm_set_config(&config_nvm);
```

9.8.1.2 Use Case

Code

Copy-paste the following code to your user application:

```
uint8_t page_buffer[NVMCTRL_PAGE_SIZE];

for (uint32_t i = 0; i < NVMCTRL_PAGE_SIZE; i++) {
    page_buffer[i] = i;
}

enum status_code error_code;

do
{
    error_code = nvm_erase_row(
            100 * NVMCTRL_ROW_PAGES * NVMCTRL_PAGE_SIZE);
} while (error_code == STATUS_BUSY);

do
{
    error_code = nvm_write_buffer(
            100 * NVMCTRL_ROW_PAGES * NVMCTRL_PAGE_SIZE,
            page_buffer, NVMCTRL_PAGE_SIZE);
} while (error_code == STATUS_BUSY);

do
{
    error_code = nvm_read_buffer(
            100 * NVMCTRL_ROW_PAGES * NVMCTRL_PAGE_SIZE,
            page_buffer, NVMCTRL_PAGE_SIZE);
} while (error_code == STATUS_BUSY);
```

Workflow

1. Set up a buffer one NVM page in size to hold data to read or write into NVM memory.

```
uint8_t page_buffer[NVMCTRL_PAGE_SIZE];
```

2. Fill the buffer with a pattern of data.

```
for (uint32_t i = 0; i < NVMCTRL_PAGE_SIZE; i++) {
    page_buffer[i] = i;
}
```

3. Create a variable to hold the error status from the called NVM functions.

```
enum status_code error_code;
```

4. Erase a page of NVM data. As the NVM could be busy initializing or completing a previous operation, a loop is used to retry the command while the NVM controller is busy.

```
do
{
    error_code = nvm_erase_row(
            100 * NVMCTRL_ROW_PAGES * NVMCTRL_PAGE_SIZE);
} while (error_code == STATUS_BUSY);
```

Note This must be performed before writing new data into a NVM page.

5. Write the buffer of data to the previously erased page of the NVM.

```
do
{
    error_code = nvm_write_buffer(
            100 * NVMCTRL_ROW_PAGES * NVMCTRL_PAGE_SIZE,
            page_buffer, NVMCTRL_PAGE_SIZE);
} while (error_code == STATUS_BUSY);
```

Note The new data will be written to NVM memory automatically, as the NVM controller is configured in automatic page write mode.

6. Read back the written page of page from the NVM into the buffer.

```
do
{
    error_code = nvm_read_buffer(
            100 * NVMCTRL_ROW_PAGES * NVMCTRL_PAGE_SIZE,
            page_buffer, NVMCTRL_PAGE_SIZE);
} while (error_code == STATUS_BUSY);
```

10. SAM D20/D21 Peripheral Access Controller Driver (PAC)

This driver for SAM D20/D21 devices provides an interface for the locking and unlocking of peripheral registers within the device. When a peripheral is locked, accidental writes to the peripheral will be blocked and a CPU exception will be raised.

The following peripherals are used by this module:

- PAC (Peripheral Access Controller)

The outline of this documentation is as follows:

- Prerequisites
- Module Overview
- Special Considerations
- Extra Information
- Examples
- API Overview

10.1 Prerequisites

There are no prerequisites for this module.

10.2 Module Overview

The SAM D20/D21 devices are fitted with a Peripheral Access Controller (PAC) that can be used to lock and unlock write access to a peripheral's registers (see Non-Writable Registers). Locking a peripheral minimizes the risk of unintended configuration changes to a peripheral as a consequence of Run-away Code or use of a Faulty Module Pointer.

Physically, the PAC restricts write access through the AHB bus to registers used by the peripheral, making the register non-writable. PAC locking of modules should be implemented in configuration critical applications where avoiding unintended peripheral configuration changes are to be regarded in the highest of priorities.

All interrupt must be disabled while a peripheral is unlocked to make sure correct lock/unlock scheme is upheld.

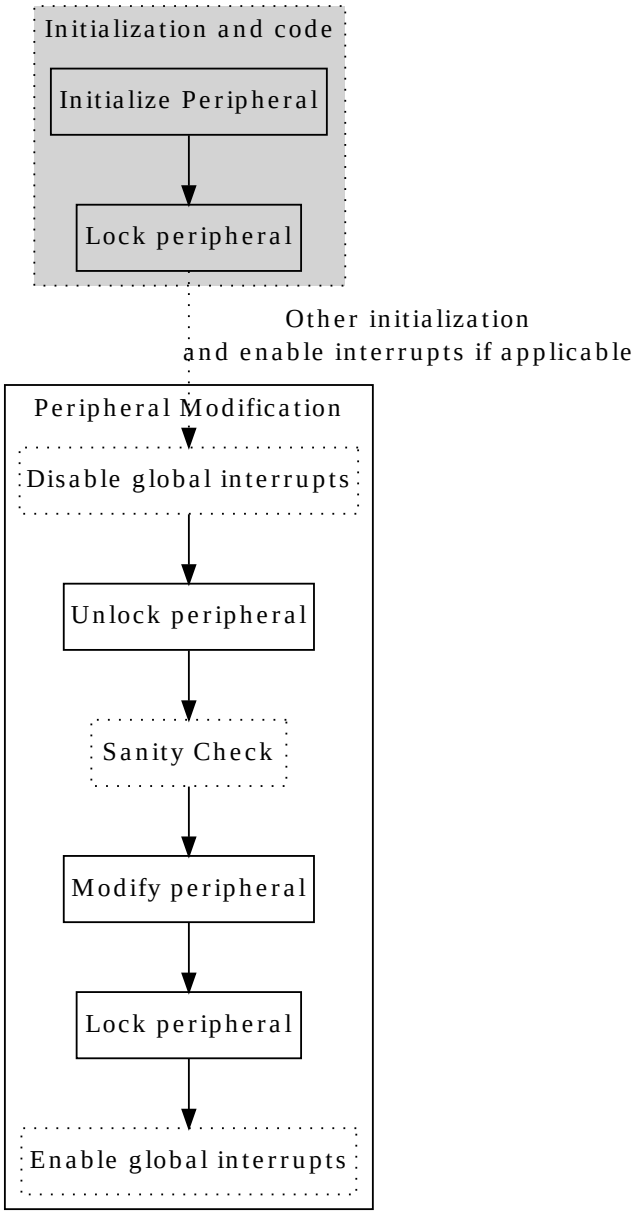
10.2.1 Locking Scheme

The module has a built in safety feature requiring that an already locked peripheral is not relocked, and that already unlocked peripherals are not unlocked again. Attempting to unlock and already unlocked peripheral, or attempting to lock a peripheral that is currently locked will generate a non-maskable interrupt (NMI). This implies that the implementer must keep strict control over the peripheral's lock-state before modifying them. With this added safety, the probability of stopping run-away code increases as the program pointer can be caught inside the exception handler, and necessary countermeasures can be initiated. The implementer should also consider using sanity checks after an unlock has been performed to further increase the security.

10.2.2 Recommended Implementation

A recommended implementation of the PAC can be seen in Figure 10-1: Recommended Implementation on page 246.

Figure 10-1. Recommended Implementation



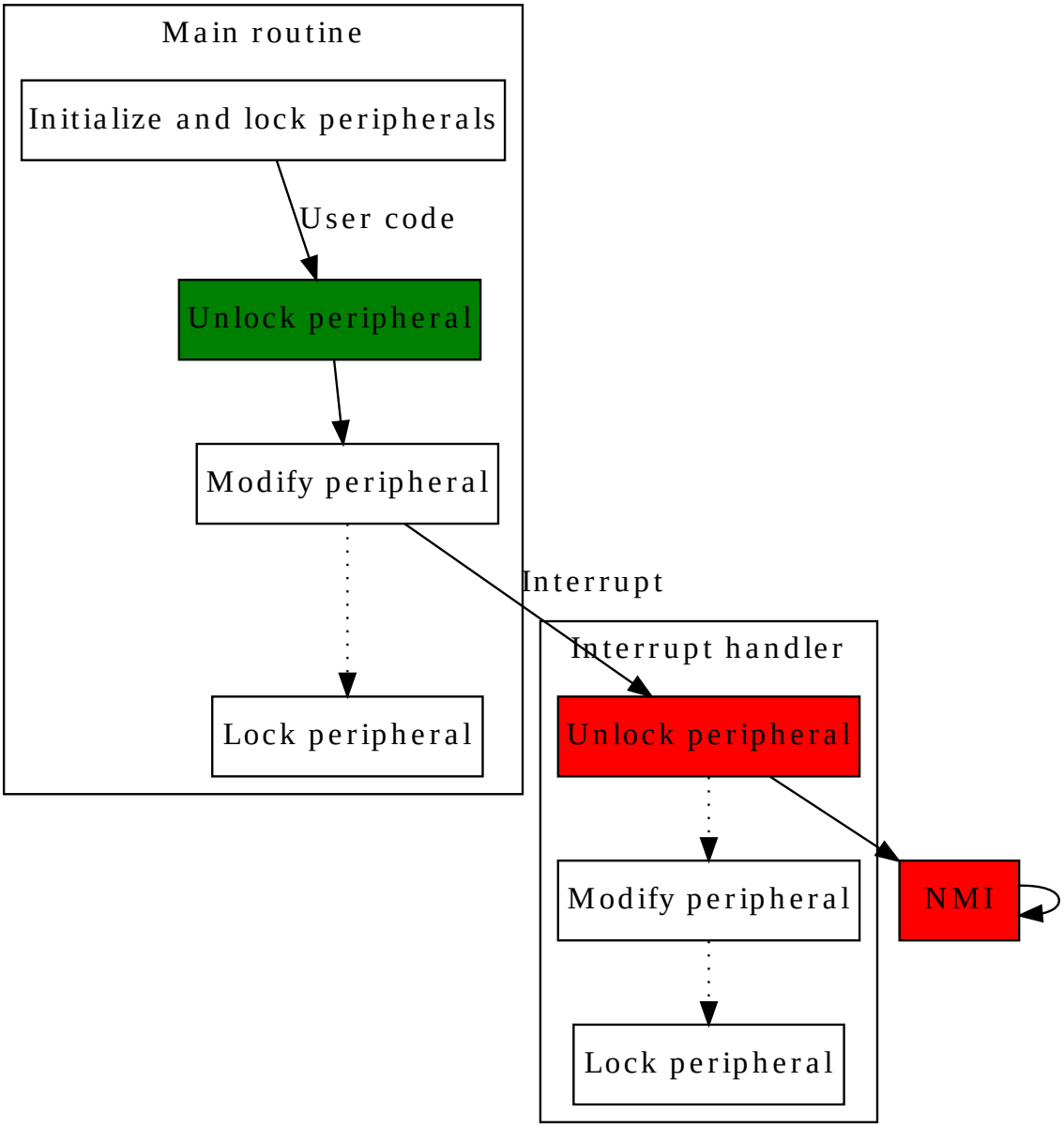
10.2.3 Why Disable Interrupts

Global interrupts must be disabled while a peripheral is unlocked as an interrupt handler would not know the current state of the peripheral lock. If the interrupt tries to alter the lock state, it can cause an exception as it potentially tries to unlock an already unlocked peripheral. Reading current lock state is to be avoided as it removes the security provided by the PAC (Reading Lock State).

Note Global interrupts should also be disabled when a peripheral is unlocked inside an interrupt handler.

An example to illustrate the potential hazard of not disabling interrupts is shown in Figure 10-2: Why Disable Interrupts on page 247.

Figure 10-2. Why Disable Interrupts



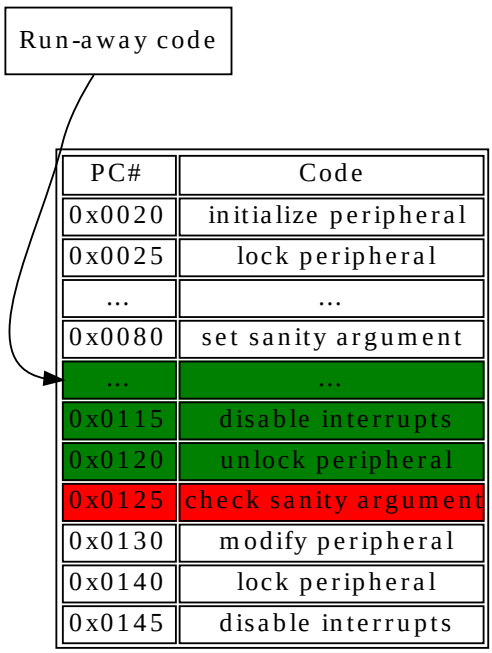
10.2.4 Run-away Code

Run-away code can be caused by the MCU being operated outside its specification, faulty code or EMI issues. If a run-away code occurs, it is favorable to catch the issue as soon as possible. With a correct implementation of the PAC, the run-away code can potentially be stopped.

A graphical example showing how a PAC implementation will behave for different circumstances of run-away code in shown in Figure 10-3: Run-away Code on page 248 and Figure 10-4: Run-away Code on page 249.

Figure 10-3. Run-away Code

1. Run-away code is caught in sanity check. A NMI is executed.



2. Run-away code is caught when modifying locked peripheral. A NMI is executed.

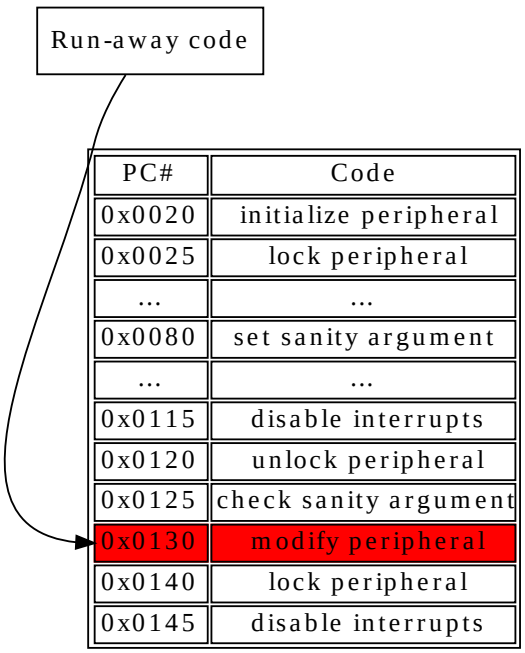
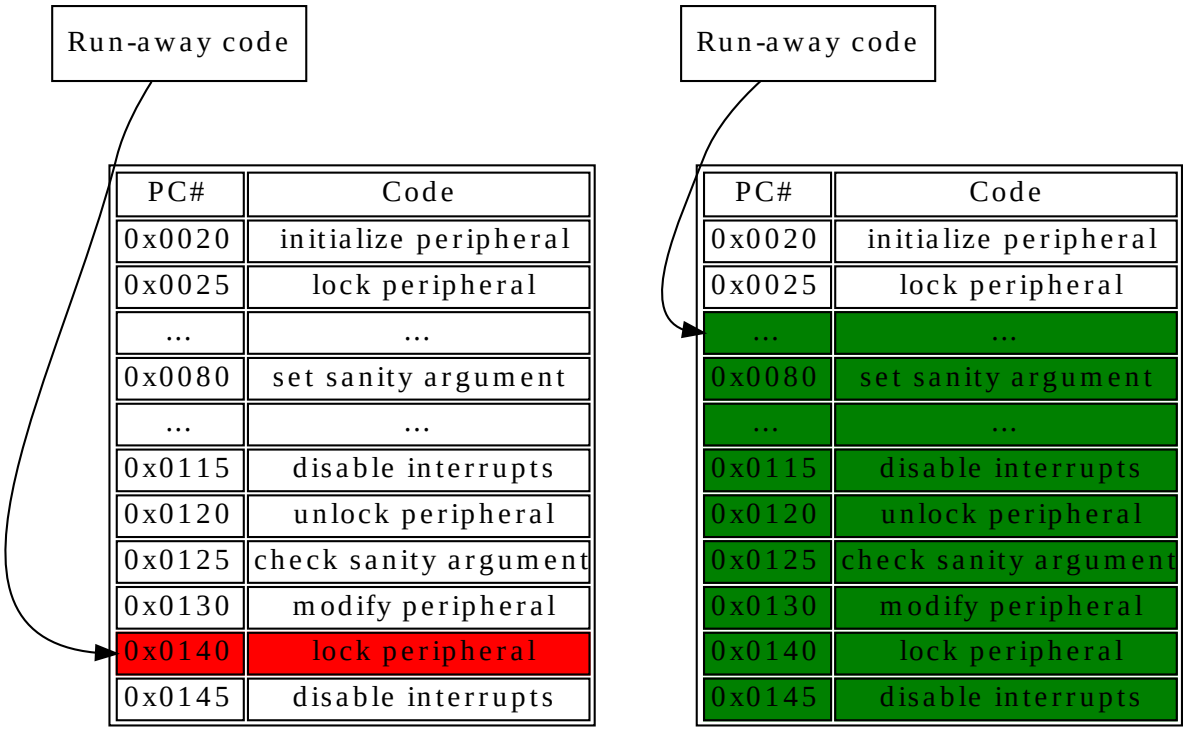


Figure 10-4. Run-away Code



In the example, green indicates that the command is allowed, red indicates where the run-away code will be caught, and the arrow where the run-away code enters the application. In special circumstances, like example 4 above, the run-away code will not be caught. However, the protection scheme will greatly enhance peripheral configuration security from being affected by run-away code.

10.2.4.1 Key-Argument

To protect the module functions against run-away code themselves, a key is required as one of the input arguments. The key-argument will make sure that run-away code entering the function without a function call will be rejected before inflicting any damage. The argument is simply set to be the bitwise inverse of the module flag, i.e.

```
system_peripheral_<lock_state>(SYSTEM_PERIPHERAL_<module>,
        ~SYSTEM_PERIPHERAL_<module>);
```

Where the lock state can be either lock or unlock, and module refer to the peripheral that is to be locked/unlocked.

10.2.5 Faulty Module Pointer

The PAC also protects the application from user errors such as the use of incorrect module pointers in function arguments, given that the module is locked. It is therefore recommended that any unused peripheral is locked during application initialization.

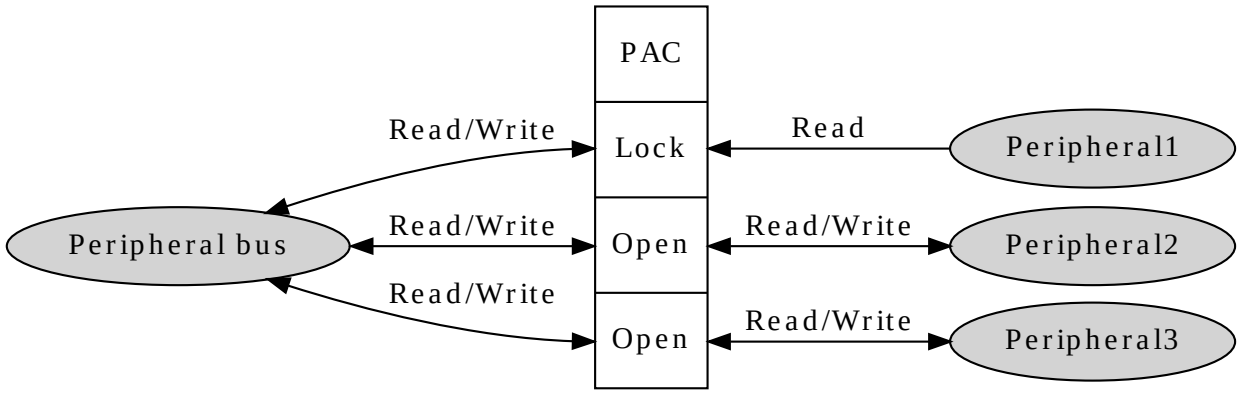
10.2.6 Use of __no_inline

Using the function attribute `__no_inline` will ensure that there will only be one copy of each functions in the PAC driver API in the application. This will lower the likelihood that run-away code will hit any of these functions.

10.2.7 Physical Connection

Figure 10-5: Physical Connection on page 250 shows how this module is interconnected within the device.

Figure 10-5. Physical Connection



10.3 Special Considerations

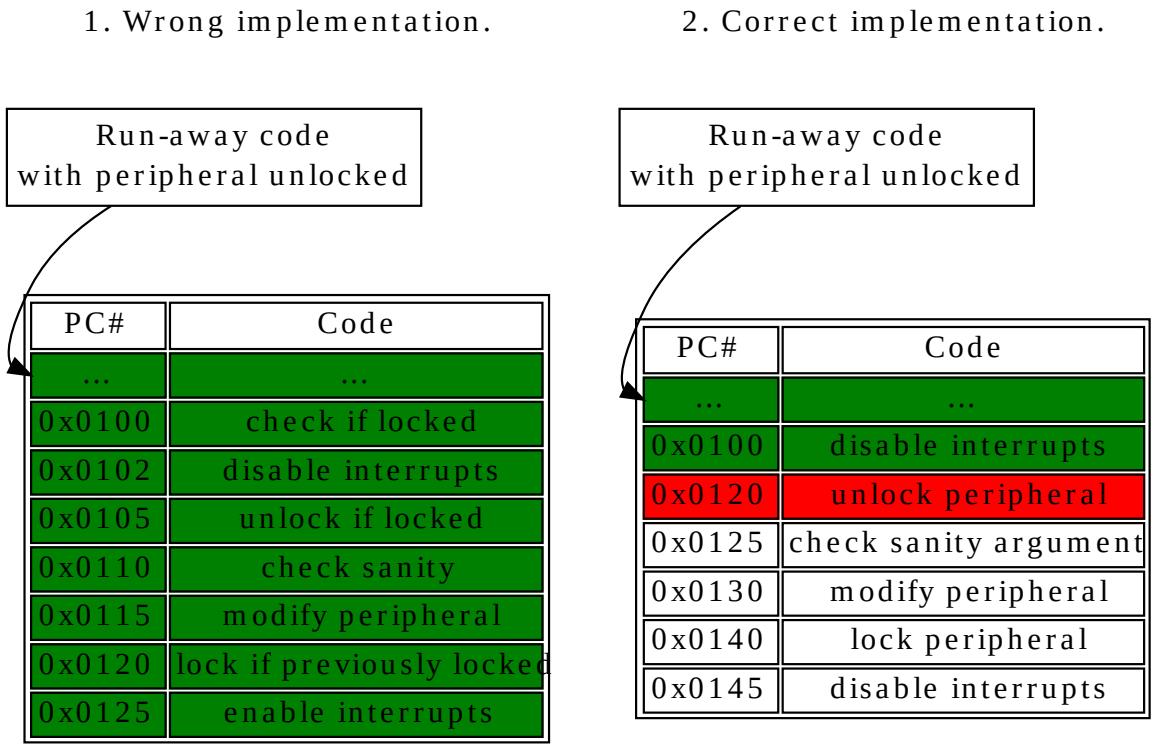
10.3.1 Non-Writable Registers

Not all registers in a given peripheral can be set non-writable. Which registers this applies to is showed in List of Non-Write Protected Registers and the peripheral's subsection "Register Access Protection" in the device datasheet.

10.3.2 Reading Lock State

Reading the state of the peripheral lock is to be avoided as it greatly compromises the protection initially provided by the PAC. If a lock/unlock is implemented conditionally, there is a risk that eventual errors are not caught in the protection scheme. Examples indicating the issue are shown in Figure 10-6: Reading Lock State on page 250.

Figure 10-6. Reading Lock State



In the left figure above, one can see the run-away code continues as all illegal operations are conditional. On the right side figure, the run-away code is caught as it tries to unlock the peripheral.

10.4 Extra Information

For extra information see Extra Information for PAC Driver. This includes:

- Acronyms
- Dependencies
- Errata
- Module History

10.5 Examples

For a list of examples related to this driver, see Examples for PAC Driver.

10.6 API Overview

10.6.1 Macro Definitions

10.6.1.1 Macro SYSTEM_PERIPHERAL_ID

```
#define SYSTEM_PERIPHERAL_ID(peripheral) \
  ID_##peripheral
```

Retrieves the ID of a specified peripheral name, giving its peripheral bus location.

Table 10-1. Parameters

Data direction	Parameter name	Description
[in]	peripheral	Name of the peripheral instance

Returns Bus ID of the specified peripheral instance.

10.6.2 Function Definitions

10.6.2.1 Peripheral lock and unlock

Function system_peripheral_lock()

Lock a given peripheral's control registers.

```
__no_inline enum status_code system_peripheral_lock(
  const uint32_t peripheral_id,
  const uint32_t key)
```

Locks a given peripheral's control registers, to deny write access to the peripheral to prevent accidental changes to the module's configuration.

Warning Locking an already locked peripheral will cause a hard fault exception, and terminate program execution.

Table 10-2. Parameters

Data direction	Parameter name	Description
[in]	peripheral_id	ID for the peripheral to be locked, sourced via the SYSTEM_PERIPHERAL_ID macro.
[in]	key	Bitwise inverse of peripheral ID, used as key to reduce the chance of accidental locking. See Key-Argument.

Returns Status of the peripheral lock procedure.

Table 10-3. Return Values

Return value	Description
STATUS_OK	If the peripheral was successfully locked.
STATUS_ERR_INVALID_ARG	If invalid argument(s) were supplied.

Function system_peripheral_unlock()

Unlock a given peripheral's control registers.

```
__no_inline enum status_code system_peripheral_unlock(
  const uint32_t peripheral_id,
  const uint32_t key)
```

Unlocks a given peripheral's control registers, allowing write access to the peripheral so that changes can be made to the module's configuration.

Warning Unlocking an already locked peripheral will cause a hard fault exception, and terminate program execution.

Table 10-4. Parameters

Data direction	Parameter name	Description
[in]	peripheral_id	ID for the peripheral to be unlocked, sourced via the SYSTEM_PERIPHERAL_ID macro.
[in]	key	Bitwise inverse of peripheral ID, used as key to reduce the chance of accidental unlocking. See Key-Argument.

Returns Status of the peripheral unlock procedure.

Table 10-5. Return Values

Return value	Description
STATUS_OK	If the peripheral was successfully locked.
STATUS_ERR_INVALID_ARG	If invalid argument(s) were supplied.

10.7 List of Non-Write Protected Registers

Look in device datasheet peripheral's subsection "Register Access Protection" to see which is actually available for your device.

Module	Non-write protected register
AC	INTFLAG
	STATUSA
	STATUSB
	STATUSC
ADC	INTFLAG
	STATUS
	RESULT
EVSYS	INTFLAG
	CHSTATUS
NVMCTRL	INTFLAG
	STATUS
PM	INTFLAG
PORT	N/A
RTC	INTFLAG
	READREQ
	STATUS
SYSCTRL	INTFLAG
SERCOM	INTFALG
	STATUS
	DATA
TC	INTFLAG
	STATUS
WDT	INTFLAG
	STATUS
	(CLEAR)

10.8 Extra Information for PAC Driver

10.8.1 Acronyms

Below is a table listing the acronyms used in this module, along with their intended meanings.

Acronym	Description
AC	Analog Comparator
ADC	Analog-to-Digital Converter
EVSYS	Event System
NMI	Non-Maskable Interrupt
NVMCTRL	Non-Volatile Memory Controller
PAC	Peripheral Access Controller
PM	Power Manager
RTC	Real-Time Counter
SERCOM	Serial Communication Interface
SYSCTRL	System Controller
TC	Timer/Counter
WDT	Watch Dog Timer

10.8.2 Dependencies

This driver has the following dependencies:

- None

10.8.3 Errata

There are no errata related to this driver.

10.8.4 Module History

An overview of the module history is presented in the table below, with details on the enhancements and fixes made to the module since its first release. The current version of this corresponds to the newest version in the table.

Changelog
Added support for SAMD21
Initial Release

10.9 Examples for PAC Driver

This is a list of the available Quick Start guides (QSGs) and example applications for SAM D20/D21 Peripheral Access Controller Driver (PAC). QSGs are simple examples with step-by-step instructions to configure and use this driver in a selection of use cases. Note that QSGs can be compiled as a standalone application or be added to the user application.

- Quick Start Guide for PAC - Basic

10.9.1 Quick Start Guide for PAC - Basic

In this use case, the peripheral-lock will be used to lock and unlock the PORT peripheral access, and show how to implement the PAC module when the PORT registers needs to be altered. The PORT will be set up as follows:

- One pin in input mode, with pull-up and falling edge-detect.
- One pin in output mode.

10.9.1.1 Setup

Prerequisites

There are no special setup requirements for this use-case.

Code

Copy-paste the following setup code to your user application:

```
void config_port_pins(void)
{
    struct port_config pin_conf;

    port_get_config_defaults(&pin_conf);

    pin_conf.direction  = PORT_PIN_DIR_INPUT;
    pin_conf.input_pull = PORT_PIN_PULL_UP;
    port_pin_set_config(BUTTON_0_PIN, &pin_conf);

    pin_conf.direction = PORT_PIN_DIR_OUTPUT;
    port_pin_set_config(LED_0_PIN, &pin_conf);
}
```

Add to user application initialization (typically the start of `main()`):

```
config_port_pins();
```

10.9.1.2 Use Case

Code

Copy-paste the following code to your user application:

```
system_init();

config_port_pins();

system_peripheral_lock(SYSTEM_PERIPHERAL_ID(PORT),
        ~SYSTEM_PERIPHERAL_ID(PORT));

system_interrupt_enable_global();

while (port_pin_get_input_level(BUTTON_0_PIN)) {
    /* Wait for button press */
}

system_interrupt_enter_critical_section();

system_peripheral_unlock(SYSTEM_PERIPHERAL_ID(PORT),
        ~SYSTEM_PERIPHERAL_ID(PORT));

port_pin_toggle_output_level(LED_0_PIN);

system_peripheral_lock(SYSTEM_PERIPHERAL_ID(PORT),
        ~SYSTEM_PERIPHERAL_ID(PORT));

system_interrupt_leave_critical_section();

while (1) {
```

```
    /* Do nothing */
}
```

Workflow

1. Configure some GPIO port pins for input and output.

```
config_port_pins();
```

2. Lock peripheral access for the PORT module; attempting to update the module while it is in a protected state will cause a Hard Fault exception.

```
system_peripheral_lock(SYSTEM_PERIPHERAL_ID(PORT),
        ~SYSTEM_PERIPHERAL_ID(PORT));
```

3. Enable global interrupts.

```
system_interrupt_enable_global();
```

4. Loop to wait for a button press before continuing.

```
while (port_pin_get_input_level(BUTTON_0_PIN)) {
    /* Wait for button press */
}
```

5. Enter a critical section, so that the PAC module can be unlocked safely and the peripheral manipulated without the possibility of an interrupt modifying the protected module's state.

```
system_interrupt_enter_critical_section();
```

6. Unlock the PORT peripheral registers.

```
system_peripheral_unlock(SYSTEM_PERIPHERAL_ID(PORT),
        ~SYSTEM_PERIPHERAL_ID(PORT));
```

7. Toggle pin 11, and clear edge detect flag.

```
port_pin_toggle_output_level(LED_0_PIN);
```

8. Lock the PORT peripheral registers.

```
system_peripheral_lock(SYSTEM_PERIPHERAL_ID(PORT),
        ~SYSTEM_PERIPHERAL_ID(PORT));
```

9. Exit the critical section to allow interrupts to function normally again.

```
system_interrupt_leave_critical_section();
```

10. Enter an infinite while loop once the module state has been modified successfully.

```
while (1) {
```

```
    /* Do nothing */
}
```

11. SAM D20/D21 Port Driver (PORT)

This driver for SAM D20/D21 devices provides an interface for the configuration and management of the device's General Purpose Input/Output (GPIO) pin functionality, for manual pin state reading and writing.

The following peripherals are used by this module:

- PORT (GPIO Management)

The outline of this documentation is as follows:

11.1 Prerequisites

There are no prerequisites for this module.

11.2 Module Overview

The device GPIO (PORT) module provides an interface between the user application logic and external hardware peripherals, when general pin state manipulation is required. This driver provides an easy-to-use interface to the physical pin input samplers and output drivers, so that pins can be read from or written to for general purpose external hardware control.

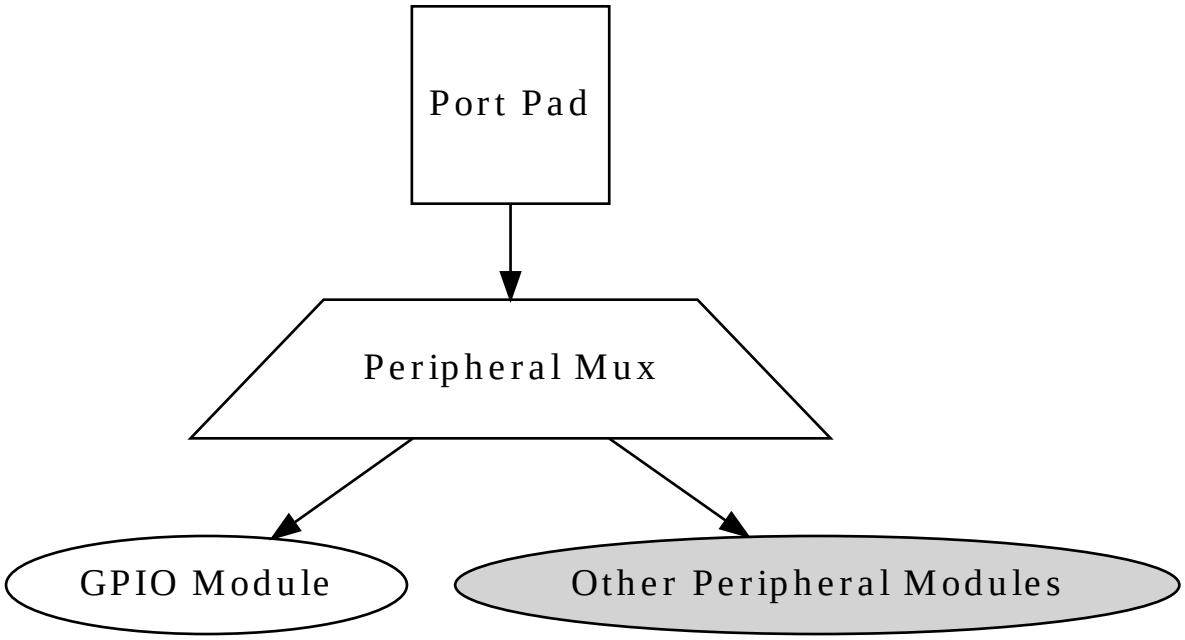
11.2.1 Physical and Logical GPIO Pins

SAM D20/D21 devices use two naming conventions for the I/O pins in the device; one physical, and one logical. Each physical pin on a device package is assigned both a physical port and pin identifier (e.g. "PORTA.0") as well as a monotonically incrementing logical GPIO number (e.g. "GPIO0"). While the former is used to map physical pins to their physical internal device module counterparts, for simplicity the design of this driver uses the logical GPIO numbers instead.

11.2.2 Physical Connection

Figure 11-1: Physical Connection on page 259 shows how this module is interconnected within the device.

Figure 11-1. Physical Connection



11.3 Special Considerations

The SAM D20/D21 port pin input sampler can be disabled when the pin is configured in pure output mode to save power; reading the pin state of a pin configured in output-only mode will read the logical output state that was last set.

11.4 Extra Information

For extra information see Extra Information for PORT Driver. This includes:

- Acronyms
- Dependencies
- Errata
- Module History

11.5 Examples

For a list of examples related to this driver, see Examples for PORT Driver.

11.6 API Overview

11.6.1 Structure Definitions

11.6.1.1 Struct port_config

Configuration structure for a port pin instance. This structure should be initialized by the port_get_config_defaults() function before being modified by the user application.

Table 11-1. Members

Type	Name	Description
enum port_pin_dir	direction	Port buffer input/output direction.

Type	Name	Description
enum port_pin_pull	input_pull	Port pull-up/pull-down for input pins.
bool	powersave	Enable lowest possible powerstate on the pin[1]

Notes: [1]All other configurations will be ignored, the pin will be disabled

11.6.2 Macro Definitions

11.6.2.1 PORT Alias Macros

Macro PORTA

```
#define PORTA PORT->Group[0]
```

Convenience definition for GPIO module group A on the device (if available).

Macro PORTB

```
#define PORTB PORT->Group[1]
```

Convenience definition for GPIO module group B on the device (if available).

Macro PORTC

```
#define PORTC PORT->Group[2]
```

Convenience definition for GPIO module group C on the device (if available).

Macro PORTD

```
#define PORTD PORT->Group[3]
```

Convenience definition for GPIO module group D on the device (if available).

11.6.3 Function Definitions

11.6.3.1 State reading/writing (physical group orientated)

Function port_get_group_from_gpio_pin()

Retrieves the PORT module group instance from a given GPIO pin number.

```
PortGroup * port_get_group_from_gpio_pin(
  const uint8_t gpio_pin)
```

Retrieves the PORT module group instance associated with a given logical GPIO pin number.

Table 11-2. Parameters

Data direction	Parameter name	Description
[in]	gpio_pin	Index of the GPIO pin to convert.

Returns Base address of the associated PORT module.

Function port_group_get_input_level()

Retrieves the state of a group of port pins that are configured as inputs.

```
uint32_t port_group_get_input_level(
  const PortGroup *const port,
  const uint32_t mask)
```

Reads the current logic level of a port module's pins and returns the current levels as a bitmask.

Table 11-3. Parameters

Data direction	Parameter name	Description
[in]	port	Base of the PORT module to read from.
[in]	mask	Mask of the port pin(s) to read.

Returns Status of the port pin(s) input buffers.

Function port_group_get_output_level()

Retrieves the state of a group of port pins that are configured as outputs.

```
uint32_t port_group_get_output_level(
  const PortGroup *const port,
  const uint32_t mask)
```

Reads the current logical output level of a port module's pins and returns the current levels as a bitmask.

Table 11-4. Parameters

Data direction	Parameter name	Description
[in]	port	Base of the PORT module to read from.
[in]	mask	Mask of the port pin(s) to read.

Returns Status of the port pin(s) output buffers.

Function port_group_set_output_level()

Sets the state of a group of port pins that are configured as outputs.

```
void port_group_set_output_level(
  PortGroup *const port,
  const uint32_t mask,
  const uint32_t level_mask)
```

Sets the current output level of a port module's pins to a given logic level.

Table 11-5. Parameters

Data direction	Parameter name	Description
[out]	port	Base of the PORT module to write to.
[in]	mask	Mask of the port pin(s) to change.
[in]	level_mask	Mask of the port level(s) to set.

Function port_group_toggle_output_level()

Toggles the state of a group of port pins that are configured as an outputs.

```
void port_group_toggle_output_level(
  PortGroup *const port,
  const uint32_t mask)
```

Toggles the current output levels of a port module's pins.

Table 11-6. Parameters

Data direction	Parameter name	Description
[out]	port	Base of the PORT module to write to.
[in]	mask	Mask of the port pin(s) to toggle.

11.6.3.2 Configuration and initialization

Function port_get_config_defaults()

Initializes a Port pin/group configuration structure to defaults.

```
void port_get_config_defaults(
  struct port_config *const config)
```

Initializes a given Port pin/group configuration structure to a set of known default values. This function should be called on all new instances of these configuration structures before being modified by the user application.

The default configuration is as follows:

- Input mode with internal pullup enabled

Table 11-7. Parameters

Data direction	Parameter name	Description
[out]	config	Configuration structure to initialize to default values.

Function port_pin_set_config()

Writes a Port pin configuration to the hardware module.

```
void port_pin_set_config(
  const uint8_t gpio_pin,
  const struct port_config *const config)
```

Writes out a given configuration of a Port pin configuration to the hardware module.

Note If the pin direction is set as an output, the pull-up/pull-down input configuration setting is ignored.

Table 11-8. Parameters

Data direction	Parameter name	Description
[in]	gpio_pin	Index of the GPIO pin to configure.
[in]	config	Configuration settings for the pin.

Function port_group_set_config()

Writes a Port group configuration group to the hardware module.

```
void port_group_set_config(
  PortGroup *const port,
  const uint32_t mask,
  const struct port_config *const config)
```

Writes out a given configuration of a Port group configuration to the hardware module.

Note If the pin direction is set as an output, the pull-up/pull-down input configuration setting is ignored.

Table 11-9. Parameters

Data direction	Parameter name	Description
[out]	port	Base of the PORT module to write to.
[in]	mask	Mask of the port pin(s) to configure.
[in]	config	Configuration settings for the pin group.

11.6.3.3 State reading/writing (logical pin orientated)

Function port_pin_get_input_level()

Retrieves the state of a port pin that is configured as an input.

```
bool port_pin_get_input_level(
  const uint8_t gpio_pin)
```

Reads the current logic level of a port pin and returns the current level as a boolean value.

Table 11-10. Parameters

Data direction	Parameter name	Description
[in]	gpio_pin	Index of the GPIO pin to read.

Returns Status of the port pin's input buffer.

Function port_pin_get_output_level()

Retrieves the state of a port pin that is configured as an output.

```
bool port_pin_get_output_level(
  const uint8_t gpio_pin)
```

Reads the current logical output level of a port pin and returns the current level as a boolean value.

Table 11-11. Parameters

Data direction	Parameter name	Description
[in]	gpio_pin	Index of the GPIO pin to read.

Returns Status of the port pin's output buffer.

Function port_pin_set_output_level()

Sets the state of a port pin that is configured as an output.

```
void port_pin_set_output_level(
  const uint8_t gpio_pin,
  const bool level)
```

Sets the current output level of a port pin to a given logic level.

Table 11-12. Parameters

Data direction	Parameter name	Description
[in]	gpio_pin	Index of the GPIO pin to write to.
[in]	level	Logical level to set the given pin to.

Function port_pin_toggle_output_level()

Toggles the state of a port pin that is configured as an output.

```
void port_pin_toggle_output_level(
  const uint8_t gpio_pin)
```

Toggles the current output level of a port pin.

Table 11-13. Parameters

Data direction	Parameter name	Description
[in]	gpio_pin	Index of the GPIO pin to toggle.

11.6.4 Enumeration Definitions

11.6.4.1 Enum port_pin_dir

Enum for the possible pin direction settings of the port pin configuration structure, to indicate the direction the pin should use.

Table 11-14. Members

Enum value	Description
PORT_PIN_DIR_INPUT	The pin's input buffer should be enabled, so that the pin state can be read.
PORT_PIN_DIR_OUTPUT	The pin's output buffer should be enabled, so that the pin state can be set.
PORT_PIN_DIR_OUTPUT_WTH_READBACK	The pin's output and input buffers should be enabled, so that the pin state can be set and read back.

11.6.4.2 Enum port_pin_pull

Enum for the possible pin pull settings of the port pin configuration structure, to indicate the type of logic level pull the pin should use.

Table 11-15. Members

Enum value	Description
PORT_PIN_PULL_NONE	No logical pull should be applied to the pin.
PORT_PIN_PULL_UP	Pin should be pulled up when idle.
PORT_PIN_PULL_DOWN	Pin should be pulled down when idle.

11.7 Extra Information for PORT Driver

11.7.1 Acronyms

Below is a table listing the acronyms used in this module, along with their intended meanings.

Acronym	Description
GPIO	General Purpose Input/Output
MUX	Multiplexer

11.7.2 Dependencies

This driver has the following dependencies:

- System Pin Multiplexer Driver

11.7.3 Errata

There are no errata related to this driver.

11.7.4 Module History

An overview of the module history is presented in the table below, with details on the enhancements and fixes made to the module since its first release. The current version of this corresponds to the newest version in the table.

Changelog
Added support for SAMD21
Initial Release

11.8 Examples for PORT Driver

This is a list of the available Quick Start guides (QSGs) and example applications for SAM D20/D21 Port Driver (PORT). QSGs are simple examples with step-by-step instructions to configure and use this driver in a selection of use cases. Note that QSGs can be compiled as a standalone application or be added to the user application.

- Quick Start Guide for PORT - Basic

11.8.1 Quick Start Guide for PORT - Basic

In this use case, the PORT module is configured for:

- One pin in input mode, with pull-up enabled
- One pin in output mode

This use case sets up the PORT to read the current state of a GPIO pin set as an input, and mirrors the opposite logical state on a pin configured as an output.

11.8.1.1 Setup

Prerequisites

There are no special setup requirements for this use-case.

Code

Copy-paste the following setup code to your user application:

```
void configure_port_pins(void)
{
    struct port_config config_port_pin;
    port_get_config_defaults(&config_port_pin);

    config_port_pin.direction  = PORT_PIN_DIR_INPUT;
    config_port_pin.input_pull = PORT_PIN_PULL_UP;
    port_pin_set_config(BUTTON_0_PIN, &config_port_pin);

    config_port_pin.direction = PORT_PIN_DIR_OUTPUT;
    port_pin_set_config(LED_0_PIN, &config_port_pin);
}
```

Add to user application initialization (typically the start of `main()`):

```
configure_port_pins();
```

Workflow

1. Create a PORT module pin configuration struct, which can be filled out to adjust the configuration of a single port pin.

```
struct port_config config_port_pin;
```

2. Initialize the pin configuration struct with the module's default values.

```
port_get_config_defaults(&config_port_pin);
```

Note This should always be performed before using the configuration struct to ensure that all values are initialized to known default settings.

3. Adjust the configuration struct to request an input pin.

```
config_port_pin.direction  = PORT_PIN_DIR_INPUT;
config_port_pin.input_pull = PORT_PIN_PULL_UP;
```

4. Configure push button pin with the initialized pin configuration struct, to enable the input sampler on the pin.

```
port_pin_set_config(BUTTON_0_PIN, &config_port_pin);
```

5. Adjust the configuration struct to request an output pin.

```
config_port_pin.direction = PORT_PIN_DIR_OUTPUT;
```

Note The existing configuration struct may be re-used, as long as any values that have been altered from the default settings are taken into account by the user application.

6. Configure LED pin with the initialized pin configuration struct, to enable the output driver on the pin.

```
port_pin_set_config(LED_0_PIN, &config_port_pin);
```

11.8.1.2 Use Case

Code

Copy-paste the following code to your user application:

```
while (true) {
    bool pin_state = port_pin_get_input_level(BUTTON_0_PIN);

    port_pin_set_output_level(LED_0_PIN, !pin_state);
}
```

Workflow

1. Read in the current input sampler state of push button pin, which has been configured as an input in the use-case setup code.

```
bool pin_state = port_pin_get_input_level(BUTTON_0_PIN);
```

2. Write the inverted pin level state to LED pin, which has been configured as an output in the use-case setup code.

```
port_pin_set_output_level(LED_0_PIN, !pin_state);
```

12. SAM D20/D21 RTC Calendar Driver (RTC CAL)

This driver for SAM D20/D21 devices provides an interface for the configuration and management of the device's Real Time Clock functionality in Calendar operating mode, for the configuration and retrieval of the current time and date as maintained by the RTC module. The following driver API modes are covered by this manual:

- Polled APIs
- Callback APIs

The following peripherals are used by this module:

- RTC (Real Time Clock)

The outline of this documentation is as follows:

12.1 Prerequisites

There are no prerequisites for this module.

12.2 Module Overview

The RTC module in the SAM D20/D21 devices is a 32-bit counter, with a 10-bit programmable prescaler. Typically, the RTC clock is run continuously, including in the device's low-power sleep modes, to track the current time and date information. The RTC can be used as a source to wake up the system at a scheduled time or periodically using the alarm functions.

In this driver, the RTC is operated in Calendar mode. This allows for an easy integration of a real time clock and calendar into a user application to track the passing of time and/or perform scheduled tasks.

Whilst operating in Calendar mode, the RTC features:

- Time tracking in seconds, minutes and hours
  - 12 hour or 24 hour mode
- Date tracking in day, month and year
  - Automatic leap year correction

12.2.1 Alarms and Overflow

The RTC has 4 independent hardware alarms that can be configured by the user application. These alarms will be will triggered on match with the current clock value, and can be set up to trigger an interrupt, event, or both. The RTC can also be configured to clear the clock value on alarm match, resetting the clock to the original start time.

If the RTC is operated in clock-only mode (i.e. with calendar disabled), the RTC counter value will instead be cleared on overflow once the maximum count value has been reached:

$$COUNT_{MAX} = 2^{32} - 1 \tag{12.1}$$

When the RTC is operated with the calendar enabled and run using a nominal 1 Hz input clock frequency, a register overflow will occur after 64 years.

12.2.2 Periodic Events

The RTC can generate events at periodic intervals, allowing for direct peripheral actions without CPU intervention. The periodic events can be generated on the upper 8 bits of the RTC prescaler, and will be generated on the rising edge transition of the specified bit. The resulting periodic frequency can be calculated by the following formula:

$$f_{PERIODIC} = \frac{f_{ASY}}{2^{n+3}} \tag{12.2}$$

Where

$$f_{ASY} \tag{12.3}$$

refers to the *asynchronous* clock set up in the RTC module configuration. For the RTC to operate correctly in calendar mode, this frequency must be 1KHz, while the RTC's internal prescaler should be set to divide by 1024. The **n** parameter is the event source generator index of the RTC module. If the asynchronous clock is operated at the recommended 1KHz, the formula results in the values shown in Table 12-1: RTC event frequencies for each prescaler bit using a 1KHz clock on page 270.

Table 12-1. RTC event frequencies for each prescaler bit using a 1KHz clock

n	Periodic event
7	1 Hz
6	2 Hz
5	4 Hz
4	8 Hz
3	16 Hz
2	32 Hz
1	64 Hz
0	128 Hz

Note The connection of events between modules requires the use of the SAM D20/D21 Event System Driver (EVENTS) to route output event of one module to the the input event of another. For more information on event routing, refer to the event driver documentation.

12.2.3 Digital Frequency Correction

The RTC module contains Digital Frequency Correction logic to compensate for inaccurate source clock frequencies which would otherwise result in skewed time measurements. The correction scheme requires that at least two bits in the RTC module prescaler are reserved by the correction logic. As a result of this implementation, frequency correction is only available when the RTC is running from a 1 Hz reference clock.

The correction procedure is implemented by subtracting or adding a single cycle from the RTC prescaler every 1024 RTC GCLK cycles. The adjustment is applied the specified number of time (max 127) over 976 of these periods. The corresponding correction in PPM will be given by:

$$Correction(PPM) = \frac{VALUE}{999424}10^6 \tag{12.4}$$

The RTC clock will tick faster if provided with a positive correction value, and slower when given a negative correction value.

12.3 Special Considerations

12.3.1 Year limit

The RTC module has a year range of 63 years from the starting year configured when the module is initialized. Dates outside the start to end year range described below will need software adjustment:

$$[YEAR_{START}, YEAR_{START} + 64) \quad (12.5)$$

12.3.2 Clock Setup

The RTC is typically clocked by a specialized GCLK generator that has a smaller prescaler than the others. By default the RTC clock is on, selected to use the internal 32 kHz RC-oscillator with a prescaler of 32, giving a resulting clock frequency of 1024 Hz to the RTC. When the internal RTC prescaler is set to 1024, this yields an end-frequency of 1Hz for correct time keeping operations.

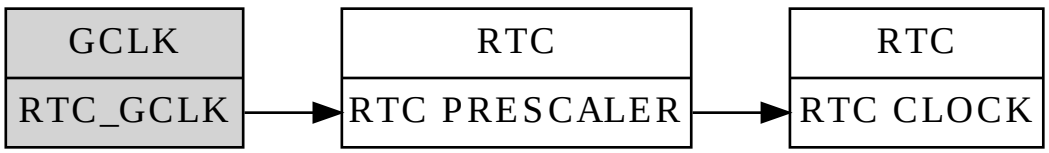
The implementer also has the option to set other end-frequencies. Table 12-2: RTC output frequencies from allowable input clocks on page 271 lists the available RTC frequencies for each possible GCLK and RTC input prescaler options.

Table 12-2. RTC output frequencies from allowable input clocks

End-frequency	GCLK prescaler	RTC Prescaler
32 KHz	1	1
1 KHz	32	1
1 Hz	32	1024

The overall RTC module clocking scheme is shown in Figure 12-1: Clock Setup on page 271.

Figure 12-1. Clock Setup



Note For the calendar to operate correctly, an asynchronous clock of 1Hz should be used.

12.4 Extra Information

For extra information see Extra Information for RTC (CAL) Driver. This includes:

- Acronyms
- Dependencies
- Errata
- Module History

12.5 Examples

For a list of examples related to this driver, see Examples for RTC CAL Driver.

12.6 API Overview

12.6.1 Structure Definitions

12.6.1.1 Struct rtc_calendar_alarm_time

Alarm structure containing time of the alarm and a mask to determine when the alarm will trigger.

Table 12-3. Members

Type	Name	Description
enum rtc_calendar_alarm_mask	mask	Alarm mask to determine on what precision the alarm will match.

Type	Name	Description
struct rtc_calendar_time	time	Alarm time.

12.6.1.2 Struct rtc_calendar_config

Configuration structure for the RTC instance. This structure should be initialized using the rtc_calendar_get_config_defaults() before any user configurations are set.

Table 12-4. Members

Type	Name	Description
struct rtc_calendar_alarm_time	alarm[]	Alarm values.
bool	clear_on_match	If true, clears the clock on alarm match.
bool	clock_24h	If true, time is represented in 24 hour mode.
bool	continuously_update	If true, the digital counter registers will be continuously updated so that internal synchronization is not needed when reading the current count.
enum rtc_calendar_prescaler	prescaler	Input clock prescaler for the RTC module.
uint16_t	year_init_value	Initial year for counter value 0.

12.6.1.3 Struct rtc_calendar_events

Event flags for the rtc_calendar_enable_events() and rtc_calendar_disable_events().

Table 12-5. Members

Type	Name	Description
bool	generate_event_on_alarm[]	Generate an output event on a alarm channel match against the RTC count.
bool	generate_event_on_overflow	Generate an output event on each overflow of the RTC count.
bool	generate_event_on_periodic[]	Generate an output event periodically at a binary division of the RTC counter frequency (see Periodic Events).

12.6.1.4 Struct rtc_calendar_time

Time structure containing the time given by or set to the RTC calendar. The structure uses seven values to give second, minute, hour, PM/AM, day, month and year. It should be initialized via the rtc_calendar_get_time_defaults() function before use.

Table 12-6. Members

Type	Name	Description
uint8_t	day	Day value, where day 1 is the first day of the month.

Type	Name	Description
uint8_t	hour	Hour value.
uint8_t	minute	Minute value.
uint8_t	month	Month value, where month 1 is January.
bool	pm	PM/AM value, true for PM, or false for AM.
uint8_t	second	Second value.
uint16_t	year	Year value.

12.6.2 Function Definitions

12.6.2.1 Configuration and initialization

Function rtc_calendar_is_syncing()

Determines if the hardware module(s) are currently synchronizing to the bus.

```
bool rtc_calendar_is_syncing(
  struct rtc_module *const module)
```

Checks to see if the underlying hardware peripheral module(s) are currently synchronizing across multiple clock domains to the hardware bus, This function can be used to delay further operations on a module until such time that it is ready, to prevent blocking delays for synchronization in the user application.

Table 12-7. Parameters

Data direction	Parameter name	Description
[in]	module	RTC hardware module

Returns Synchronization status of the underlying hardware module(s).

Table 12-8. Return Values

Return value	Description
true	if the module has completed synchronization
false	if the module synchronization is ongoing

Function rtc_calendar_get_time_defaults()

Initialize a time structure.

```
void rtc_calendar_get_time_defaults(
  struct rtc_calendar_time *const time)
```

This will initialize a given time structure to the time 00:00:00 (hh:mm:ss) and date 2000-01-01 (YYYY-MM-DD).

Table 12-9. Parameters

Data direction	Parameter name	Description
[out]	time	Time structure to initialize.

Function rtc_calendar_get_config_defaults()

Gets the RTC default settings.

```
void rtc_calendar_get_config_defaults(
  struct rtc_calendar_config *const config)
```

Initializes the configuration structure to the known default values. This function should be called at the start of any RTC initiation.

The default configuration is as follows:

- Input clock divided by a factor of 1024.
- Clear on alarm match off.
- Continuously sync clock off.
- 12 hour calendar.
- Start year 2000 (Year 0 in the counter will be year 2000).
- Events off.
- Alarms set to January 1. 2000, 00:00:00.
- Alarm will match on second, minute, hour, day, month and year.

Table 12-10. Parameters

Data direction	Parameter name	Description
[out]	config	Configuration structure to be initialized to default values.

Function rtc_calendar_reset()

Resets the RTC module Resets the RTC module to hardware defaults.

```
void rtc_calendar_reset(
  struct rtc_module *const module)
```

Table 12-11. Parameters

Data direction	Parameter name	Description
[in, out]	module	Pointer to the software instance struct

Function rtc_calendar_enable()

Enables the RTC module.

```
void rtc_calendar_enable(
  struct rtc_module *const module)
```

Enables the RTC module once it has been configured, ready for use. Most module configuration parameters cannot be altered while the module is enabled.

Table 12-12. Parameters

Data direction	Parameter name	Description
[in, out]	module	Pointer to the software instance struct

Function rtc_calendar_disable()

Disables the RTC module.

```
void rtc_calendar_disable(
  struct rtc_module *const module)
```

Disables the RTC module.

Table 12-13. Parameters

Data direction	Parameter name	Description
[in, out]	module	Pointer to the software instance struct

Function rtc_calendar_init()

Initializes the RTC module with given configurations.

```
void rtc_calendar_init(
  struct rtc_module *const module,
  Rtc *const hw,
  const struct rtc_calendar_config *const config)
```

Initializes the module, setting up all given configurations to provide the desired functionality of the RTC.

Table 12-14. Parameters

Data direction	Parameter name	Description
[out]	module	Pointer to the software instance struct
[in]	hw	Pointer to hardware instance
[in]	config	Pointer to the configuration structure.

Function rtc_calendar_swap_time_mode()

Swaps between 12h and 24h clock mode.

```
void rtc_calendar_swap_time_mode(
  struct rtc_module *const module)
```

Swaps the current RTC time mode.

- If currently in 12h mode, it will swap to 24h.
- If currently in 24h mode, it will swap to 12h.

Note This will not change setting in user's configuration structure.

Table 12-15. Parameters

Data direction	Parameter name	Description
[in, out]	module	Pointer to the software instance struct

Function rtc_calendar_frequency_correction()

Calibrate for too-slow or too-fast oscillator.

```
enum status_code rtc_calendar_frequency_correction(
  struct rtc_module *const module,
  const int8_t value)
```

When used, the RTC will compensate for an inaccurate oscillator. The RTC module will add or subtract cycles from the RTC prescaler to adjust the frequency in approximately 1 PPM steps. The provided correction value should be between -127 and 127, allowing for a maximum 127 PPM correction in either direction.

If no correction is needed, set value to zero.

Note Can only be used when the RTC is operated at 1Hz.

Table 12-16. Parameters

Data direction	Parameter name	Description
[in, out]	module	Pointer to the software instance struct
[in]	value	Between -127 and 127 used for the correction.

Returns Status of the calibration procedure.

Table 12-17. Return Values

Return value	Description
STATUS_OK	If calibration was done correctly.
STATUS_ERR_INVALID_ARG	If invalid argument(s) were provided.

12.6.2.2 Time and alarm management

Function rtc_calendar_set_time()

Set the current calendar time to desired time.

```
void rtc_calendar_set_time(
  struct rtc_module *const module,
  const struct rtc_calendar_time *const time)
```

Sets the time provided to the calendar.

Table 12-18. Parameters

Data direction	Parameter name	Description
[in, out]	module	Pointer to the software instance struct
[in]	time	The time to set in the calendar.

Function rtc_calendar_get_time()

Get the current calendar value.

```
void rtc_calendar_get_time(
  struct rtc_module *const module,
  struct rtc_calendar_time *const time)
```

Retrieves the current time of the calendar.

Table 12-19. Parameters

Data direction	Parameter name	Description
[in, out]	module	Pointer to the software instance struct
[out]	time	Pointer to value that will be filled with current time.

Function rtc_calendar_set_alarm()

Set the alarm time for the specified alarm.

```
enum status_code rtc_calendar_set_alarm(
  struct rtc_module *const module,
  const struct rtc_calendar_alarm_time *const alarm,
  const enum rtc_calendar_alarm alarm_index)
```

Sets the time and mask specified to the requested alarm.

Table 12-20. Parameters

Data direction	Parameter name	Description
[in, out]	module	Pointer to the software instance struct
[in]	alarm	The alarm struct to set the alarm with.
[in]	alarm_index	The index of the alarm to set.

Returns Status of setting alarm.

Table 12-21. Return Values

Return value	Description
STATUS_OK	If alarm was set correctly.
STATUS_ERR_INVALID_ARG	If invalid argument(s) were provided.

Function rtc_calendar_get_alarm()

Get the current alarm time of specified alarm.

```
enum status_code rtc_calendar_get_alarm(
  struct rtc_module *const module,
  struct rtc_calendar_alarm_time *const alarm,
  const enum rtc_calendar_alarm alarm_index)
```

Retrieves the current alarm time for the alarm specified.

Table 12-22. Parameters

Data direction	Parameter name	Description
[in, out]	module	Pointer to the software instance struct
[out]	alarm	Pointer to the struct that will be filled with alarm time and mask of the specified alarm.
[in]	alarm_index	Index of alarm to get alarm time from.

Returns Status of getting alarm.

Table 12-23. Return Values

Return value	Description
STATUS_OK	If alarm was read correctly.
STATUS_ERR_INVALID_ARG	If invalid argument(s) were provided.

12.6.2.3 Status flag management

Function rtc_calendar_is_overflow()

Check if an RTC overflow has occurred.

```
bool rtc_calendar_is_overflow(
  struct rtc_module *const module)
```

Checks the overflow flag in the RTC. The flag is set when there is an overflow in the clock.

Table 12-24. Parameters

Data direction	Parameter name	Description
[in, out]	module	Pointer to the software instance struct

Returns Overflow state of the RTC module.

Table 12-25. Return Values

Return value	Description
true	If the RTC count value has overflowed
false	If the RTC count value has not overflowed

Function rtc_calendar_clear_overflow()

Clears the RTC overflow flag.

```
void rtc_calendar_clear_overflow(
  struct rtc_module *const module)
```

Table 12-26. Parameters

Data direction	Parameter name	Description
[in, out]	module	Pointer to the software instance struct

Clears the RTC module counter overflow flag, so that new overflow conditions can be detected.

Function rtc_calendar_is_alarm_match()

Check the RTC alarm flag.

```
bool rtc_calendar_is_alarm_match(
  struct rtc_module *const module,
  const enum rtc_calendar_alarm alarm_index)
```

Check if the specified alarm flag is set. The flag is set when there is an compare match between the alarm value and the clock.

Table 12-27. Parameters

Data direction	Parameter name	Description
[in, out]	module	Pointer to the software instance struct
[in]	alarm_index	Index of the alarm to check.

Returns Match status of the specified alarm.

Table 12-28. Return Values

Return value	Description
true	If the specified alarm has matched the current time

Return value	Description
false	If the specified alarm has not matched the current time

Function rtc_calendar_clear_alarm_match()

Clears the RTC alarm match flag.

```
enum status_code rtc_calendar_clear_alarm_match(
  struct rtc_module *const module,
  const enum rtc_calendar_alarm alarm_index)
```

Clear the requested alarm match flag, so that future alarm matches can be determined.

Table 12-29. Parameters

Data direction	Parameter name	Description
[in, out]	module	Pointer to the software instance struct
[in]	alarm_index	The index of the alarm match to clear.

Returns Status of the alarm match clear operation.

Table 12-30. Return Values

Return value	Description
STATUS_OK	If flag was cleared correctly.
STATUS_ERR_INVALID_ARG	If invalid argument(s) were provided.

12.6.2.4 Event management

Function rtc_calendar_enable_events()

Enables a RTC event output.

```
void rtc_calendar_enable_events(
  struct rtc_module *const module,
  struct rtc_calendar_events *const events)
```

Enables one or more output events from the RTC module. See rtc_calendar_events for a list of events this module supports.

Note Events cannot be altered while the module is enabled.

Table 12-31. Parameters

Data direction	Parameter name	Description
[in, out]	module	Pointer to the software instance struct
[in]	events	Struct containing flags of events to enable

Function rtc_calendar_disable_events()

Disables a RTC event output.

```
void rtc_calendar_disable_events(
  struct rtc_module *const module,
  struct rtc_calendar_events *const events)
```

Disabled one or more output events from the RTC module. See rtc_calendar_events for a list of events this module supports.

Note Events cannot be altered while the module is enabled.

Table 12-32. Parameters

Data direction	Parameter name	Description
[in, out]	module	Pointer to the software instance struct
[in]	events	Struct containing flags of events to disable

12.6.2.5 Callbacks

Function rtc_calendar_register_callback()

Registers callback for the specified callback type.

```
enum status_code rtc_calendar_register_callback(
  struct rtc_module *const module,
  rtc_calendar_callback_t callback,
  enum rtc_calendar_callback callback_type)
```

Associates the given callback function with the specified callback type. To enable the callback, the rtc_calendar_enable_callback function must be used.

Table 12-33. Parameters

Data direction	Parameter name	Description
[in, out]	module	Pointer to the software instance struct
[in]	callback	Pointer to the function desired for the specified callback
[in]	callback_type	Callback type to register

Returns Status of registering callback

Table 12-34. Return Values

Return value	Description
STATUS_OK	Registering was done successfully

Return value	Description
STATUS_ERR_INVALID_ARG	If trying to register a callback not available

Function rtc_calendar_unregister_callback()

Unregisters callback for the specified callback type.

```
enum status_code rtc_calendar_unregister_callback(
  struct rtc_module *const module,
  enum rtc_calendar_callback callback_type)
```

When called, the currently registered callback for the given callback type will be removed.

Table 12-35. Parameters

Data direction	Parameter name	Description
[in, out]	module	Pointer to the software instance struct
[in]	callback_type	Specifies the callback type to unregister

Returns Status of unregistering callback

Table 12-36. Return Values

Return value	Description
STATUS_OK	Unregistering was done successfully
STATUS_ERR_INVALID_ARG	If trying to unregister a callback not available

Function rtc_calendar_enable_callback()

Enables callback.

```
void rtc_calendar_enable_callback(
  struct rtc_module *const module,
  enum rtc_calendar_callback callback_type)
```

Enables the callback specified by the callback_type.

Table 12-37. Parameters

Data direction	Parameter name	Description
[in, out]	module	Pointer to the software instance struct
[in]	callback_type	Callback type to enable

Function rtc_calendar_disable_callback()

Disables callback.

```
void rtc_calendar_disable_callback(
  struct rtc_module *const module,
  enum rtc_calendar_callback callback_type)
```

Disables the callback specified by the callback_type.

Table 12-38. Parameters

Data direction	Parameter name	Description
[in, out]	module	Pointer to the software instance struct
[in]	callback_type	Callback type to disable

12.6.3 Enumeration Definitions

12.6.3.1 Enum rtc_calendar_alarm

Available alarm channels.

Note Not all alarm channels are available on all devices.

Table 12-39. Members

Enum value	Description
RTC_CALENDAR_ALARM_0	Alarm channel 0.
RTC_CALENDAR_ALARM_1	Alarm channel 1.
RTC_CALENDAR_ALARM_2	Alarm channel 2.
RTC_CALENDAR_ALARM_3	Alarm channel 3.

12.6.3.2 Enum rtc_calendar_alarm_mask

Available mask options for alarms.

Table 12-40. Members

Enum value	Description
RTC_CALENDAR_ALARM_MASK_DISABLED	Alarm disabled
RTC_CALENDAR_ALARM_MASK_SEC	Alarm match on second
RTC_CALENDAR_ALARM_MASK_MIN	Alarm match on second and minute
RTC_CALENDAR_ALARM_MASK_HOUR	Alarm match on second, minute and hour
RTC_CALENDAR_ALARM_MASK_DAY	Alarm match on second, minutes hour and day
RTC_CALENDAR_ALARM_MASK_MONTH	Alarm match on second, minute, hour, day and month
RTC_CALENDAR_ALARM_MASK_YEAR	Alarm match on second, minute, hour, day, month and year

12.6.3.3 Enum rtc_calendar_callback

The available callback types for the RTC calendar module.

Table 12-41. Members

Enum value	Description
RTC_CALENDAR_CALLBACK_ALARM_0	Callback for alarm 0
RTC_CALENDAR_CALLBACK_ALARM_1	Callback for alarm 1
RTC_CALENDAR_CALLBACK_ALARM_2	Callback for alarm 2
RTC_CALENDAR_CALLBACK_ALARM_3	Callback for alarm 3
RTC_CALENDAR_CALLBACK_OVERFLOW	Callback for overflow

12.6.3.4 Enum rtc_calendar_prescaler

The available input clock prescaler values for the RTC calendar module.

Table 12-42. Members

Enum value	Description
RTC_CALENDAR_PRESCALER_DIV_1	RTC input clock frequency is prescaled by a factor of 1.
RTC_CALENDAR_PRESCALER_DIV_2	RTC input clock frequency is prescaled by a factor of 2.
RTC_CALENDAR_PRESCALER_DIV_4	RTC input clock frequency is prescaled by a factor of 4.
RTC_CALENDAR_PRESCALER_DIV_8	RTC input clock frequency is prescaled by a factor of 8.
RTC_CALENDAR_PRESCALER_DIV_16	RTC input clock frequency is prescaled by a factor of 16.
RTC_CALENDAR_PRESCALER_DIV_32	RTC input clock frequency is prescaled by a factor of 32.
RTC_CALENDAR_PRESCALER_DIV_64	RTC input clock frequency is prescaled by a factor of 64.
RTC_CALENDAR_PRESCALER_DIV_128	RTC input clock frequency is prescaled by a factor of 128.
RTC_CALENDAR_PRESCALER_DIV_256	RTC input clock frequency is prescaled by a factor of 256.
RTC_CALENDAR_PRESCALER_DIV_512	RTC input clock frequency is prescaled by a factor of 512.
RTC_CALENDAR_PRESCALER_DIV_1024	RTC input clock frequency is prescaled by a factor of 1024.

12.7 Extra Information for RTC (CAL) Driver

12.7.1 Acronyms

Below is a table listing the acronyms used in this module, along with their intended meanings.

Acronym	Description
RTC	Real Time Counter

Acronym	Description
PPM	Part Per Million
RC	Resistor/Capacitor

12.7.2 Dependencies

This driver has the following dependencies:

- None

12.7.3 Errata

There are no errata related to this driver.

12.7.4 Module History

An overview of the module history is presented in the table below, with details on the enhancements and fixes made to the module since its first release. The current version of this corresponds to the newest version in the table.

Changelog
Added support for SAMD21 and added driver instance parameter to all API function calls, except get_config_defaults.
Updated initialization function to also enable the digital interface clock to the module if it is disabled.
Initial Release

12.8 Examples for RTC CAL Driver

This is a list of the available Quick Start guides (QSGs) and example applications for SAM D20/D21 RTC Calendar Driver (RTC CAL). QSGs are simple examples with step-by-step instructions to configure and use this driver in a selection of use cases. Note that QSGs can be compiled as a standalone application or be added to the user application.

- Quick Start Guide for RTC (CAL) - Basic
- Quick Start Guide for RTC (CAL) - Callback

12.8.1 Quick Start Guide for RTC (CAL) - Basic

In this use case, the RTC is set up in calendar mode. The time is set and also a alarm is set to show a general use of the RTC in calendar mode. Also the clock is swapped from 24h to 12h mode after initialization. The board LED will be toggled once the current time matches the set time.

12.8.1.1 Prerequisites

The Generic Clock Generator for the RTC should be configured and enabled; if you are using the System Clock driver, this may be done via `conf_clocks.h`.

Clocks and Oscillators

The `conf_clock.h` file needs to be changed with the following values to configure the clocks and oscillators for the module.

The following oscillator settings are needed:

```
/* SYSTEM_CLOCK_SOURCE_OSC32K configuration - Internal 32KHz oscillator */
#  define CONF_CLOCK_OSC32K_ENABLE                 true
#  define CONF_CLOCK_OSC32K_STARTUP_TIME           SYSTEM_OSC32K_STARTUP_130
#  define CONF_CLOCK_OSC32K_ENABLE_1KHZ_OUTPUT     true
```

```
#  define CONF_CLOCK_OSC32K_ENABLE_32KHZ_OUTPUT   true
#  define CONF_CLOCK_OSC32K_ON_DEMAND             true
#  define CONF_CLOCK_OSC32K_RUN_IN_STANDBY        false
```

The following generic clock settings are needed:

```
/* Configure GCLK generator 2 (RTC) */
#  define CONF_CLOCK_GCLK_2_ENABLE                true
#  define CONF_CLOCK_GCLK_2_RUN_IN_STANDBY        false
#  define CONF_CLOCK_GCLK_2_CLOCK_SOURCE          SYSTEM_CLOCK_SOURCE_OSC32K
#  define CONF_CLOCK_GCLK_2_PRESCALER             32
#  define CONF_CLOCK_GCLK_2_OUTPUT_ENABLE         false
```

12.8.1.2 Setup

Initialization Code

Create a rtc_module struct and add to the main application source file, outside of any functions:

```
struct rtc_module rtc_instance;
```

Copy-paste the following setup code to your application:

```
void configure_rtc_calendar(void)
{
    /* Initialize RTC in calendar mode. */
    struct rtc_calendar_config config_rtc_calendar;
    rtc_calendar_get_config_defaults(&config_rtc_calendar);

    struct rtc_calendar_time alarm;
    rtc_calendar_get_time_defaults(&alarm);
    alarm.year   = 2013;
    alarm.month  = 1;
    alarm.day    = 1;
    alarm.hour   = 0;
    alarm.minute = 0;
    alarm.second = 4;

    config_rtc_calendar.clock_24h     = true;
    config_rtc_calendar.alarm[0].time = alarm;
    config_rtc_calendar.alarm[0].mask = RTC_CALENDAR_ALARM_MASK_YEAR;

    rtc_calendar_init(&rtc_instance, RTC, &config_rtc_calendar);

    rtc_calendar_enable(&rtc_instance);
}
```

Add to Main

Add the following to `main()`.

```
system_init();

struct rtc_calendar_time time;
time.year   = 2012;
time.month  = 12;
time.day    = 31;
time.hour   = 23;
```

```
time.minute = 59;
time.second = 59;

configure_rtc_calendar();

/* Set current time. */
rtc_calendar_set_time(&rtc_instance, &time);

rtc_calendar_swap_time_mode(&rtc_instance);
```

Workflow

1. Make configuration structure.

```
struct rtc_calendar_config config_rtc_calendar;
```

2. Fill the configuration structure with the default driver configuration.

```
rtc_calendar_get_config_defaults(&config_rtc_calendar);
```

Note This should always be performed before using the configuration struct to ensure that all values are initialized to known default settings.

3. Make time structure for alarm and set with default and desired values.

```
struct rtc_calendar_time alarm;
rtc_calendar_get_time_defaults(&alarm);
alarm.year   = 2013;
alarm.month  = 1;
alarm.day    = 1;
alarm.hour   = 0;
alarm.minute = 0;
alarm.second = 4;
```

4. Change configurations as desired.

```
config_rtc_calendar.clock_24h     = true;
config_rtc_calendar.alarm[0].time = alarm;
config_rtc_calendar.alarm[0].mask = RTC_CALENDAR_ALARM_MASK_YEAR;
```

5. Initialize module.

```
rtc_calendar_init(&rtc_instance, RTC, &config_rtc_calendar);
```

6. Enable module

```
rtc_calendar_enable(&rtc_instance);
```

12.8.1.3 Implementation

Add the following to `main()`.

```
while (true) {
```

```
    if (rtc_calendar_is_alarm_match(&rtc_instance, RTC_CALENDAR_ALARM_0)) {
        /* Do something on RTC alarm match here */
        port_pin_toggle_output_level(LED_0_PIN);

        rtc_calendar_clear_alarm_match(&rtc_instance, RTC_CALENDAR_ALARM_0);
    }
}
```

Workflow

1. Start an infinite loop, to continuously poll for a RTC alarm match.

```
while (true) {
```

2. Check to see if a RTC alarm match has occurred.

```
if (rtc_calendar_is_alarm_match(&rtc_instance, RTC_CALENDAR_ALARM_0)) {
```

3. Once an alarm match occurs, perform the desired user action.

```
/* Do something on RTC alarm match here */
port_pin_toggle_output_level(LED_0_PIN);
```

4. Clear the alarm match, so that future alarms may occur.

```
rtc_calendar_clear_alarm_match(&rtc_instance, RTC_CALENDAR_ALARM_0);
```

12.8.2 Quick Start Guide for RTC (CAL) - Callback

In this use case, the RTC is set up in calendar mode. The time is set and an alarm is enabled, as well as a callback for when the alarm time is hit. Each time the callback fires, the alarm time is reset to 5 seconds in the future and the board LED toggled.

12.8.2.1 Prerequisites

The Generic Clock Generator for the RTC should be configured and enabled; if you are using the System Clock driver, this may be done via `conf_clocks.h`.

Clocks and Oscillators

The `conf_clock.h` file needs to be changed with the following values to configure the clocks and oscillators for the module.

The following oscillator settings are needed:

```
/* SYSTEM_CLOCK_SOURCE_OSC32K configuration - Internal 32KHz oscillator */
#  define CONF_CLOCK_OSC32K_ENABLE                 true
#  define CONF_CLOCK_OSC32K_STARTUP_TIME           SYSTEM_OSC32K_STARTUP_130
#  define CONF_CLOCK_OSC32K_ENABLE_1KHZ_OUTPUT     true
#  define CONF_CLOCK_OSC32K_ENABLE_32KHZ_OUTPUT    true
#  define CONF_CLOCK_OSC32K_ON_DEMAND              true
#  define CONF_CLOCK_OSC32K_RUN_IN_STANDBY         false
```

The following generic clock settings are needed:

```
/* Configure GCLK generator 2 (RTC) */
#  define CONF_CLOCK_GCLK_2_ENABLE                 true
```

```
#  define CONF_CLOCK_GCLK_2_RUN_IN_STANDBY        false
#  define CONF_CLOCK_GCLK_2_CLOCK_SOURCE          SYSTEM_CLOCK_SOURCE_OSC32K
#  define CONF_CLOCK_GCLK_2_PRESCALER             32
#  define CONF_CLOCK_GCLK_2_OUTPUT_ENABLE         false
```

12.8.2.2 Setup

Code

Create a rtc_module struct and add to the main application source file, outside of any functions:

```
struct rtc_module rtc_instance;
```

The following must be added to the user application:

Function for setting up the module:

```
void configure_rtc_calendar(void)
{
    /* Initialize RTC in calendar mode. */
    struct rtc_calendar_config config_rtc_calendar;
    rtc_calendar_get_config_defaults(&config_rtc_calendar);

    struct rtc_calendar_time alarm;
    rtc_calendar_get_time_defaults(&alarm);
    alarm.year      = 2013;
    alarm.month     = 1;
    alarm.day       = 1;
    alarm.hour      = 0;
    alarm.minute    = 0;
    alarm.second    = 4;

    config_rtc_calendar.clock_24h = true;
    config_rtc_calendar.alarm[0].time = alarm;
    config_rtc_calendar.alarm[0].mask = RTC_CALENDAR_ALARM_MASK_YEAR;

    rtc_calendar_init(&rtc_instance, RTC, &config_rtc_calendar);

    rtc_calendar_enable(&rtc_instance);
}
```

Callback function:

```
void rtc_match_callback(void)
{
    /* Do something on RTC alarm match here */
    port_pin_toggle_output_level(LED_0_PIN);

    /* Set new alarm in 5 seconds */
    struct rtc_calendar_alarm_time alarm;
    rtc_calendar_get_time(&rtc_instance, &alarm.time);

    alarm.mask = RTC_CALENDAR_ALARM_MASK_SEC;

    alarm.time.second += 5;
    alarm.time.second = alarm.time.second % 60;

    rtc_calendar_set_alarm(&rtc_instance, &alarm, RTC_CALENDAR_ALARM_0);
}
```

Function for setting up the callback functionality of the driver:

```
void configure_rtc_callbacks(void)
{
    rtc_calendar_register_callback(
            &rtc_instance, rtc_match_callback, RTC_CALENDAR_CALLBACK_ALARM_0);
    rtc_calendar_enable_callback(&rtc_instance, RTC_CALENDAR_CALLBACK_ALARM_0);
}
```

Add to user application `main()`:

```
system_init();

struct rtc_calendar_time time;
rtc_calendar_get_time_defaults(&time);
time.year   = 2012;
time.month  = 12;
time.day    = 31;
time.hour   = 23;
time.minute = 59;
time.second = 59;

/* Configure and enable RTC */
configure_rtc_calendar();

/* Configure and enable callback */
configure_rtc_callbacks();

/* Set current time. */
rtc_calendar_set_time(&rtc_instance, &time);
```

Workflow

1. Initialize system.

   ```
   system_init();
   ```

2. Create and initialize a time structure.

   ```
   struct rtc_calendar_time time;
   rtc_calendar_get_time_defaults(&time);
   time.year   = 2012;
   time.month  = 12;
   time.day    = 31;
   time.hour   = 23;
   time.minute = 59;
   time.second = 59;
   ```

3. Configure and enable module.

   ```
   configure_rtc_calendar();
   ```

   a. Create a RTC configuration structure to hold the desired RTC driver settings and fill it with the default driver configuration values.

      ```
      struct rtc_calendar_config config_rtc_calendar;
      ```

```
rtc_calendar_get_config_defaults(&config_rtc_calendar);
```

Note This should always be performed before using the configuration struct to ensure that all values are initialized to known default settings.

b. Create and initialize an alarm.

```
struct rtc_calendar_time alarm;
rtc_calendar_get_time_defaults(&alarm);
alarm.year      = 2013;
alarm.month     = 1;
alarm.day       = 1;
alarm.hour      = 0;
alarm.minute    = 0;
alarm.second    = 4;
```

c. Change settings in the configuration and set alarm.

```
config_rtc_calendar.clock_24h = true;
config_rtc_calendar.alarm[0].time = alarm;
config_rtc_calendar.alarm[0].mask = RTC_CALENDAR_ALARM_MASK_YEAR;
```

d. Initialize the module with the set configurations.

```
rtc_calendar_init(&rtc_instance, RTC, &config_rtc_calendar);
```

e. Enable the module.

```
rtc_calendar_enable(&rtc_instance);
```

4. Configure callback functionality.

```
configure_rtc_callbacks();
```

a. Register overflow callback.

```
rtc_calendar_register_callback(
        &rtc_instance, rtc_match_callback, RTC_CALENDAR_CALLBACK_ALARM_0);
```

b. Enable overflow callback.

```
rtc_calendar_enable_callback(&rtc_instance, RTC_CALENDAR_CALLBACK_ALARM_0);
```

5. Set time of the RTC calendar.

```
rtc_calendar_set_time(&rtc_instance, &time);
```

12.8.2.3 Implementation

Code

Add to user application main:

```
while (true) {
    /* Infinite loop */
}
```

Workflow

1. Infinite while loop while waiting for callbacks.

```
while (true) {
```

12.8.2.4 Callback

Each time the RTC time matches the configured alarm, the callback function will be called.

Workflow

1. Create alarm struct and initialize the time with current time.

```
struct rtc_calendar_alarm_time alarm;
rtc_calendar_get_time(&rtc_instance, &alarm.time);
```

2. Set alarm to trigger on seconds only.

```
alarm.mask = RTC_CALENDAR_ALARM_MASK_SEC;
```

3. Add one second to the current time and set new alarm.

```
alarm.time.second += 5;
alarm.time.second = alarm.time.second % 60;

rtc_calendar_set_alarm(&rtc_instance, &alarm, RTC_CALENDAR_ALARM_0);
```

13. SAM D20/D21 RTC Count Driver (RTC COUNT)

This driver for SAM D20/D21 devices provides an interface for the configuration and management of the device's Real Time Clock functionality in Count operating mode, for the configuration and retrieval of the current RTC counter value. The following driver API modes are covered by this manual:

- Polled APIs
- Callback APIs

The following peripherals are used by this module:

- RTC (Real Time Clock)

The outline of this documentation is as follows:

- Prerequisites
- Module Overview
- Special Considerations
- Extra Information
- Examples
- API Overview

13.1 Prerequisites

There are no prerequisites for this module.

13.2 Module Overview

The RTC module in the SAM D20/D21 devices is a 32-bit counter, with a 10-bit programmable prescaler. Typically, the RTC clock is run continuously, including in the device's low-power sleep modes, to track the current time and date information. The RTC can be used as a source to wake up the system at a scheduled time or periodically using the alarm functions.

In this driver, the RTC is operated in Count mode. This allows for an easy integration of an asynchronous counter into a user application, which is capable of operating while the device is in sleep mode.

Whilst operating in Count mode, the RTC features:

- 16-bit counter mode
  - Selectable counter period
  - Up to 6 configurable compare values
- 32-bit counter mode
  - Clear counter value on match
  - Up to 4 configurable compare values

13.3 Compare and Overflow

The RTC can be used with up to 4/6 compare values (depending on selected operation mode). These compare values will trigger on match with the current RTC counter value, and can be set up to trigger an interrupt, event, or both. The RTC can also be configured to clear the counter value on compare match in 32-bit mode, resetting the count value back to zero.

If the RTC is operated without the Clear on Match option enabled, or in 16-bit mode, the RTC counter value will instead be cleared on overflow once the maximum count value has been reached:

$$COUNT_{MAX} = 2^{32} - 1 \tag{13.1}$$

for 32-bit counter mode, and

$$COUNT_{MAX} = 2^{16} - 1 \tag{13.2}$$

for 16-bit counter mode.

When running in 16-bit mode, the overflow value is selectable with a period value. The counter overflow will then occur when the counter value reaches the specified period value.

13.3.1 Periodic Events

The RTC can generate events at periodic intervals, allowing for direct peripheral actions without CPU intervention. The periodic events can be generated on the upper 8 bits of the RTC prescaler, and will be generated on the rising edge transition of the specified bit. The resulting periodic frequency can be calculated by the following formula:

$$f_{PERIODIC} = \frac{f_{ASY}}{2^{n+3}} \tag{13.3}$$

Where

$$f_{ASY} \tag{13.4}$$

refers to the *asynchronous* clock set up in the RTC module configuration. The **n** parameter is the event source generator index of the RTC module. If the asynchronous clock is operated at the recommended frequency of 1 KHz, the formula results in the values shown in Table 13-1: RTC event frequencies for each prescaler bit using a 1KHz clock on page 294.

Table 13-1. RTC event frequencies for each prescaler bit using a 1KHz clock

n	Periodic event
7	1 Hz
6	2 Hz
5	4 Hz
4	8 Hz
3	16 Hz
2	32 Hz
1	64 Hz
0	128 Hz

Note The connection of events between modules requires the use of the SAM D20/D21 Event System Driver (EVENTS) to route output event of one module to the the input event of another. For more information on event routing, refer to the event driver documentation.

13.3.2 Digital Frequency Correction

The RTC module contains Digital Frequency Correction logic to compensate for inaccurate source clock frequencies which would otherwise result in skewed time measurements. The correction scheme requires that at least two bits in the RTC module prescaler are reserved by the correction logic. As a result of this implementation, frequency correction is only available when the RTC is running from a 1 Hz reference clock.

The correction procedure is implemented by subtracting or adding a single cycle from the RTC prescaler every 1024 RTC GCLK cycles. The adjustment is applied the specified number of time (max 127) over 976 of these periods. The corresponding correction in PPM will be given by:

$$Correction(PPM) = \frac{VALUE}{999424}10^6 \quad (13.5)$$

The RTC clock will tick faster if provided with a positive correction value, and slower when given a negative correction value.

13.4 Special Considerations

13.4.1 Clock Setup

The RTC is typically clocked by a specialized GCLK generator that has a smaller prescaler than the others. By default the RTC clock is on, selected to use the internal 32 KHz RC-oscillator with a prescaler of 32, giving a resulting clock frequency of 1 KHz to the RTC. When the internal RTC prescaler is set to 1024, this yields an end-frequency of 1 Hz.

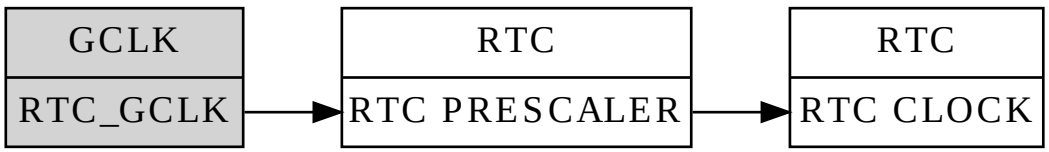
The implementer also has the option to set other end-frequencies. Table 13-2: RTC output frequencies from allowable input clocks on page 295 lists the available RTC frequencies for each possible GCLK and RTC input prescaler options.

Table 13-2. RTC output frequencies from allowable input clocks

End-frequency	GCLK prescaler	RTC Prescaler
32 KHz	1	1
1 KHz	32	1
1 Hz	32	1024

The overall RTC module clocking scheme is shown in Figure 13-1: Clock Setup on page 295.

Figure 13-1. Clock Setup



13.5 Extra Information

For extra information see Extra Information for RTC COUNT Driver. This includes:

- Acronyms
- Dependencies
- Errata
- Module History

13.6 Examples

For a list of examples related to this driver, see Examples for RTC (COUNT) Driver.

13.7 API Overview

13.7.1 Structure Definitions

13.7.1.1 Struct rtc_count_config

Configuration structure for the RTC instance. This structure should be initialized using the rtc_count_get_config_defaults() before any user configurations are set.

Table 13-3. Members

Type	Name	Description
bool	clear_on_match	If true, clears the counter value on compare match. Only available whilst running in 32-bit mode.
uint32_t	compare_values[]	Array of Compare values. Not all Compare values are available in 32-bit mode.
bool	continuously_update	Continuously update the counter value so no synchronization is needed for reading.
enum rtc_count_mode	mode	Select the operation mode of the RTC.
enum rtc_count_prescaler	prescaler	Input clock prescaler for the RTC module.

13.7.1.2 Struct rtc_count_events

Event flags for the rtc_count_enable_events() and rtc_count_disable_events().

Table 13-4. Members

Type	Name	Description
bool	generate_event_on_compare[]	Generate an output event on a compare channel match against the RTC count.
bool	generate_event_on_overflow	Generate an output event on each overflow of the RTC count.
bool	generate_event_on_periodic[]	Generate an output event periodically at a binary division of the RTC counter frequency (see Periodic Events).

13.7.2 Function Definitions

13.7.2.1 Configuration and initialization

Function rtc_count_is_syncing()

Determines if the hardware module(s) are currently synchronizing to the bus.

```
bool rtc_count_is_syncing(
  struct rtc_module *const module)
```

Checks to see if the underlying hardware peripheral module(s) are currently synchronizing across multiple clock domains to the hardware bus, This function can be used to delay further operations on a module until such time that it is ready, to prevent blocking delays for synchronization in the user application.

Table 13-5. Parameters

Data direction	Parameter name	Description
[in]	module	RTC hardware module

Returns Synchronization status of the underlying hardware module(s).

Table 13-6. Return Values

Return value	Description
true	if the module has completed synchronization
false	if the module synchronization is ongoing

Function rtc_count_get_config_defaults()

Gets the RTC default configurations.

```
void rtc_count_get_config_defaults(
  struct rtc_count_config *const config)
```

Initializes the configuration structure to default values. This function should be called at the start of any RTC initialization.

The default configuration is as follows:

- Input clock divided by a factor of 1024.
- RTC in 32 bit mode.
- Clear on compare match off.
- Continuously sync count register off.
- No event source on.
- All compare values equal 0.

Table 13-7. Parameters

Data direction	Parameter name	Description
[out]	config	Configuration structure to be initialized to default values.

Function rtc_count_reset()

Resets the RTC module. Resets the RTC to hardware defaults.

```
void rtc_count_reset(
  struct rtc_module *const module)
```

Table 13-8. Parameters

Data direction	Parameter name	Description
[in, out]	module	Pointer to the software instance struct

Function rtc_count_enable()

Enables the RTC module.

```
void rtc_count_enable(
  struct rtc_module *const module)
```

Enables the RTC module once it has been configured, ready for use. Most module configuration parameters cannot be altered while the module is enabled.

Table 13-9. Parameters

Data direction	Parameter name	Description
[in, out]	module	RTC hardware module

Function rtc_count_disable()

Disables the RTC module.

```
void rtc_count_disable(
  struct rtc_module *const module)
```

Disables the RTC module.

Table 13-10. Parameters

Data direction	Parameter name	Description
[in, out]	module	RTC hardware module

Function rtc_count_init()

Initializes the RTC module with given configurations.

```
enum status_code rtc_count_init(
  struct rtc_module *const module,
  Rtc *const hw,
  const struct rtc_count_config *const config)
```

Initializes the module, setting up all given configurations to provide the desired functionality of the RTC.

Table 13-11. Parameters

Data direction	Parameter name	Description
[out]	module	Pointer to the software instance struct
[in]	hw	Pointer to hardware instance
[in]	config	Pointer to the configuration structure.

Returns Status of the initialization procedure.

Table 13-12. Return Values

Return value	Description
STATUS_OK	If the initialization was run stressfully.

Return value	Description
STATUS_ERR_INVALID_ARG	If invalid argument(s) were given.

Function rtc_count_frequency_correction()

Calibrate for too-slow or too-fast oscillator.

```
enum status_code rtc_count_frequency_correction(
  struct rtc_module *const module,
  const int8_t value)
```

When used, the RTC will compensate for an inaccurate oscillator. The RTC module will add or subtract cycles from the RTC prescaler to adjust the frequency in approximately 1 PPM steps. The provided correction value should be between 0 and 127, allowing for a maximum 127 PPM correction.

If no correction is needed, set value to zero.

Note Can only be used when the RTC is operated in 1Hz.

Table 13-13. Parameters

Data direction	Parameter name	Description
[in, out]	module	Pointer to the software instance struct
[in]	value	Ranging from -127 to 127 used for the correction.

Returns Status of the calibration procedure.

Table 13-14. Return Values

Return value	Description
STATUS_OK	If calibration was executed correctly.
STATUS_ERR_INVALID_ARG	If invalid argument(s) were provided.

13.7.2.2 Count and compare value management

Function rtc_count_set_count()

Set the current count value to desired value.

```
enum status_code rtc_count_set_count(
  struct rtc_module *const module,
  const uint32_t count_value)
```

Sets the value of the counter to the specified value.

Table 13-15. Parameters

Data direction	Parameter name	Description
[in, out]	module	Pointer to the software instance struct

Data direction	Parameter name	Description
[in]	count_value	The value to be set in count register.

Returns Status of setting the register.

Table 13-16. Return Values

Return value	Description
STATUS_OK	If everything was executed correctly.
STATUS_ERR_INVALID_ARG	If invalid argument(s) were provided.

Function rtc_count_get_count()

Get the current count value.

```
uint32_t rtc_count_get_count(
  struct rtc_module *const module)
```

Table 13-17. Parameters

Data direction	Parameter name	Description
[in, out]	module	Pointer to the software instance struct

Returns the current count value.

Returns The current counter value as a 32 bit unsigned integer.

Function rtc_count_set_compare()

Set the compare value for the specified compare.

```
enum status_code rtc_count_set_compare(
  struct rtc_module *const module,
  const uint32_t comp_value,
  const enum rtc_count_compare comp_index)
```

Sets the value specified by the implementer to the requested compare.

Note Compare 4 and 5 are only available in 16 bit mode.

Table 13-18. Parameters

Data direction	Parameter name	Description
[in, out]	module	Pointer to the software instance struct
[in]	comp_value	The value to be written to the compare.

Data direction	Parameter name	Description
[in]	comp_index	Index of the compare to set.

Returns Status indicating if compare was successfully set.

Table 13-19. Return Values

Return value	Description
STATUS_OK	If compare was successfully set.
STATUS_ERR_INVALID_ARG	If invalid argument(s) were provided.
STATUS_ERR_BAD_FORMAT	If the module was not initialized in a mode.

Function rtc_count_get_compare()

Get the current compare value of specified compare.

```
enum status_code rtc_count_get_compare(
  struct rtc_module *const module,
  uint32_t *const comp_value,
  const enum rtc_count_compare comp_index)
```

Retrieves the current value of the specified compare.

Note Compare 4 and 5 are only available in 16 bit mode.

Table 13-20. Parameters

Data direction	Parameter name	Description
[in, out]	module	Pointer to the software instance struct
[out]	comp_value	Pointer to 32 bit integer that will be populated with the current compare value.
[in]	comp_index	Index of compare to check.

Returns Status of the reading procedure.

Table 13-21. Return Values

Return value	Description
STATUS_OK	If the value was read correctly.
STATUS_ERR_INVALID_ARG	If invalid argument(s) were provided.
STATUS_ERR_BAD_FORMAT	If the module was not initialized in a mode.

Function rtc_count_set_period()

Set the given value to the period.

```
enum status_code rtc_count_set_period(
  struct rtc_module *const module,
  uint16_t period_value)
```

Sets the given value to the period.

Note Only available in 16 bit mode.

Table 13-22. Parameters

Data direction	Parameter name	Description
[in, out]	module	Pointer to the software instance struct
[in]	period_value	The value to set to the period.

Returns Status of setting the period value.

Table 13-23. Return Values

Return value	Description
STATUS_OK	If the period was set correctly.
STATUS_ERR_UNSUPPORTED_DEV	If module is not operated in 16 bit mode.

Function rtc_count_get_period()

Retrieves the value of period.

```
enum status_code rtc_count_get_period(
  struct rtc_module *const module,
  uint16_t *const period_value)
```

Retrieves the value of the period for the 16 bit mode counter.

Note Only available in 16 bit mode.

Table 13-24. Parameters

Data direction	Parameter name	Description
[in, out]	module	Pointer to the software instance struct
[out]	period_value	Pointer to value for return argument.

Returns Status of getting the period value.

Table 13-25. Return Values

Return value	Description
STATUS_OK	If the period value was read correctly.

Return value	Description
STATUS_ERR_UNSUPPORTED_DEV	If incorrect mode was set.

13.7.2.3 Status management

Function rtc_count_is_overflow()

Check if an RTC overflow has occurred.

```
bool rtc_count_is_overflow(
  struct rtc_module *const module)
```

Checks the overflow flag in the RTC. The flag is set when there is an overflow in the clock.

Table 13-26. Parameters

Data direction	Parameter name	Description
[in, out]	module	RTC hardware module

Returns

Overflow state of the RTC module.

Table 13-27. Return Values

Return value	Description
true	If the RTC count value has overflowed
false	If the RTC count value has not overflowed

Function rtc_count_clear_overflow()

Clears the RTC overflow flag.

```
void rtc_count_clear_overflow(
  struct rtc_module *const module)
```

Clears the RTC module counter overflow flag, so that new overflow conditions can be detected.

Table 13-28. Parameters

Data direction	Parameter name	Description
[in, out]	module	RTC hardware module

Function rtc_count_is_compare_match()

Check if RTC compare match has occurred.

```
bool rtc_count_is_compare_match(
  struct rtc_module *const module,
  const enum rtc_count_compare comp_index)
```

Checks the compare flag to see if a match has occurred. The compare flag is set when there is a compare match between counter and the compare.

Note Compare 4 and 5 are only available in 16 bit mode.

Table 13-29. Parameters

Data direction	Parameter name	Description
[in, out]	module	Pointer to the software instance struct
[in]	comp_index	Index of compare to check current flag.

Function rtc_count_clear_compare_match()

Clears RTC compare match flag.

```
enum status_code rtc_count_clear_compare_match(
  struct rtc_module *const module,
  const enum rtc_count_compare comp_index)
```

Clears the compare flag. The compare flag is set when there is a compare match between the counter and the compare.

Note Compare 4 and 5 are only available in 16 bit mode.

Table 13-30. Parameters

Data direction	Parameter name	Description
[in, out]	module	Pointer to the software instance struct
[in]	comp_index	Index of compare to check current flag.

Returns Status indicating if flag was successfully cleared.

Table 13-31. Return Values

Return value	Description
STATUS_OK	If flag was successfully cleared.
STATUS_ERR_INVALID_ARG	If invalid argument(s) were provided.
STATUS_ERR_BAD_FORMAT	If the module was not initialized in a mode.

13.7.2.4 Event management

Function rtc_count_enable_events()

Enables a RTC event output.

```
void rtc_count_enable_events(
  struct rtc_module *const module,
  struct rtc_count_events *const events)
```

Enables one or more output events from the RTC module. See rtc_count_events for a list of events this module supports.

Note Events cannot be altered while the module is enabled.

Table 13-32. Parameters

Data direction	Parameter name	Description
[in, out]	module	RTC hardware module
[in]	events	Struct containing flags of events to enable

Function rtc_count_disable_events()

Disables a RTC event output.

```
void rtc_count_disable_events(
  struct rtc_module *const module,
  struct rtc_count_events *const events)
```

Disabled one or more output events from the RTC module. See rtc_count_events for a list of events this module supports.

Note Events cannot be altered while the module is enabled.

Table 13-33. Parameters

Data direction	Parameter name	Description
[in, out]	module	RTC hardware module
[in]	events	Struct containing flags of events to disable

13.7.2.5 Callbacks

Function rtc_count_register_callback()

Registers callback for the specified callback type.

```
enum status_code rtc_count_register_callback(
  struct rtc_module *const module,
  rtc_count_callback_t callback,
  enum rtc_count_callback callback_type)
```

Associates the given callback function with the specified callback type. To enable the callback, the rtc_count_enable_callback function must be used.

Table 13-34. Parameters

Data direction	Parameter name	Description
[in, out]	module	Pointer to the software instance struct
[in]	callback	Pointer to the function desired for the specified callback
[in]	callback_type	Callback type to register

Returns Status of registering callback

Table 13-35. Return Values

Return value	Description
STATUS_OK	Registering was done successfully
STATUS_ERR_INVALID_ARG	If trying to register a callback not available

Function rtc_count_unregister_callback()

Unregisters callback for the specified callback type.

```
enum status_code rtc_count_unregister_callback(
  struct rtc_module *const module,
  enum rtc_count_callback callback_type)
```

When called, the currently registered callback for the given callback type will be removed.

Table 13-36. Parameters

Data direction	Parameter name	Description
[in, out]	module	Pointer to the software instance struct
[in]	callback_type	Specifies the callback type to unregister

Returns Status of unregistering callback

Table 13-37. Return Values

Return value	Description
STATUS_OK	Unregistering was done successfully
STATUS_ERR_INVALID_ARG	If trying to unregister a callback not available

Function rtc_count_enable_callback()

Enables callback.

```
void rtc_count_enable_callback(
  struct rtc_module *const module,
  enum rtc_count_callback callback_type)
```

Enables the callback specified by the callback_type.

Table 13-38. Parameters

Data direction	Parameter name	Description
[in, out]	module	Pointer to the software instance struct
[in]	callback_type	Callback type to enable

Function rtc_count_disable_callback()

Disables callback.

```
void rtc_count_disable_callback(
  struct rtc_module *const module,
  enum rtc_count_callback callback_type)
```

Disables the callback specified by the callback_type.

Table 13-39. Parameters

Data direction	Parameter name	Description
[in, out]	module	Pointer to the software instance struct
[in]	callback_type	Callback type to disable

13.7.3 Enumeration Definitions

13.7.3.1 Enum rtc_count_callback

The available callback types for the RTC count module.

Table 13-40. Members

Enum value	Description
RTC_COUNT_CALLBACK_COMPARE_0	Callback for compare channel 0
RTC_COUNT_CALLBACK_COMPARE_1	Callback for compare channel 1
RTC_COUNT_CALLBACK_COMPARE_2	Callback for compare channel 2
RTC_COUNT_CALLBACK_COMPARE_3	Callback for compare channel 3
RTC_COUNT_CALLBACK_COMPARE_4	Callback for compare channel 4
RTC_COUNT_CALLBACK_COMPARE_5	Callback for compare channel 5
RTC_COUNT_CALLBACK_OVERFLOW	Callback for overflow

13.7.3.2 Enum rtc_count_compare

Note Not all compare channels are available in all devices and modes.

Table 13-41. Members

Enum value	Description
RTC_COUNT_COMPARE_0	Compare channel 0.
RTC_COUNT_COMPARE_1	Compare channel 1.
RTC_COUNT_COMPARE_2	Compare channel 2.
RTC_COUNT_COMPARE_3	Compare channel 3.
RTC_COUNT_COMPARE_4	Compare channel 4.
RTC_COUNT_COMPARE_5	Compare channel 5.

13.7.3.3 Enum rtc_count_mode

RTC Count operating modes, to select the counting width and associated module operation.

Table 13-42. Members

Enum value	Description
RTC_COUNT_MODE_16BIT	RTC Count module operates in 16-bit mode.
RTC_COUNT_MODE_32BIT	RTC Count module operates in 32-bit mode.

13.7.3.4 Enum rtc_count_prescaler

The available input clock prescaler values for the RTC count module.

Table 13-43. Members

Enum value	Description
RTC_COUNT_PRESCALER_DIV_1	RTC input clock frequency is prescaled by a factor of 1.
RTC_COUNT_PRESCALER_DIV_2	RTC input clock frequency is prescaled by a factor of 2.
RTC_COUNT_PRESCALER_DIV_4	RTC input clock frequency is prescaled by a factor of 4.
RTC_COUNT_PRESCALER_DIV_8	RTC input clock frequency is prescaled by a factor of 8.
RTC_COUNT_PRESCALER_DIV_16	RTC input clock frequency is prescaled by a factor of 16.
RTC_COUNT_PRESCALER_DIV_32	RTC input clock frequency is prescaled by a factor of 32.
RTC_COUNT_PRESCALER_DIV_64	RTC input clock frequency is prescaled by a factor of 64.
RTC_COUNT_PRESCALER_DIV_128	RTC input clock frequency is prescaled by a factor of 128.
RTC_COUNT_PRESCALER_DIV_256	RTC input clock frequency is prescaled by a factor of 256.
RTC_COUNT_PRESCALER_DIV_512	RTC input clock frequency is prescaled by a factor of 512.

Enum value	Description
RTC_COUNT_PRESCALER_DIV_1024	RTC input clock frequency is prescaled by a factor of 1024.

13.8 Extra Information for RTC COUNT Driver

13.8.1 Acronyms

Below is a table listing the acronyms used in this module, along with their intended meanings.

Acronym	Description
RTC	Real Time Counter
PPM	Part Per Million
RC	Resistor/Capacitor

13.8.2 Dependencies

This driver has the following dependencies:

- None

13.8.3 Errata

There are no errata related to this driver.

13.8.4 Module History

An overview of the module history is presented in the table below, with details on the enhancements and fixes made to the module since its first release. The current version of this corresponds to the newest version in the table.

Changelog
Added support for SAMD21 and added driver instance parameter to all API function calls, except get_config_defaults.
Updated initialization function to also enable the digital interface clock to the module if it is disabled.
Initial Release

13.9 Examples for RTC (COUNT) Driver

This is a list of the available Quick Start guides (QSGs) and example applications for SAM D20/D21 RTC Count Driver (RTC COUNT). QSGs are simple examples with step-by-step instructions to configure and use this driver in a selection of use cases. Note that QSGs can be compiled as a standalone application or be added to the user application.

- Quick Start Guide for RTC (COUNT) - Basic
- Quick Start Guide for RTC (COUNT) - Callback

13.9.1 Quick Start Guide for RTC (COUNT) - Basic

In this use case, the RTC is set up in count mode. The example configures the RTC in 16 bit mode, with continuous updates to the COUNT register, together with a set compare register value. Every 1000ms a LED on the board is toggled.

13.9.1.1 Prerequisites

The Generic Clock Generator for the RTC should be configured and enabled; if you are using the System Clock driver, this may be done via `conf_clocks.h`.

Clocks and Oscillators

The `conf_clock.h` file needs to be changed with the following values to configure the clocks and oscillators for the module.

The following oscillator settings are needed:

```
/* SYSTEM_CLOCK_SOURCE_OSC32K configuration - Internal 32KHz oscillator */
#  define CONF_CLOCK_OSC32K_ENABLE                 true
#  define CONF_CLOCK_OSC32K_STARTUP_TIME           SYSTEM_OSC32K_STARTUP_130
#  define CONF_CLOCK_OSC32K_ENABLE_1KHZ_OUTPUT     true
#  define CONF_CLOCK_OSC32K_ENABLE_32KHZ_OUTPUT    true
#  define CONF_CLOCK_OSC32K_ON_DEMAND              true
#  define CONF_CLOCK_OSC32K_RUN_IN_STANDBY         false
```

The following generic clock settings are needed:

```
/* Configure GCLK generator 2 (RTC) */
#  define CONF_CLOCK_GCLK_2_ENABLE                 true
#  define CONF_CLOCK_GCLK_2_RUN_IN_STANDBY         false
#  define CONF_CLOCK_GCLK_2_CLOCK_SOURCE           SYSTEM_CLOCK_SOURCE_OSC32K
#  define CONF_CLOCK_GCLK_2_PRESCALER              32
#  define CONF_CLOCK_GCLK_2_OUTPUT_ENABLE          false
```

13.9.1.2 Setup

Initialization Code

Create a rtc_module struct and add to the main application source file, outside of any functions:

```
struct rtc_module rtc_instance;
```

Copy-paste the following setup code to your applications `main()`:

```
void configure_rtc_count(void)
{
    struct rtc_count_config config_rtc_count;

    rtc_count_get_config_defaults(&config_rtc_count);

    config_rtc_count.prescaler           = RTC_COUNT_PRESCALER_DIV_1;
    config_rtc_count.mode                = RTC_COUNT_MODE_16BIT;
    config_rtc_count.continuously_update = true;
    config_rtc_count.compare_values[0]   = 1000;
    rtc_count_init(&rtc_instance, RTC, &config_rtc_count);

    rtc_count_enable(&rtc_instance);
}
```

Add to Main

Add the following to your `main()`.

```
configure_rtc_count();
```

Workflow

1. Create a RTC configuration structure to hold the desired RTC driver settings.

```
struct rtc_count_config config_rtc_count;
```

2. Fill the configuration structure with the default driver configuration.

```
rtc_count_get_config_defaults(&config_rtc_count);
```

Note This should always be performed before using the configuration struct to ensure that all values are initialized to known default settings.

3. Alter the RTC driver configuration to run in 16-bit counting mode, with continuous counter register updates.

```
config_rtc_count.prescaler           = RTC_COUNT_PRESCALER_DIV_1;
config_rtc_count.mode                = RTC_COUNT_MODE_16BIT;
config_rtc_count.continuously_update = true;
config_rtc_count.compare_values[0]   = 1000;
```

4. Initialize the RTC module.

```
rtc_count_init(&rtc_instance, RTC, &config_rtc_count);
```

5. Enable the RTC module, so that it may begin counting.

```
rtc_count_enable(&rtc_instance);
```

13.9.1.3 Implementation

Code used to implement the initialized module.

Code

Add after initialization in main().

```
rtc_count_set_period(&rtc_instance, 2000);

while (true) {
    if (rtc_count_is_compare_match(&rtc_instance, RTC_COUNT_COMPARE_0)) {
        /* Do something on RTC count match here */
        port_pin_toggle_output_level(LED_0_PIN);

        rtc_count_clear_compare_match(&rtc_instance, RTC_COUNT_COMPARE_0);
    }
}
```

Workflow

1. Set RTC period to 2000ms (2 seconds) so that it will overflow and reset back to zero every two seconds.

```
rtc_count_set_period(&rtc_instance, 2000);
```

2. Enter an infinite loop to poll the RTC driver to check when a comparison match occurs.

```
while (true) {
```

3. Check if the RTC driver has found a match on compare channel 0 against the current RTC count value.

```
if (rtc_count_is_compare_match(&rtc_instance, RTC_COUNT_COMPARE_0)) {
```

4. Once a compare match occurs, perform the desired user action.

```
/* Do something on RTC count match here */
port_pin_toggle_output_level(LED_0_PIN);
```

5. Clear the compare match, so that future matches may occur.

```
rtc_count_clear_compare_match(&rtc_instance, RTC_COUNT_COMPARE_0);
```

13.9.2 Quick Start Guide for RTC (COUNT) - Callback

In this use case, the RTC is set up in count mode. The quick start configures the RTC in 16 bit mode and to continuously update COUNT register. The rest of the configuration is according to the default. A callback is implemented for when the RTC overflows.

13.9.2.1 Prerequisites

The Generic Clock Generator for the RTC should be configured and enabled; if you are using the System Clock driver, this may be done via `conf_clocks.h`.

Clocks and Oscillators

The `conf_clock.h` file needs to be changed with the following values to configure the clocks and oscillators for the module.

The following oscillator settings are needed:

```
/* SYSTEM_CLOCK_SOURCE_OSC32K configuration - Internal 32KHz oscillator */
#  define CONF_CLOCK_OSC32K_ENABLE                 true
#  define CONF_CLOCK_OSC32K_STARTUP_TIME           SYSTEM_OSC32K_STARTUP_130
#  define CONF_CLOCK_OSC32K_ENABLE_1KHZ_OUTPUT     true
#  define CONF_CLOCK_OSC32K_ENABLE_32KHZ_OUTPUT    true
#  define CONF_CLOCK_OSC32K_ON_DEMAND              true
#  define CONF_CLOCK_OSC32K_RUN_IN_STANDBY         false
```

The following generic clock settings are needed:

```
/* Configure GCLK generator 2 (RTC) */
#  define CONF_CLOCK_GCLK_2_ENABLE                 true
#  define CONF_CLOCK_GCLK_2_RUN_IN_STANDBY         false
#  define CONF_CLOCK_GCLK_2_CLOCK_SOURCE           SYSTEM_CLOCK_SOURCE_OSC32K
#  define CONF_CLOCK_GCLK_2_PRESCALER              32
#  define CONF_CLOCK_GCLK_2_OUTPUT_ENABLE          false
```

13.9.2.2 Setup

Code

Create a rtc_module struct and add to the main application source file, outside of any functions:

```
struct rtc_module rtc_instance;
```

The following must be added to the user application:

Function for setting up the module:

```
void configure_rtc_count(void)
{
    struct rtc_count_config config_rtc_count;
    rtc_count_get_config_defaults(&config_rtc_count);

    config_rtc_count.prescaler           = RTC_COUNT_PRESCALER_DIV_1;
    config_rtc_count.mode                = RTC_COUNT_MODE_16BIT;
    config_rtc_count.continuously_update = true;
    rtc_count_init(&rtc_instance, RTC, &config_rtc_count);

    rtc_count_enable(&rtc_instance);
}
```

Callback function:

```
void rtc_overflow_callback(void)
{
    /* Do something on RTC overflow here */
    port_pin_toggle_output_level(LED_0_PIN);
}
```

Function for setting up the callback functionality of the driver:

```
void configure_rtc_callbacks(void)
{
    rtc_count_register_callback(
            &rtc_instance, rtc_overflow_callback, RTC_COUNT_CALLBACK_OVERFLOW);
    rtc_count_enable_callback(&rtc_instance, RTC_COUNT_CALLBACK_OVERFLOW);
}
```

Add to user application main():

```
/* Initialize system. Must configure conf_clocks.h first. */
system_init();

/* Configure and enable RTC */
configure_rtc_count();

/* Configure and enable callback */
configure_rtc_callbacks();

/* Set period */
rtc_count_set_period(&rtc_instance, 2000);
```

Workflow

1. Initialize system.

   ```
   system_init();
   ```

2. Configure and enable module.

   ```
   configure_rtc_count();
   ```

3. Create a RTC configuration structure to hold the desired RTC driver settings and fill it with the default driver configuration values.

```
struct rtc_count_config config_rtc_count;
rtc_count_get_config_defaults(&config_rtc_count);
```

Note This should always be performed before using the configuration struct to ensure that all values are initialized to known default settings.

4. Alter the RTC driver configuration to run in 16-bit counting mode, with continuous counter register updates and a compare value of 1000ms.

```
config_rtc_count.prescaler           = RTC_COUNT_PRESCALER_DIV_1;
config_rtc_count.mode                = RTC_COUNT_MODE_16BIT;
config_rtc_count.continuously_update = true;
```

5. Initialize the RTC module.

```
rtc_count_init(&rtc_instance, RTC, &config_rtc_count);
```

6. Enable the RTC module, so that it may begin counting.

```
rtc_count_enable(&rtc_instance);
```

7. Configure callback functionality.

```
configure_rtc_callbacks();
```

   a. Register overflow callback.

```
rtc_count_register_callback(
        &rtc_instance, rtc_overflow_callback, RTC_COUNT_CALLBACK_OVERFLOW);
```

   b. Enable overflow callback.

```
rtc_count_enable_callback(&rtc_instance, RTC_COUNT_CALLBACK_OVERFLOW);
```

8. Set period.

```
rtc_count_set_period(&rtc_instance, 2000);
```

13.9.2.3 Implementation

Code

Add to user application main:

```
while (true) {
    /* Infinite while loop */
}
```

Workflow

1. Infinite while loop while waiting for callbacks.

```
while (true) {
    /* Infinite while loop */
}
```

13.9.2.4 Callback

Each time the RTC counter overflows, the callback function will be called.

Workflow

1. Perform the desired user action for each RTC overflow:

```
/* Do something on RTC overflow here */
port_pin_toggle_output_level(LED_0_PIN);
```

14. SAM D20/D21 Serial Peripheral Interface Driver (SERCOM SPI)

This driver for SAM D20/D21 devices provides an interface for the configuration and management of the SERCOM module in its SPI mode to transfer SPI data frames. The following driver API modes are covered by this manual:

- Polled APIs
- Callback APIs

The following peripherals are used by this module:

- SERCOM (Serial Communication Interface)

The outline of this documentation is as follows:

- Prerequisites
- Module Overview
- Special Considerations
- Extra Information
- Examples
- API Overview

14.1 Prerequisites

There are no prerequisites.

14.2 Module Overview

The Serial Peripheral Interface (SPI) is a high-speed synchronous data transfer interface using three or four pins. It allows fast communication between a master device and one or more peripheral devices.

A device connected to the bus must act as a master or a slave. The master initiates and controls all data transactions. The SPI master initiates a communication cycle by pulling low the Slave Select (SS) pin of the desired slave. The Slave Select pin is active low. Master and slave prepare data to be sent in their respective shift registers, and the master generates the required clock pulses on the SCK line to interchange data. Data is always shifted from master to slave on the Master Out - Slave In (MOSI) line, and from slave to master on the Master In - Slave Out (MISO) line. After each data transfer, the master can synchronize to the slave by pulling the SS line high.

14.2.1 Driver Feature Macro Definition

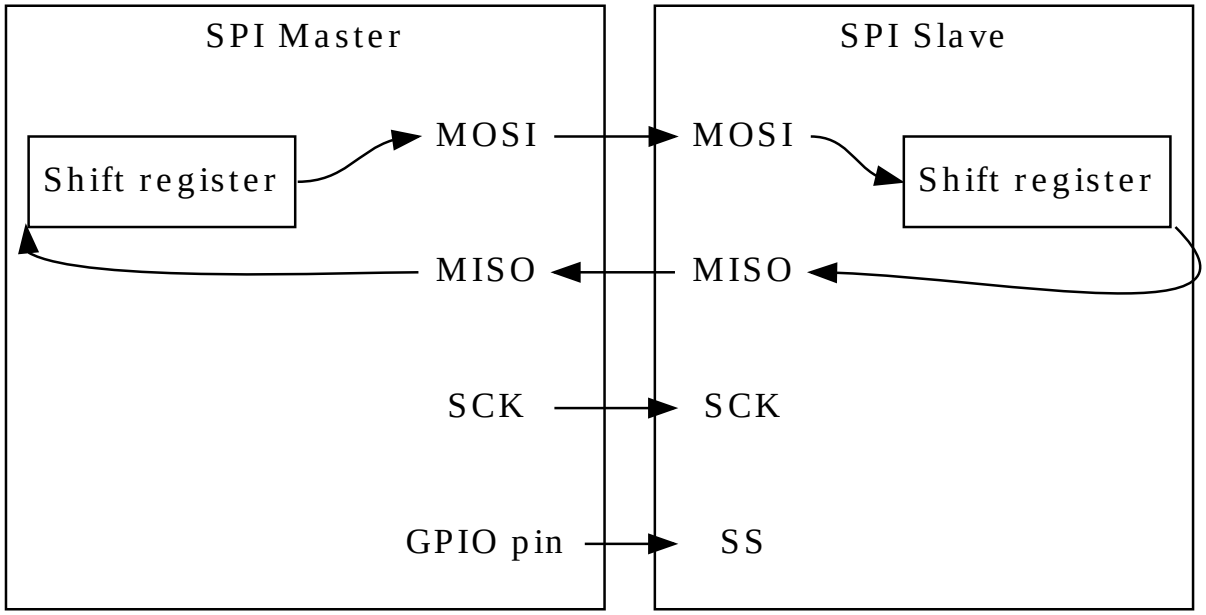
Driver Feature Macro	Supported devices
FEATURE_SPI_SLAVE_SELECT_LOW_DETECT	SAMD21
FEATURE_SPI_HARDWARE_SLAVE_SELECT	SAMD21
FEATURE_SPI_ERROR_INTERRUPT	SAMD21

Note The specific features are only available in the driver when the selected device supports those features.

14.2.2 SPI Bus Connection

In Figure 14-1: SPI Bus Connection on page 317, the connection between one master and one slave is shown.

Figure 14-1. SPI Bus Connection



The different lines are as follows:

- **MOSI** Master Input Slave Output. The line where the data is shifted out from the master and in to the slave.
- **MISO** Master Output Slave Input. The line where the data is shifted out from the slave and in to the master.
- **SCK** Serial Clock. Generated by the master device.
- **SS** Slave Select. To initiate a transaction, the master must pull this line low.

If the bus consists of several SPI slaves, they can be connected in parallel and the SPI master can use general I/O pins to control separate SS lines to each slave on the bus.

It is also possible to connect all slaves in series. In this configuration, a common SS is provided to N slaves, enabling them simultaneously. The MISO from the N-1 slaves is connected to the MOSI on the next slave. The Nth slave connects its MISO back to the master. For a complete transaction, the master must shift N+1 characters.

14.2.3 SPI Character Size

The SPI character size is configurable to 8 or 9 bits.

14.2.4 Master Mode

When configured as a master, the SS pin will be configured as an output.

14.2.4.1 Data Transfer

Writing a character will start the SPI clock generator, and the character is transferred to the shift register when the shift register is empty. Once this is done, a new character can be written. As each character is shifted out from the master, a character is shifted in from the slave. If the receiver is enabled, the data is moved to the receive buffer at the completion of the frame and can be read.

14.2.5 Slave Mode

When configured as a slave, the SPI interface will remain inactive with MISO tri-stated as long as the SS pin is driven high.

14.2.5.1 Data Transfer

The data register can be updated at any time. As the SPI slave shift register is clocked by SCK, a minimum of three SCK cycles are needed from the time new data is written, until the character is ready to be shifted out. If the shift register has not been loaded with data, the current contents will be transmitted.

If constant transmission of data is needed in SPI slave mode, the system clock should be faster than SCK. If the receiver is enabled, the received character can be read from the. When SS line is driven high, the slave will not receive any additional data.

14.2.5.2 Address Recognition

When the SPI slave is configured with address recognition, the first character in a transaction is checked for an address match. If there is a match, the MISO output is enabled and the transaction is processed. If the address does not match, the complete transaction is ignored.

If the device is asleep, it can be woken up by an address match in order to process the transaction.

Note In master mode, an address packet is written by the spi_select_slave function if the address_enabled configuration is set in the spi_slave_inst_config struct.

14.2.6 Data Modes

There are four combinations of SCK phase and polarity with respect to serial data. Table 14-1: SPI Data Modes on page 318 shows the clock polarity (CPOL) and clock phase (CPHA) in the different modes. *Leading edge* is the first clock edge in a clock cycle and *trailing edge* is the last clock edge in a clock cycle.

Table 14-1. SPI Data Modes

Mode	CPOL	CPHA	Leading Edge	Trailing Edge
0	0	0	Rising, Sample	Falling, Setup
1	0	1	Rising, Setup	Falling, Sample
2	1	0	Falling, Sample	Rising, Setup
3	1	1	Falling, Setup	Rising, Sample

14.2.7 SERCOM Pads

The SERCOM pads are automatically configured as seen in Table 14-2: SERCOM SPI Pad Usages on page 318. If the receiver is disabled, the data input (MISO for master, MOSI for slave) can be used for other purposes.

In master mode, the SS pin(s) must be configured using the spi_slave_inst struct.

Table 14-2. SERCOM SPI Pad Usages

Pin	Master SPI	Slave SPI
MOSI	Output	Input
MISO	Input	Output
SCK	Output	Input
SS	User defined output enable	Input

14.2.8 Operation in Sleep Modes

The SPI module can operate in all sleep modes by setting the run_in_standby option in the spi_config struct. The operation in slave and master mode is shown in the table below.

run_in_standby	Slave	Master
false	Disabled, all reception is dropped	GCLK disabled when master is idle, wake on transmit complete

run_in_standby	Slave	Master
true	Wake on reception	GCLK is enabled while in sleep modes, wake on all interrupts

14.2.9 Clock Generation

In SPI master mode, the clock (SCK) is generated internally using the SERCOM baud rate generator. In SPI slave mode, the clock is provided by an external master on the SCK pin. This clock is used to directly clock the SPI shift register.

14.3 Special Considerations

14.3.1 Pin MUX Settings

The pin MUX settings must be configured properly, as not all settings can be used in different modes of operation.

14.4 Extra Information

For extra information see Extra Information for SERCOM SPI Driver. This includes:

- Acronyms
- Dependencies
- Workarounds Implemented by Driver
- Module History

14.5 Examples

For a list of examples related to this driver, see Examples for SERCOM SPI Driver.

14.6 API Overview

14.6.1 Variable and Type Definitions

14.6.1.1 Type spi_callback_t

```
typedef void(* spi_callback_t )(const struct spi_module *const module)
```

Type of the callback functions

14.6.2 Structure Definitions

14.6.2.1 Struct spi_config

Configuration structure for an SPI instance. This structure should be initialized by the spi_get_config_defaults function before being modified by the user application.

Table 14-3. Members

Type	Name	Description
enum spi_character_size	character_size	SPI character size
enum spi_data_order	data_order	Data order
enum gclk_generator	generator_source	GCLK generator to use as clock source.
bool	master_slave_select_enable	Enable Master Slave Select

Type	Name	Description
enum spi_mode	mode	SPI mode
union spi_config.mode_specific	mode_specific	Union for slave or master specific configuration
enum spi_signal_mux_setting	mux_setting	Mux setting
uint32_t	pinmux_pad0	PAD0 pinmux
uint32_t	pinmux_pad1	PAD1 pinmux
uint32_t	pinmux_pad2	PAD2 pinmux
uint32_t	pinmux_pad3	PAD3 pinmux
bool	receiver_enable	Enable receiver
bool	run_in_standby	Enabled in sleep modes
bool	select_slave_low_detect_enable	Enable Slave Select Low Detect
enum spi_transfer_mode	transfer_mode	Transfer mode

14.6.2.2 Union spi_config.mode_specific

Union for slave or master specific configuration

Table 14-4. Members

Type	Name	Description
struct spi_master_config	master	Master specific configuration
struct spi_slave_config	slave	Slave specific configuration

14.6.2.3 Struct spi_master_config

SPI Master configuration structure

Table 14-5. Members

Type	Name	Description
uint32_t	baudrate	Baud rate

14.6.2.4 Struct spi_module

SERCOM SPI driver software instance structure, used to retain software state information of an associated hardware module instance.

Note The fields of this structure should not be altered by the user application; they are reserved for module-internal use only.

14.6.2.5 Struct spi_slave_config

SPI slave configuration structure

Table 14-6. Members

Type	Name	Description
uint8_t	address	Address

Type	Name	Description
uint8_t	address_mask	Address mask
enum spi_addr_mode	address_mode	Address mode
enum spi_frame_format	frame_format	Frame format
bool	preload_enable	Preload data to the shift register while SS is high

14.6.2.6 Struct spi_slave_inst

SPI peripheral slave software instance structure, used to configure the correct SPI transfer mode settings for an attached slave. See spi_select_slave.

Table 14-7. Members

Type	Name	Description
uint8_t	address	Address of slave device
bool	address_enabled	Address recognition enabled in slave device
uint8_t	ss_pin	Pin to use as Slave Select

14.6.2.7 Struct spi_slave_inst_config

SPI Peripheral slave configuration structure

Table 14-8. Members

Type	Name	Description
uint8_t	address	Address of slave
bool	address_enabled	Enable address
uint8_t	ss_pin	Pin to use as Slave Select

14.6.3 Macro Definitions

14.6.3.1 Driver feature definition

Define SERCOM SPI features set according to different device family.

Macro FEATURE_SPI_SLAVE_SELECT_LOW_DETECT

```
#define FEATURE_SPI_SLAVE_SELECT_LOW_DETECT
```

SPI slave select low detection

Macro FEATURE_SPI_HARDWARE_SLAVE_SELECT

```
#define FEATURE_SPI_HARDWARE_SLAVE_SELECT
```

Slave select can be controlled by hardware

Macro FEATURE_SPI_ERROR_INTERRUPT

```
#define FEATURE_SPI_ERROR_INTERRUPT
```

SPI with error detect feature

14.6.3.2 Macro PINMUX_DEFAULT

```
#define PINMUX_DEFAULT 0
```

SPI sync scheme version 2 Default pin mux

14.6.3.3 Macro PINMUX_UNUSED

```
#define PINMUX_UNUSED 0xFFFFFFFF
```

Unused PIN mux

14.6.3.4 Macro SPI_TIMEOUT

```
#define SPI_TIMEOUT 10000
```

SPI timeout value

14.6.4 Function Definitions

14.6.4.1 Driver initialization and configuration

Function spi_get_config_defaults()

Initializes an SPI configuration structure to default values.

```
void spi_get_config_defaults(
  struct spi_config *const config)
```

This function will initialize a given SPI configuration structure to a set of known default values. This function should be called on any new instance of the configuration structures before being modified by the user application.

The default configuration is as follows:

- Master mode enabled
- MSB of the data is transmitted first
- Transfer mode 0
- MUX Setting D

- Character size 8 bit
- Not enabled in sleep mode
- Receiver enabled
- Baudrate 100000
- Default pinmux settings for all pads
- GCLK generator 0

Table 14-9. Parameters

Data direction	Parameter name	Description
[out]	config	Configuration structure to initialize to default values

Function spi_slave_inst_get_config_defaults()

Initializes an SPI peripheral slave device configuration structure to default values.

```
void spi_slave_inst_get_config_defaults(
  struct spi_slave_inst_config *const config)
```

This function will initialize a given SPI slave device configuration structure to a set of known default values. This function should be called on any new instance of the configuration structures before being modified by the user application.

The default configuration is as follows:

- Slave Select on GPIO pin 10
- Addressing not enabled

Table 14-10. Parameters

Data direction	Parameter name	Description
[out]	config	Configuration structure to initialize to default values

Function spi_attach_slave()

Attaches an SPI peripheral slave.

```
void spi_attach_slave(
  struct spi_slave_inst *const slave,
  struct spi_slave_inst_config *const config)
```

This function will initialize the software SPI peripheral slave, based on the values of the config struct. The slave can then be selected and optionally addressed by the spi_select_slave function.

Table 14-11. Parameters

Data direction	Parameter name	Description
[out]	slave	Pointer to the software slave instance struct

Data direction	Parameter name	Description
[in]	config	Pointer to the config struct

Function spi_init()

Initializes the SERCOM SPI module.

```
enum status_code spi_init(
  struct spi_module *const module,
  Sercom *const hw,
  const struct spi_config *const config)
```

This function will initialize the SERCOM SPI module, based on the values of the config struct.

Table 14-12. Parameters

Data direction	Parameter name	Description
[out]	module	Pointer to the software instance struct
[in]	hw	Pointer to hardware instance
[in]	config	Pointer to the config struct

Returns Status of the initialization

Table 14-13. Return Values

Return value	Description
STATUS_OK	Module initiated correctly.
STATUS_ERR_DENIED	If module is enabled.
STATUS_BUSY	If module is busy resetting.
STATUS_ERR_INVALID_ARG	If invalid argument(s) were provided.

14.6.4.2 Enable/Disable

Function spi_enable()

Enables the SERCOM SPI module.

```
void spi_enable(
  struct spi_module *const module)
```

This function will enable the SERCOM SPI module.

Table 14-14. Parameters

Data direction	Parameter name	Description
[in, out]	module	Pointer to the software instance struct

Function spi_disable()

Disables the SERCOM SPI module.

```
void spi_disable(
  struct spi_module *const module)
```

This function will disable the SERCOM SPI module.

Table 14-15. Parameters

Data direction	Parameter name	Description
[in, out]	module	Pointer to the software instance struct

Function spi_reset()

Resets the SPI module.

```
void spi_reset(
  struct spi_module *const module)
```

This function will reset the SPI module to its power on default values and disable it.

Table 14-16. Parameters

Data direction	Parameter name	Description
[in, out]	module	Pointer to the software instance struct

14.6.4.3 Lock/Unlock

Function spi_lock()

Attempt to get lock on driver instance.

```
enum status_code spi_lock(
  struct spi_module *const module)
```

This function checks the instance's lock, which indicates whether or not it is currently in use, and sets the lock if it was not already set.

The purpose of this is to enable exclusive access to driver instances, so that, e.g., transactions by different services will not interfere with each other.

Table 14-17. Parameters

Data direction	Parameter name	Description
[in, out]	module	Pointer to the driver instance to lock.

Table 14-18. Return Values

Return value	Description
STATUS_OK	if the module was locked.

Return value	Description
STATUS_BUSY	if the module was already locked.

Function spi_unlock()

Unlock driver instance.

```
void spi_unlock(
  struct spi_module *const module)
```

This function clears the instance lock, indicating that it is available for use.

Table 14-19. Parameters

Data direction	Parameter name	Description
[in, out]	module	Pointer to the driver instance to lock.

Table 14-20. Return Values

Return value	Description
STATUS_OK	if the module was locked.
STATUS_BUSY	if the module was already locked.

14.6.4.4 Ready to write/read

Function spi_is_write_complete()

Checks if the SPI in master mode has shifted out last data, or if the master has ended the transfer in slave mode.

```
bool spi_is_write_complete(
  struct spi_module *const module)
```

This function will check if the SPI master module has shifted out last data, or if the slave select pin has been drawn high by the master for the SPI slave module.

Table 14-21. Parameters

Data direction	Parameter name	Description
[in]	module	Pointer to the software instance struct

Returns Indication of whether any writes are ongoing

Table 14-22. Return Values

Return value	Description
true	If the SPI master module has shifted out data, or slave select has been drawn high for SPI slave

Return value	Description
false	If the SPI master module has not shifted out data

Function spi_is_ready_to_write()

Checks if the SPI module is ready to write data.

```
bool spi_is_ready_to_write(
  struct spi_module *const module)
```

This function will check if the SPI module is ready to write data.

Table 14-23. Parameters

Data direction	Parameter name	Description
[in]	module	Pointer to the software instance struct

Returns

Indication of whether the module is ready to read data or not

Table 14-24. Return Values

Return value	Description
true	If the SPI module is ready to write data
false	If the SPI module is not ready to write data

Function spi_is_ready_to_read()

Checks if the SPI module is ready to read data.

```
bool spi_is_ready_to_read(
  struct spi_module *const module)
```

This function will check if the SPI module is ready to read data.

Table 14-25. Parameters

Data direction	Parameter name	Description
[in]	module	Pointer to the software instance struct

Returns

Indication of whether the module is ready to read data or not

Table 14-26. Return Values

Return value	Description
true	If the SPI module is ready to read data

Return value	Description
false	If the SPI module is not ready to read data

14.6.4.5 Read/Write

Function spi_write()

Transfers a single SPI character.

```
enum status_code spi_write(
  struct spi_module * module,
  uint16_t tx_data)
```

This function will send a single SPI character via SPI and ignore any data shifted in by the connected device. To both send and receive data, use the spi_transceive_wait function or use the spi_read function after writing a character. The spi_is_ready_to_write function should be called before calling this function.

Note that this function does not handle the SS (Slave Select) pin(s) in master mode; this must be handled from the user application.

Note In slave mode, the data will not be transferred before a master initiates a transaction.

Table 14-27. Parameters

Data direction	Parameter name	Description
[in]	module	Pointer to the software instance struct
[in]	tx_data	Data to transmit

Returns Status of the procedure

Table 14-28. Return Values

Return value	Description
STATUS_OK	If the data was written
STATUS_BUSY	If the last write was not completed

Function spi_write_buffer_wait()

Sends a buffer of length SPI characters.

```
enum status_code spi_write_buffer_wait(
  struct spi_module *const module,
  const uint8_t * tx_data,
  uint16_t length)
```

This function will send a buffer of SPI characters via the SPI and discard any data that is received. To both send and receive a buffer of data, use the spi_transceive_buffer_wait function.

Note that this function does not handle the _SS (slave select) pin(s) in master mode; this must be handled by the user application.

Table 14-29. Parameters

Data direction	Parameter name	Description
[in]	module	Pointer to the software instance struct
[in]	tx_data	Pointer to the buffer to transmit
[in]	length	Number of SPI characters to transfer

Returns

Status of the write operation

Table 14-30. Return Values

Return value	Description
STATUS_OK	If the write was completed
STATUS_ABORTED	If transaction was ended by master before entire buffer was transferred
STATUS_ERR_INVALID_ARG	If invalid argument(s) were provided
STATUS_ERR_TIMEOUT	If the operation was not completed within the timeout in slave mode

Function spi_read()

Reads last received SPI character.

```
enum status_code spi_read(
  struct spi_module *const module,
  uint16_t * rx_data)
```

This function will return the last SPI character shifted into the receive register by the spi_write function

Note

The spi_is_ready_to_read function should be called before calling this function.

Receiver must be enabled in the configuration

Table 14-31. Parameters

Data direction	Parameter name	Description
[in]	module	Pointer to the software instance struct
[out]	rx_data	Pointer to store the received data

Returns

Status of the read operation.

Table 14-32. Return Values

Return value	Description
STATUS_OK	If data was read

Return value	Description
STATUS_ERR_IO	If no data is available
STATUS_ERR_OVERFLOW	If the data is overflown

Function spi_read_buffer_wait()

Reads buffer of length SPI characters.

```
enum status_code spi_read_buffer_wait(
  struct spi_module *const module,
  uint8_t * rx_data,
  uint16_t length,
  uint16_t dummy)
```

This function will read a buffer of data from an SPI peripheral by sending dummy SPI character if in master mode, or by waiting for data in slave mode.

Note If address matching is enabled for the slave, the first character received and placed in the buffer will be the address.

Table 14-33. Parameters

Data direction	Parameter name	Description
[in]	module	Pointer to the software instance struct
[out]	rx_data	Data buffer for received data
[in]	length	Length of data to receive
[in]	dummy	8- or 9-bit dummy byte to shift out in master mode

Returns Status of the read operation

Table 14-34. Return Values

Return value	Description
STATUS_OK	If the read was completed
STATUS_ABORTED	If transaction was ended by master before entire buffer was transferred
STATUS_ERR_INVALID_ARG	If invalid argument(s) were provided.
STATUS_ERR_TIMEOUT	If the operation was not completed within the timeout in slave mode.
STATUS_ERR_DENIED	If the receiver is not enabled
STATUS_ERR_OVERFLOW	If the data is overflown

Function spi_transceive_wait()

Sends and reads a single SPI character.

```
enum status_code spi_transceive_wait(
  struct spi_module *const module,
  uint16_t tx_data,
  uint16_t * rx_data)
```

This function will transfer a single SPI character via SPI and return the SPI character that is shifted into the shift register.

In master mode the SPI character will be sent immediately and the received SPI character will be read as soon as the shifting of the data is complete.

In slave mode this function will place the data to be sent into the transmit buffer. It will then block until an SPI master has shifted a complete SPI character, and the received data is available.

Note

The data to be sent might not be sent before the next transfer, as loading of the shift register is dependent on SCK.

If address matching is enabled for the slave, the first character received and placed in the buffer will be the address.

Table 14-35. Parameters

Data direction	Parameter name	Description
[in]	module	Pointer to the software instance struct
[in]	tx_data	SPI character to transmit
[out]	rx_data	Pointer to store the received SPI character

Returns

Status of the operation.

Table 14-36. Return Values

Return value	Description
STATUS_OK	If the operation was completed
STATUS_ERR_TIMEOUT	If the operation was not completed within the timeout in slave mode
STATUS_ERR_DENIED	If the receiver is not enabled
STATUS_ERR_OVERFLOW	If the incoming data is overflown

Function spi_transceive_buffer_wait()

Sends and receives a buffer of length SPI characters.

```
enum status_code spi_transceive_buffer_wait(
  struct spi_module *const module,
  uint8_t * tx_data,
  uint8_t * rx_data,
```

```
  uint16_t length)
```

This function will send and receive a buffer of data via the SPI.

In master mode the SPI characters will be sent immediately and the received SPI character will be read as soon as the shifting of the SPI character is complete.

In slave mode this function will place the data to be sent into the transmit buffer. It will then block until an SPI master has shifted the complete buffer and the received data is available.

Table 14-37. Parameters

Data direction	Parameter name	Description
[in]	module	Pointer to the software instance struct
[in]	tx_data	Pointer to the buffer to transmit
[out]	rx_data	Pointer to the buffer where received data will be stored
[in]	length	Number of SPI characters to transfer

Returns Status of the operation

Table 14-38. Return Values

Return value	Description
STATUS_OK	If the operation was completed
STATUS_ERR_INVALID_ARG	If invalid argument(s) were provided.
STATUS_ERR_TIMEOUT	If the operation was not completed within the timeout in slave mode.
STATUS_ERR_DENIED	If the receiver is not enabled
STATUS_ERR_OVERFLOW	If the data is overflown

Function spi_select_slave()

Selects slave device.

```
enum status_code spi_select_slave(
  struct spi_module *const module,
  struct spi_slave_inst *const slave,
  bool select)
```

This function will drive the slave select pin of the selected device low or high depending on the select boolean. If slave address recognition is enabled, the address will be sent to the slave when selecting it.

Table 14-39. Parameters

Data direction	Parameter name	Description
[in]	module	Pointer to the software module struct
[in]	slave	Pointer to the attached slave

Data direction	Parameter name	Description
[in]	select	Boolean stating if the slave should be selected or deselected

Returns Status of the operation

Table 14-40. Return Values

Return value	Description
STATUS_OK	If the slave device was selected
STATUS_ERR_UNSUPPORTED_DEV	If the SPI module is operating in slave mode
STATUS_BUSY	If the SPI module is not ready to write the slave address

14.6.4.6 Callback Management

Function spi_register_callback()

Registers a SPI callback function.

```
void spi_register_callback(
  struct spi_module *const module,
  spi_callback_t callback_func,
  enum spi_callback callback_type)
```

Registers a callback function which is implemented by the user.

Note The callback must be enabled by spi_enable_callback, in order for the interrupt handler to call it when the conditions for the callback type are met.

Table 14-41. Parameters

Data direction	Parameter name	Description
[in]	module	Pointer to USART software instance struct
[in]	callback_func	Pointer to callback function
[in]	callback_type	Callback type given by an enum

Function spi_unregister_callback()

Unregisters a SPI callback function.

```
void spi_unregister_callback(
  struct spi_module * module,
  enum spi_callback callback_type)
```

Unregisters a callback function which is implemented by the user.

Table 14-42. Parameters

Data direction	Parameter name	Description
[in]	module	Pointer to SPI software instance struct
[in]	callback_type	Callback type given by an enum

Function spi_enable_callback()

Enables a SPI callback of a given type.

```
void spi_enable_callback(
  struct spi_module *const module,
  enum spi_callback callback_type)
```

Enables the callback function registered by the spi_register_callback. The callback function will be called from the interrupt handler when the conditions for the callback type are met.

Table 14-43. Parameters

Data direction	Parameter name	Description
[in]	module	Pointer to SPI software instance struct
[in]	callback_type	Callback type given by an enum

Function spi_disable_callback()

Disables callback.

```
void spi_disable_callback(
  struct spi_module *const module,
  enum spi_callback callback_type)
```

Disables the callback function registered by the spi_register_callback, and the callback will not be called from the interrupt routine.

Table 14-44. Parameters

Data direction	Parameter name	Description
[in]	module	Pointer to SPI software instance struct
[in]	callback_type	Callback type given by an enum

14.6.4.7 Writing and Reading

Function spi_write_buffer_job()

Asynchronous buffer write.

```
enum status_code spi_write_buffer_job(
  struct spi_module *const module,
  uint8_t * tx_data,
  uint16_t length)
```

Sets up the driver to write to the SPI from a given buffer. If registered and enabled, a callback function will be called when the write is finished.

Table 14-45. Parameters

Data direction	Parameter name	Description
[in]	module	Pointer to USART software instance struct
[out]	tx_data	Pointer to data buffer to receive
[in]	length	Data buffer length

Returns

Status of the write request operation.

Table 14-46. Return Values

Return value	Description
STATUS_OK	If the operation completed successfully
STATUS_ERR_BUSY	If the SPI was already busy with a write operation
STATUS_ERR_INVALID_ARG	If requested write length was zero

Function spi_read_buffer_job()

Asynchronous buffer read.

```
enum status_code spi_read_buffer_job(
  struct spi_module *const module,
  uint8_t * rx_data,
  uint16_t length,
  uint16_t dummy)
```

Sets up the driver to read from the SPI to a given buffer. If registered and enabled, a callback function will be called when the read is finished.

Note

If address matching is enabled for the slave, the first character received and placed in the RX buffer will be the address.

Table 14-47. Parameters

Data direction	Parameter name	Description
[in]	module	Pointer to SPI software instance struct
[out]	rx_data	Pointer to data buffer to receive
[in]	length	Data buffer length

Data direction	Parameter name	Description
[in]	dummy	Dummy character to send when reading in master mode.

Returns Status of the operation

Table 14-48. Return Values

Return value	Description
STATUS_OK	If the operation completed successfully
STATUS_ERR_BUSY	If the SPI was already busy with a read operation
STATUS_ERR_DENIED	If the receiver is not enabled
STATUS_ERR_INVALID_ARG	If requested read length was zero

Function spi_transceive_buffer_job()

Asynchronous buffer write and read.

```
enum status_code spi_transceive_buffer_job(
  struct spi_module *const module,
  uint8_t * tx_data,
  uint8_t * rx_data,
  uint16_t length)
```

Sets up the driver to write and read to and from given buffers. If registered and enabled, a callback function will be called when the transfer is finished.

Note If address matching is enabled for the slave, the first character received and placed in the RX buffer will be the address.

Table 14-49. Parameters

Data direction	Parameter name	Description
[in]	module	Pointer to SPI software instance struct
[in]	tx_data	Pointer to data buffer to send
[out]	rx_data	Pointer to data buffer to receive
[in]	length	Data buffer length

Returns Status of the operation

Table 14-50. Return Values

Return value	Description
STATUS_OK	If the operation completed successfully
STATUS_ERR_BUSY	If the SPI was already busy with a read operation
STATUS_ERR_DENIED	If the receiver is not enabled

Return value	Description
STATUS_ERR_INVALID_ARG	If requested read length was zero

Function spi_abort_job()

Aborts an ongoing job.

```
void spi_abort_job(
  struct spi_module *const module)
```

This function will abort the specified job type.

Table 14-51. Parameters

Data direction	Parameter name	Description
[in]	module	Pointer to SPI software instance struct

Function spi_get_job_status()

Retrieves the current status of a job.

```
enum status_code spi_get_job_status(
  const struct spi_module *const module)
```

Retrieves the current statue of a job that was previously issued.

Table 14-52. Parameters

Data direction	Parameter name	Description
[in]	module	Pointer to SPI software instance struct

Returns

Current job status.

Function spi_get_job_status_wait()

Retrieves the status of job once it ends.

```
enum status_code spi_get_job_status_wait(
  const struct spi_module *const module)
```

Waits for current job status to become non-busy, then returns its value.

Table 14-53. Parameters

Data direction	Parameter name	Description
[in]	module	Pointer to SPI software instance struct

Returns Current non-busy job status.

14.6.4.8 Function spi_is_syncing()

Determines if the SPI module is currently synchronizing to the bus.

```
bool spi_is_syncing(
  struct spi_module *const module)
```

This function will check if the underlying hardware peripheral module is currently synchronizing across multiple clock domains to the hardware bus. This function can be used to delay further operations on the module until it is ready.

Table 14-54. Parameters

Data direction	Parameter name	Description
[in]	module	SPI hardware module

Returns Synchronization status of the underlying hardware module

Table 14-55. Return Values

Return value	Description
true	Module synchronization is ongoing
false	Module synchronization is not ongoing

14.6.4.9 Function spi_set_baudrate()

Set the baudrate of the SPI module.

```
enum status_code spi_set_baudrate(
  struct spi_module *const module,
  uint32_t baudrate)
```

This function will set the baudrate of the SPI module.

Table 14-56. Parameters

Data direction	Parameter name	Description
[in]	module	Pointer to the software instance struct
[in]	baudrate	The baudrate wanted

Returns The status of the configuration

Table 14-57. Return Values

Return value	Description
STATUS_ERR_INVALID_ARG	If invalid argument(s) were provided.

Return value	Description
STATUS_OK	If the configuration was written

14.6.5 Enumeration Definitions

14.6.5.1 Enum spi_addr_mode

For slave mode when using the SPI frame with address format.

Table 14-58. Members

Enum value	Description
SPI_ADDR_MODE_MASK	`address_mask` in the spi_config struct is used as a mask to the register.
SPI_ADDR_MODE_UNIQUE	The slave responds to the two unique addresses in `address` and `address_mask` in the spi_config struct.
SPI_ADDR_MODE_RANGE	The slave responds to the range of addresses between and including `address` and `address_mask` in in the spi_config struct.

14.6.5.2 Enum spi_callback

Callbacks for SPI callback driver.

Note For slave mode, these callbacks will be called when a transaction is ended by the master pulling Slave Select high.

Table 14-59. Members

Enum value	Description
SPI_CALLBACK_BUFFER_TRANSMITTED	Callback for buffer transmitted
SPI_CALLBACK_BUFFER_RECEIVED	Callback for buffer received
SPI_CALLBACK_BUFFER_TRANSCEIVED	Callback for buffers transceived
SPI_CALLBACK_ERROR	Callback for error
SPI_CALLBACK_SLAVE_TRANSMISSION_COMPLETE	Callback for transmission ended by master before entire buffer was read or written from slave
SPI_CALLBACK_SLAVE_SELECT_LOW	Callback for slave select low
SPI_CALLBACK_COMBINED_ERROR	Callback for combined error happen

14.6.5.3 Enum spi_character_size

SPI character size.

Table 14-60. Members

Enum value	Description
SPI_CHARACTER_SIZE_8BIT	8 bit character

Enum value	Description
SPI_CHARACTER_SIZE_9BIT	9 bit character

14.6.5.4 Enum spi_data_order

SPI data order.

Table 14-61. Members

Enum value	Description
SPI_DATA_ORDER_LSB	The LSB of the data is transmitted first
SPI_DATA_ORDER_MSB	The MSB of the data is transmitted first

14.6.5.5 Enum spi_frame_format

Frame format for slave mode.

Table 14-62. Members

Enum value	Description
SPI_FRAME_FORMAT_SPI_FRAME	SPI frame
SPI_FRAME_FORMAT_SPI_FRAME_ADDR	SPI frame with address

14.6.5.6 Enum spi_interrupt_flag

Interrupt flags for the SPI module.

Table 14-63. Members

Enum value	Description
SPI_INTERRUPT_FLAG_DATA_REGISTER_EMPTY	This flag is set when the contents of the data register has been moved to the shift register and the data register is ready for new data
SPI_INTERRUPT_FLAG_TX_COMPLETE	This flag is set when the contents of the shift register has been shifted out
SPI_INTERRUPT_FLAG_RX_COMPLETE	This flag is set when data has been shifted into the data register
SPI_INTERRUPT_FLAG_SLAVE_SELECT_LOW	This flag is set when slave select low
SPI_INTERRUPT_FLAG_COMBINED_ERROR	This flag is set when combined error happen

14.6.5.7 Enum spi_mode

SPI mode selection.

Table 14-64. Members

Enum value	Description
SPI_MODE_MASTER	Master mode
SPI_MODE_SLAVE	Slave mode

14.6.5.8 Enum spi_signal_mux_setting

Set the functionality of the SERCOM pins. As not all settings can be used in different modes of operation, proper settings must be chosen according to the rest of the configuration.

See Mux Settings for a description of the various MUX setting options.

Table 14-65. Members

Enum value	Description
SPI_SIGNAL_MUX_SETTING_A	SPI MUX setting A
SPI_SIGNAL_MUX_SETTING_B	SPI MUX setting B
SPI_SIGNAL_MUX_SETTING_C	SPI MUX setting C
SPI_SIGNAL_MUX_SETTING_D	SPI MUX setting D
SPI_SIGNAL_MUX_SETTING_E	SPI MUX setting E
SPI_SIGNAL_MUX_SETTING_F	SPI MUX setting F
SPI_SIGNAL_MUX_SETTING_G	SPI MUX setting G
SPI_SIGNAL_MUX_SETTING_H	SPI MUX setting H
SPI_SIGNAL_MUX_SETTING_I	SPI MUX setting I
SPI_SIGNAL_MUX_SETTING_J	SPI MUX setting J
SPI_SIGNAL_MUX_SETTING_K	SPI MUX setting K
SPI_SIGNAL_MUX_SETTING_L	SPI MUX setting L
SPI_SIGNAL_MUX_SETTING_M	SPI MUX setting M
SPI_SIGNAL_MUX_SETTING_N	SPI MUX setting N
SPI_SIGNAL_MUX_SETTING_O	SPI MUX setting O
SPI_SIGNAL_MUX_SETTING_P	SPI MUX setting P

14.6.5.9 Enum spi_transfer_mode

SPI transfer mode.

Table 14-66. Members

Enum value	Description
SPI_TRANSFER_MODE_0	Mode 0. Leading edge: rising, sample. Trailing edge: falling, setup
SPI_TRANSFER_MODE_1	Mode 1. Leading edge: rising, setup. Trailing edge: falling, sample
SPI_TRANSFER_MODE_2	Mode 2. Leading edge: falling, sample. Trailing edge: rising, setup
SPI_TRANSFER_MODE_3	Mode 3. Leading edge: falling, setup. Trailing edge: rising, sample

14.7 Mux Settings

The following lists the possible internal SERCOM module pad function assignments, for the four SERCOM pads in both SPI Master, and SPI Slave modes. Note that this is in addition to the physical GPIO pin MUX of the device, and can be used in conjunction to optimize the serial data pin-out.

14.7.1 Master Mode Settings

The following table describes the SERCOM pin functionalities for the various MUX settings, whilst in SPI Master mode.

Note If MISO is unlisted, the SPI receiver must not be enabled for the given MUX setting.

Mux/Pad	PAD 0	PAD 1	PAD 2	PAD 3
A	MOSI	SCK	-	-
B	MOSI	SCK	-	-
C	MOSI	SCK	MISO	-
D	MOSI	SCK	-	MISO
E	MISO	-	MOSI	SCK
F	-	MISO	MOSI	SCK
G	-	-	MOSI	SCK
H	-	-	MOSI	SCK
I (1)	MISO	SCK	-	MOSI
J (1)	-	SCK	-	MOSI
K (1)	-	SCK	MISO	MOSI
L (1)	-	SCK	-	MOSI
M (1)	MOSI	-	-	SCK
N (1)	MOSI	MISO	-	SCK
O (1)	MOSI	-	MISO	SCK
P (1)	MOSI	-	-	SCK

(1) Not available in all silicon revisions.

14.7.2 Slave Mode Settings

The following table describes the SERCOM pin functionalities for the various MUX settings, whilst in SPI Slave mode.

Note If MISO is unlisted, the SPI receiver must not be enabled for the given MUX setting.

Mux/Pad	PAD 0	PAD 1	PAD 2	PAD 3
A	MISO	SCK	/SS	-
B	MISO	SCK	/SS	-
C	MISO	SCK	/SS	-
D	MISO	SCK	/SS	MOSI
E	MOSI	/SS	MISO	SCK
F	-	/SS	MISO	SCK
G	-	/SS	MISO	SCK
H	-	/SS	MISO	SCK
I (1)	MOSI	SCK	/SS	MISO

Mux/Pad	PAD 0	PAD 1	PAD 2	PAD 3
J [1]	-	SCK	/SS	MISO
K [1]	-	SCK	/SS	MISO
L [1]	-	SCK	/SS	MISO
M [1]	MISO	/SS	-	SCK
N [1]	MISO	/SS	-	SCK
O [1]	MISO	/SS	MOSI	SCK
P [1]	MISO	/SS	-	SCK

(1) Not available in all silicon revisions.

14.8 Extra Information for SERCOM SPI Driver

14.8.1 Acronyms

Below is a table listing the acronyms used in this module, along with their intended meanings.

Acronym	Description
SERCOM	Serial Communication Interface
SPI	Serial Peripheral Interface
SCK	Serial Clock
MOSI	Master Output Slave Input
MISO	Master Input Slave Output
SS	Slave Select
DIO	Data Input Output
DO	Data Output
DI	Data Input
DMA	Direct Memory Access

14.8.2 Dependencies

The SPI driver has the following dependencies:

- System Pin Multiplexer Driver

14.8.3 Workarounds Implemented by Driver

No workarounds in driver.

14.8.4 Module History

An overview of the module history is presented in the table below, with details on the enhancements and fixes made to the module since its first release. The current version of this corresponds to the newest version in the table.

Changelog
Add SAMD21 support and added new features as below: • Slave select low detect • Hardware slave select

Changelog
• DMA support
Edited slave part of write and transceive buffer functions to ensure that second character is sent at the right time.
Renamed the anonymous union in `struct` spi_config to `mode_specific`.
Initial Release

14.9 Examples for SERCOM SPI Driver

This is a list of the available Quick Start guides (QSGs) and example applications for SAM D20/D21 Serial Peripheral Interface Driver (SERCOM SPI). QSGs are simple examples with step-by-step instructions to configure and use this driver in a selection of use cases. Note that QSGs can be compiled as a standalone application or be added to the user application.

- Quick Start Guide for SERCOM SPI Master - Polled
- Quick Start Guide for SERCOM SPI Slave - Polled
- Quick Start Guide for SERCOM SPI Master - Callback
- Quick Start Guide for SERCOM SPI Slave - Callback
- Quick Start Guide for Using DMA with SERCOM SPI

14.9.1 Quick Start Guide for SERCOM SPI Master - Polled

In this use case, the SPI on extension header 1 of the Xplained Pro board will configured with the following settings:

- Master Mode enabled
- MSB of the data is transmitted first
- Transfer mode 0
- SPI MUX Setting E (see Master Mode Settings)
  - MOSI on pad 2, extension header 1, pin 16
  - MISO on pad 0, extension header 1, pin 17
  - SCK on pad 3, extension header 1, pin 18
  - SS on extension header 1, pin 15
- 8-bit character size
- Not enabled in sleep mode
- Baudrate 100000
- GLCK generator 0

14.9.1.1 Setup

Prerequisites

There are no special setup requirements for this use-case.

Code

The following must be added to the user application:

A sample buffer to send via SPI:

```
static const uint8_t buffer[BUF_LENGTH] = {
        0x00, 0x01, 0x02, 0x03, 0x04, 0x05, 0x06, 0x07, 0x08, 0x09,
         0x0A, 0x0B, 0x0C, 0x0D, 0x0E, 0x0F, 0x10, 0x11, 0x12, 0x13
};
```

Number of entries in the sample buffer:

```
#define BUF_LENGTH 20
```

GPIO pin to use as Slave Select:

```
#define SLAVE_SELECT_PIN EXT1_PIN_SPI_SS_0
```

A globally available software device instance struct to store the SPI driver state while it is in use.

```
struct spi_module spi_master_instance;
```

A globally available peripheral slave software device instance struct.

```
struct spi_slave_inst slave;
```

A function for configuring the SPI:

```
void configure_spi_master(void)
{
    struct spi_config config_spi_master;
    struct spi_slave_inst_config slave_dev_config;
    /* Configure and initialize software device instance of peripheral slave */
    spi_slave_inst_get_config_defaults(&slave_dev_config);
    slave_dev_config.ss_pin = SLAVE_SELECT_PIN;
    spi_attach_slave(&slave, &slave_dev_config);
    /* Configure, initialize and enable SERCOM SPI module */
    spi_get_config_defaults(&config_spi_master);
    config_spi_master.mux_setting = EXT1_SPI_SERCOM_MUX_SETTING;
    /* Configure pad 0 for data in */
    config_spi_master.pinmux_pad0 = EXT1_SPI_SERCOM_PINMUX_PAD0;
    /* Configure pad 1 as unused */
    config_spi_master.pinmux_pad1 = PINMUX_UNUSED;
    /* Configure pad 2 for data out */
    config_spi_master.pinmux_pad2 = EXT1_SPI_SERCOM_PINMUX_PAD2;
    /* Configure pad 3 for SCK */
    config_spi_master.pinmux_pad3 = EXT1_SPI_SERCOM_PINMUX_PAD3;
    spi_init(&spi_master_instance, EXT1_SPI_MODULE, &config_spi_master);

    spi_enable(&spi_master_instance);

}
```

Add to user application main():

```
system_init();
configure_spi_master();
```

14.9.1.2 Workflow

1. Initialize system.

```
system_init();
```

2. Setup the SPI:

```
configure_spi_master();
```

   a. Create configuration struct.

```
struct spi_config config_spi_master;
```

   b. Create peripheral slave configuration struct.

```
struct spi_slave_inst_config slave_dev_config;
```

   c. Create peripheral slave software device instance struct.

```
struct spi_slave_inst slave;
```

   d. Get default peripheral slave configuration.

```
spi_slave_inst_get_config_defaults(&slave_dev_config);
```

   e. Set Slave Select pin.

```
slave_dev_config.ss_pin = SLAVE_SELECT_PIN;
```

   f. Initialize peripheral slave software instance with configuration.

```
spi_attach_slave(&slave, &slave_dev_config);
```

   g. Get default configuration to edit.

```
spi_get_config_defaults(&config_spi_master);
```

   h. Set mux setting E.

```
config_spi_master.mux_setting = EXT1_SPI_SERCOM_MUX_SETTING;
```

   i. Set pinmux for pad 0 (data in (MISO) on extension header 1, pin 17).

```
config_spi_master.pinmux_pad0 = EXT1_SPI_SERCOM_PINMUX_PAD0;
```

   j. Set pinmux for pad 1 as unused, so the pin can be used for other purposes.

```
config_spi_master.pinmux_pad1 = PINMUX_UNUSED;
```

k. Set pinmux for pad 2 (data out (MOSI) on extension header 1, pin 16).

```
config_spi_master.pinmux_pad2 = EXT1_SPI_SERCOM_PINMUX_PAD2;
```

l. Set pinmux for pad 3 (SCK on extension header 1, pin 18).

```
config_spi_master.pinmux_pad3 = EXT1_SPI_SERCOM_PINMUX_PAD3;
```

m. Initialize SPI module with configuration.

```
spi_init(&spi_master_instance, EXT1_SPI_MODULE, &config_spi_master);
```

n. Enable SPI module.

```
spi_enable(&spi_master_instance);
```

14.9.1.3 Use Case

Code

Add the following to your user application `main()`:

```
spi_select_slave(&spi_master_instance, &slave, true);
spi_write_buffer_wait(&spi_master_instance, buffer, BUF_LENGTH);
spi_select_slave(&spi_master_instance, &slave, false);

while (true) {
    /* Infinite loop */
}
```

Workflow

1. Select slave.

```
spi_select_slave(&spi_master_instance, &slave, true);
```

2. Write buffer to SPI slave.

```
spi_write_buffer_wait(&spi_master_instance, buffer, BUF_LENGTH);
```

3. Deselect slave.

```
spi_select_slave(&spi_master_instance, &slave, false);
```

4. Infinite loop.

```
while (true) {
    /* Infinite loop */
}
```

14.9.2 Quick Start Guide for SERCOM SPI Slave - Polled

In this use case, the SPI on extension header 1 of the Xplained Pro board will configured with the following settings:

- Slave mode enabled
- Preloading of shift register enabled
- MSB of the data is transmitted first
- Transfer mode 0
- SPI MUX Setting E (see Slave Mode Settings)
  - MISO on pad 2, extension header 1, pin 16
  - MOSI on pad 0, extension header 1, pin 17
  - SCK on pad 3, extension header 1, pin 18
  - SS on pad 1, extension header 1, pin
- 8-bit character size
- Not enabled in sleep mode
- GLCK generator 0

14.9.2.1 Setup

Prerequisites

The device must be connected to a SPI master which must read from the device.

Code

The following must be added to the user application source file, outside any functions:

A sample buffer to send via SPI.

```
static const uint8_t buffer[BUF_LENGTH] = {
        0x00, 0x01, 0x02, 0x03, 0x04, 0x05, 0x06, 0x07, 0x08, 0x09,
         0x0A, 0x0B, 0x0C, 0x0D, 0x0E, 0x0F, 0x10, 0x11, 0x12, 0x13
};
```

Number of entries in the sample buffer.

```
#define BUF_LENGTH 20
```

A globally available software device instance struct to store the SPI driver state while it is in use.

```
struct spi_module spi_slave_instance;
```

A function for configuring the SPI.

```
void configure_spi_slave(void)
{
    struct spi_config config_spi_slave;
    /* Configure, initialize and enable SERCOM SPI module */
    spi_get_config_defaults(&config_spi_slave);
    config_spi_slave.mode = SPI_MODE_SLAVE;
```

```
    config_spi_slave.mode_specific.slave.preload_enable = true;
    config_spi_slave.mode_specific.slave.frame_format = SPI_FRAME_FORMAT_SPI_FRAME;
    config_spi_slave.mux_setting = EXT1_SPI_SERCOM_MUX_SETTING;
    /* Configure pad 0 for data in */
    config_spi_slave.pinmux_pad0 = EXT1_SPI_SERCOM_PINMUX_PAD0;
    /* Configure pad 1 as unused */
    config_spi_slave.pinmux_pad1 = EXT1_SPI_SERCOM_PINMUX_PAD1;
    /* Configure pad 2 for data out */
    config_spi_slave.pinmux_pad2 = EXT1_SPI_SERCOM_PINMUX_PAD2;
    /* Configure pad 3 for SCK */
    config_spi_slave.pinmux_pad3 = EXT1_SPI_SERCOM_PINMUX_PAD3;
    spi_init(&spi_slave_instance, EXT1_SPI_MODULE, &config_spi_slave);

    spi_enable(&spi_slave_instance);

}
```

Add to user application main():

```
/* Initialize system */
system_init();

configure_spi_slave();
```

Workflow

1. Initialize system.

   ```
   system_init();
   ```

2. Setup the SPI:

   ```
   configure_spi_slave();
   ```

   a. Create configuration struct.

      ```
      struct spi_config config_spi_slave;
      ```

   b. Get default configuration to edit.

      ```
      spi_get_config_defaults(&config_spi_slave);
      ```

   c. Set the SPI in slave mode.

      ```
      config_spi_slave.mode = SPI_MODE_SLAVE;
      ```

   d. Enable preloading of shift register.

      ```
      config_spi_slave.mode_specific.slave.preload_enable = true;
      ```

   e. Set frame format to SPI frame.

      ```
      config_spi_slave.mode_specific.slave.frame_format = SPI_FRAME_FORMAT_SPI_FRAME;
      ```

f. Set mux setting E.

```
config_spi_slave.mux_setting = EXT1_SPI_SERCOM_MUX_SETTING;
```

g. Set pinmux for pad 0 (data in (MOSI) on extension header 1, pin 17).

```
config_spi_slave.pinmux_pad0 = EXT1_SPI_SERCOM_PINMUX_PAD0;
```

h. Set pinmux for pad 1 (slave select on on extension header 1, pin 15)

```
config_spi_slave.pinmux_pad1 = EXT1_SPI_SERCOM_PINMUX_PAD1;
```

i. Set pinmux for pad 2 (data out (MISO) on extension header 1, pin 16).

```
config_spi_slave.pinmux_pad2 = EXT1_SPI_SERCOM_PINMUX_PAD2;
```

j. Set pinmux for pad 3 (SCK on extension header 1, pin 18).

```
config_spi_slave.pinmux_pad3 = EXT1_SPI_SERCOM_PINMUX_PAD3;
```

k. Initialize SPI module with configuration.

```
spi_init(&spi_slave_instance, EXT1_SPI_MODULE, &config_spi_slave);
```

l. Enable SPI module.

```
spi_enable(&spi_slave_instance);
```

14.9.2.2 Use Case

Code

Add the following to your user application `main()`:

```
while (spi_write_buffer_wait(&spi_slave_instance, buffer, BUF_LENGTH) != STATUS_OK) {
    /* Wait for transfer from master */
}


while (true) {
    /* Infinite loop */
}
```

Workflow

1. Write buffer to SPI master. Placed in a loop to retry in case of a timeout before a master initiates a transaction.

```
while (spi_write_buffer_wait(&spi_slave_instance, buffer, BUF_LENGTH) != STATUS_OK) {
    /* Wait for transfer from master */
}
```

2. Infinite loop.

```
while (true) {
    /* Infinite loop */
}
```

14.9.3 Quick Start Guide for SERCOM SPI Master - Callback

In this use case, the SPI on extension header 1 of the Xplained Pro board will configured with the following settings:

- Master Mode enabled
- MSB of the data is transmitted first
- Transfer mode 0
- SPI MUX Setting E (see Master Mode Settings)
  - MOSI on pad 2, extension header 1, pin 16
  - MISO on pad 0, extension header 1, pin 17
  - SCK on pad 3, extension header 1, pin 18
  - SS on extension header 1, pin 15
- 8-bit character size
- Not enabled in sleep mode
- Baudrate 100000
- GLCK generator 0

14.9.3.1 Setup

Prerequisites

There are no special setup requirements for this use-case.

Code

The following must be added to the user application:

A sample buffer to send via SPI:

```
static uint8_t buffer[BUF_LENGTH] = {
        0x00, 0x01, 0x02, 0x03, 0x04, 0x05, 0x06, 0x07, 0x08, 0x09,
         0x0A, 0x0B, 0x0C, 0x0D, 0x0E, 0x0F, 0x10, 0x11, 0x12, 0x13
};
```

Number of entries in the sample buffer:

```
#define BUF_LENGTH 20
```

GPIO pin to use as Slave Select:

```
#define SLAVE_SELECT_PIN EXT1_PIN_SPI_SS_0
```

A globally available software device instance struct to store the SPI driver state while it is in use.

```
struct spi_module spi_master_instance;
```

A globally available peripheral slave software device instance struct.

```
struct spi_slave_inst slave;
```

A function for configuring the SPI:

```
void configure_spi_master(void)
{
    struct spi_config config_spi_master;
    struct spi_slave_inst_config slave_dev_config;
    /* Configure and initialize software device instance of peripheral slave */
    spi_slave_inst_get_config_defaults(&slave_dev_config);
    slave_dev_config.ss_pin = SLAVE_SELECT_PIN;
    spi_attach_slave(&slave, &slave_dev_config);
    /* Configure, initialize and enable SERCOM SPI module */
    spi_get_config_defaults(&config_spi_master);
    config_spi_master.mux_setting = EXT1_SPI_SERCOM_MUX_SETTING;
    /* Configure pad 0 for data in */
    config_spi_master.pinmux_pad0 = EXT1_SPI_SERCOM_PINMUX_PAD0;
    /* Configure pad 1 as unused */
    config_spi_master.pinmux_pad1 = PINMUX_UNUSED;
    /* Configure pad 2 for data out */
    config_spi_master.pinmux_pad2 = EXT1_SPI_SERCOM_PINMUX_PAD2;
    /* Configure pad 3 for SCK */
    config_spi_master.pinmux_pad3 = EXT1_SPI_SERCOM_PINMUX_PAD3;
    spi_init(&spi_master_instance, EXT1_SPI_MODULE, &config_spi_master);

    spi_enable(&spi_master_instance);

}
```

A function for configuring the callback functionality of the SPI:

```
void configure_spi_master_callbacks(void)
{
    spi_register_callback(&spi_master_instance, callback_spi_master,
            SPI_CALLBACK_BUFFER_TRANSMITTED);
    spi_enable_callback(&spi_master_instance, SPI_CALLBACK_BUFFER_TRANSMITTED);
}
```

A global variable that can flag to the application that the buffer has been transferred:

```
volatile bool transfer_complete_spi_master = false;
```

Callback function:

```
static void callback_spi_master(const struct spi_module *const module)
{
    transfer_complete_spi_master = true;
}
```

Add to user application main():

```
/* Initialize system */
```

```
system_init();

configure_spi_master();
configure_spi_master_callbacks();
```

14.9.3.2 Workflow

1. Initialize system.

   ```
   system_init();
   ```

2. Setup the SPI:

   ```
   configure_spi_master();
   ```

   a. Create configuration struct.

      ```
      struct spi_config config_spi_master;
      ```

   b. Create peripheral slave configuration struct.

      ```
      struct spi_slave_inst_config slave_dev_config;
      ```

   c. Get default peripheral slave configuration.

      ```
      spi_slave_inst_get_config_defaults(&slave_dev_config);
      ```

   d. Set Slave Select pin.

      ```
      slave_dev_config.ss_pin = SLAVE_SELECT_PIN;
      ```

   e. Initialize peripheral slave software instance with configuration.

      ```
      spi_attach_slave(&slave, &slave_dev_config);
      ```

   f. Get default configuration to edit.

      ```
      spi_get_config_defaults(&config_spi_master);
      ```

   g. Set mux setting E.

      ```
      config_spi_master.mux_setting = EXT1_SPI_SERCOM_MUX_SETTING;
      ```

   h. Set pinmux for pad 0 (data in (MISO) on extension header 1, pin 17).

      ```
      config_spi_master.pinmux_pad0 = EXT1_SPI_SERCOM_PINMUX_PAD0;
      ```

   i. Set pinmux for pad 1 as unused, so the pin can be used for other purposes.

      ```
      config_spi_master.pinmux_pad1 = PINMUX_UNUSED;
      ```

j. Set pinmux for pad 2 (data out (MOSI) on extension header 1, pin 16).

```
config_spi_master.pinmux_pad2 = EXT1_SPI_SERCOM_PINMUX_PAD2;
```

k. Set pinmux for pad 3 (SCK on extension header 1, pin 18).

```
config_spi_master.pinmux_pad3 = EXT1_SPI_SERCOM_PINMUX_PAD3;
```

l. Initialize SPI module with configuration.

```
spi_init(&spi_master_instance, EXT1_SPI_MODULE, &config_spi_master);
```

m. Enable SPI module.

```
spi_enable(&spi_master_instance);
```

3. Setup the callback functionality:

```
configure_spi_master_callbacks();
```

a. Register callback function for buffer transmitted

```
spi_register_callback(&spi_master_instance, callback_spi_master,
        SPI_CALLBACK_BUFFER_TRANSMITTED);
```

b. Enable callback for buffer transmitted

```
spi_enable_callback(&spi_master_instance, SPI_CALLBACK_BUFFER_TRANSMITTED);
```

14.9.3.3 Use Case

Code

Add the following to your user application `main()`:

```
spi_select_slave(&spi_master_instance, &slave, true);
spi_write_buffer_job(&spi_master_instance, buffer, BUF_LENGTH);
while (!transfer_complete_spi_master) {
    /* Wait for write complete */
}
spi_select_slave(&spi_master_instance, &slave, false);

while (true) {
    /* Infinite loop */
}
```

Workflow

1. Select slave.

```
spi_select_slave(&spi_master_instance, &slave, true);
```

2. Write buffer to SPI slave.

```
spi_write_buffer_job(&spi_master_instance, buffer, BUF_LENGTH);
```

3. Wait for the transfer to be complete.

```
while (!transfer_complete_spi_master) {
    /* Wait for write complete */
}
```

4. Deselect slave.

```
spi_select_slave(&spi_master_instance, &slave, false);
```

5. Infinite loop.

```
while (true) {
    /* Infinite loop */
}
```

14.9.3.4 Callback

When the buffer is successfully transmitted to the slave, the callback function will be called.

Workflow

1. Let the application know that the buffer is transmitted by setting the global variable to true.

```
transfer_complete_spi_master = true;
```

14.9.4 Quick Start Guide for SERCOM SPI Slave - Callback

In this use case, the SPI on extension header 1 of the Xplained Pro board will configured with the following settings:

- Slave mode enabled
- Preloading of shift register enabled
- MSB of the data is transmitted first
- Transfer mode 0
- SPI MUX Setting E (see Slave Mode Settings)
  - MISO on pad 2, extension header 1, pin 16
  - MOSI on pad 0, extension header 1, pin 17
  - SCK on pad 3, extension header 1, pin 18
  - SS on pad 1, extension header 1, pin 15
- 8-bit character size
- Not enabled in sleep mode
- GLCK generator 0

14.9.4.1 Setup

Prerequisites

The device must be connected to a SPI master which must read from the device.

Code

The following must be added to the user application source file, outside any functions:

A sample buffer to send via SPI:

```
static uint8_t buffer[BUF_LENGTH] = {
        0x00, 0x01, 0x02, 0x03, 0x04, 0x05, 0x06, 0x07, 0x08, 0x09,
         0x0A, 0x0B, 0x0C, 0x0D, 0x0E, 0x0F, 0x10, 0x11, 0x12, 0x13
};
```

Number of entries in the sample buffer:

```
#define BUF_LENGTH 20
```

A globally available software device instance struct to store the SPI driver state while it is in use.

```
struct spi_module spi_slave_instance;
```

A function for configuring the SPI:

```
void configure_spi_slave(void)
{
    struct spi_config config_spi_slave;
    /* Configure, initialize and enable SERCOM SPI module */
    spi_get_config_defaults(&config_spi_slave);
    config_spi_slave.mode = SPI_MODE_SLAVE;
    config_spi_slave.mode_specific.slave.preload_enable = true;
    config_spi_slave.mode_specific.slave.frame_format = SPI_FRAME_FORMAT_SPI_FRAME;
    config_spi_slave.mux_setting = EXT1_SPI_SERCOM_MUX_SETTING;
    /* Configure pad 0 for data in */
    config_spi_slave.pinmux_pad0 = EXT1_SPI_SERCOM_PINMUX_PAD0;
    /* Configure pad 1 as unused */
    config_spi_slave.pinmux_pad1 = EXT1_SPI_SERCOM_PINMUX_PAD1;
    /* Configure pad 2 for data out */
    config_spi_slave.pinmux_pad2 = EXT1_SPI_SERCOM_PINMUX_PAD2;
    /* Configure pad 3 for SCK */
    config_spi_slave.pinmux_pad3 = EXT1_SPI_SERCOM_PINMUX_PAD3;
    spi_init(&spi_slave_instance, EXT1_SPI_MODULE, &config_spi_slave);

    spi_enable(&spi_slave_instance);

}
```

A function for configuring the callback functionality of the SPI:

```
void configure_spi_slave_callbacks(void)
{
    spi_register_callback(&spi_slave_instance, spi_slave_callback,
            SPI_CALLBACK_BUFFER_TRANSMITTED);
    spi_enable_callback(&spi_slave_instance, SPI_CALLBACK_BUFFER_TRANSMITTED);
}
```

A global variable that can flag to the application that the buffer has been transferred:

```
volatile bool transfer_complete_spi_slave = false;
```

Callback function:

```
static void spi_slave_callback(const struct spi_module *const module)
{
    transfer_complete_spi_slave = true;
}
```

Add to user application main():

```
/* Initialize system */
system_init();

configure_spi_slave();
configure_spi_slave_callbacks();
```

Workflow

1. Initialize system.

   ```
   system_init();
   ```

2. Setup the SPI:

   ```
   configure_spi_slave();
   ```

   a. Create configuration struct.

      ```
      struct spi_config config_spi_slave;
      ```

   b. Get default configuration to edit.

      ```
      spi_get_config_defaults(&config_spi_slave);
      ```

   c. Set the SPI in slave mode.

      ```
      config_spi_slave.mode = SPI_MODE_SLAVE;
      ```

   d. Enable preloading of shift register.

      ```
      config_spi_slave.mode_specific.slave.preload_enable = true;
      ```

   e. Set frame format to SPI frame.

      ```
      config_spi_slave.mode_specific.slave.frame_format = SPI_FRAME_FORMAT_SPI_FRAME;
      ```

   f. Set mux setting E.

      ```
      config_spi_slave.mux_setting = EXT1_SPI_SERCOM_MUX_SETTING;
      ```

g. Set pinmux for pad 0 (data in (MOSI) on extension header 1, pin 17).

```
config_spi_slave.pinmux_pad0 = EXT1_SPI_SERCOM_PINMUX_PAD0;
```

h. Set pinmux for pad 1 (slave select on on extension header 1, pin 15)

```
config_spi_slave.pinmux_pad1 = EXT1_SPI_SERCOM_PINMUX_PAD1;
```

i. Set pinmux for pad 2 (data out (MISO) on extension header 1, pin 16).

```
config_spi_slave.pinmux_pad2 = EXT1_SPI_SERCOM_PINMUX_PAD2;
```

j. Set pinmux for pad 3 (SCK on extension header 1, pin 18).

```
config_spi_slave.pinmux_pad3 = EXT1_SPI_SERCOM_PINMUX_PAD3;
```

k. Initialize SPI module with configuration.

```
spi_init(&spi_slave_instance, EXT1_SPI_MODULE, &config_spi_slave);
```

l. Enable SPI module.

```
spi_enable(&spi_slave_instance);
```

3. Setup the callback functionality:

```
configure_spi_slave_callbacks();
```

a. Register callback function for buffer transmitted

```
spi_register_callback(&spi_slave_instance, spi_slave_callback,
        SPI_CALLBACK_BUFFER_TRANSMITTED);
```

b. Enable callback for buffer transmitted

```
spi_enable_callback(&spi_slave_instance, SPI_CALLBACK_BUFFER_TRANSMITTED);
```

14.9.4.2 Use Case

Code

Add the following to your user application `main()`:

```
spi_write_buffer_job(&spi_slave_instance, buffer, BUF_LENGTH);
while(!transfer_complete_spi_slave) {
    /* Wait for transfer from master */
}


while (true) {
    /* Infinite loop */
```

```
}
```

Workflow

1. Initiate a write buffer job.

```
spi_write_buffer_job(&spi_slave_instance, buffer, BUF_LENGTH);
```

2. Wait for the transfer to be complete.

```
while(!transfer_complete_spi_slave) {
    /* Wait for transfer from master */
}
```

3. Infinite loop.

```
while (true) {
    /* Infinite loop */
}
```

14.9.4.3 Callback

When the buffer is successfully transmitted to the master, the callback function will be called.

Workflow

1. Let the application know that the buffer is transmitted by setting the global variable to true.

```
transfer_complete_spi_slave = true;
```

14.9.5 Quick Start Guide for Using DMA with SERCOM SPI

The supported device list:

- SAMD21

This quick start will transmit a buffer data from master to slave through DMA. In this use case the SPI master will be configured with the following settings:

- Master Mode enabled
- MSB of the data is transmitted first
- Transfer mode 0
- SPI MUX Setting E
  - MOSI on pad 2, extension header 2, pin 16
  - MISO on pad 0, extension header 2, pin 17
  - SCK on pad 3, extension header 2, pin 18
  - SS on extension header 2, pin 15
- 8-bit character size
- Not enabled in sleep mode
- Baudrate 100000
- GLCK generator 0

The SPI slave will be configured with the following settings:

- Slave mode enabled
- Preloading of shift register enabled
- MSB of the data is transmitted first
- Transfer mode 0
- SPI MUX Setting E
  - MISO on pad 2, extension header 1, pin 16
  - MOSI on pad 0, extension header 1, pin 17
  - SCK on pad 3, extension header 1, pin 18
  - SS on pad 1, extension header 1, pin
- 8-bit character size
- Not enabled in sleep mode
- GLCK generator 0

14.9.5.1 Setup

Prerequisites

The following connections has to be made using wires:

- **SS_0:** EXT1 PIN15 (PA05) <> EXT2 PIN15 (PA17)
- **DO/DI**: EXT1 PIN16 (PA06) <> EXT2 PIN17 (PA16)
- **DI/DO**: EXT1 PIN17 (PA04) <> EXT2 PIN16 (PA18)
- **SCK:** EXT1 PIN18 (PA07) <> EXT2 PIN18 (PA19)

Code

Add to the main application source file, outside of any functions:

```
#define BUF_LENGTH 20
```

```
#define TEST_SPI_BAUDRATE             1000000UL
```

```
#define SLAVE_SELECT_PIN EXT2_PIN_SPI_SS_0
```

```
static const uint8_t buffer_tx[BUF_LENGTH] = {
        0x01, 0x02, 0x03, 0x04, 0x05, 0x06, 0x07, 0x08, 0x09, 0x0A,
        0x0B, 0x0C, 0x0D, 0x0E, 0x0F, 0x10, 0x11, 0x12, 0x13, 0x14,
};
static uint8_t buffer_rx[BUF_LENGTH];
```

```
struct spi_module spi_master_instance;
struct spi_module spi_slave_instance;
```

```
static volatile bool transfer_tx_is_done = false;
static volatile bool transfer_rx_is_done = false;
```

```
struct spi_slave_inst slave;
```

```
COMPILER_ALIGNED(16)
DmacDescriptor example_descriptor_tx;
DmacDescriptor example_descriptor_rx;
```

Copy-paste the following setup code to your user application:

```
static void transfer_tx_done( const struct dma_resource* const resource )
{
    transfer_tx_is_done = true;
}

static void transfer_rx_done( const struct dma_resource* const resource )
{
    transfer_rx_is_done = true;
}

static void configure_dma_resource_tx(struct dma_resource *tx_resource)
{
    struct dma_resource_config tx_config;

    dma_get_config_defaults(&tx_config);

    tx_config.peripheral_trigger = PERIPHERAL_TRIGGER_SERCOM_TX;
    tx_config.trigger_action = DMA_TRIGGER_ACTON_BEAT;

    dma_allocate(tx_resource, &tx_config);
}

static void configure_dma_resource_rx(struct dma_resource *rx_resource)
{
    struct dma_resource_config rx_config;

    dma_get_config_defaults(&rx_config);

    rx_config.peripheral_trigger = PERIPHERAL_TRIGGER_SERCOM_RX;
    rx_config.trigger_action = DMA_TRIGGER_ACTON_BEAT;

    dma_allocate(rx_resource, &rx_config);
}

static void setup_transfer_descriptor_tx(DmacDescriptor *tx_descriptor)
{
    struct dma_descriptor_config tx_descriptor_config;

    dma_descriptor_get_config_defaults(&tx_descriptor_config);

    tx_descriptor_config.beat_size = DMA_BEAT_SIZE_BYTE;
    tx_descriptor_config.dst_increment_enable = false;
    tx_descriptor_config.block_transfer_count = sizeof(buffer_tx)/sizeof(uint8_t);
    tx_descriptor_config.source_address = (uint32_t)buffer_tx + sizeof(buffer_tx);
    tx_descriptor_config.destination_address =
        (uint32_t)(&spi_master_instance.hw->SPI.DATA.reg);

    dma_descriptor_create(tx_descriptor, &tx_descriptor_config);
}

static void setup_transfer_descriptor_rx(DmacDescriptor *rx_descriptor)
```

```
{
    struct dma_descriptor_config rx_descriptor_config;

    dma_descriptor_get_config_defaults(&rx_descriptor_config);

    rx_descriptor_config.beat_size = DMA_BEAT_SIZE_BYTE;
    rx_descriptor_config.src_increment_enable = false;
    rx_descriptor_config.block_transfer_count = sizeof(buffer_rx)/sizeof(uint8_t);
    rx_descriptor_config.source_address =
        (uint32_t)(&spi_slave_instance.hw->SPI.DATA.reg);
    rx_descriptor_config.destination_address =
        (uint32_t)buffer_rx + sizeof(buffer_rx);

    dma_descriptor_create(rx_descriptor, &rx_descriptor_config);
}

static void configure_spi_master(void)
{
    struct spi_config config_spi_master;
    struct spi_slave_inst_config slave_dev_config;
    /* Configure and initialize software device instance of peripheral slave */
    spi_slave_inst_get_config_defaults(&slave_dev_config);
    slave_dev_config.ss_pin = SLAVE_SELECT_PIN;
    spi_attach_slave(&slave, &slave_dev_config);
    /* Configure, initialize and enable SERCOM SPI module */
    spi_get_config_defaults(&config_spi_master);
    config_spi_master.mode_specific.master.baudrate = TEST_SPI_BAUDRATE;
    config_spi_master.mux_setting = EXT2_SPI_SERCOM_MUX_SETTING;
    /* Configure pad 0 for data in */
    config_spi_master.pinmux_pad0 = EXT2_SPI_SERCOM_PINMUX_PAD0;
    /* Configure pad 1 as unused */
    config_spi_master.pinmux_pad1 = PINMUX_UNUSED;
    /* Configure pad 2 for data out */
    config_spi_master.pinmux_pad2 = EXT2_SPI_SERCOM_PINMUX_PAD2;
    /* Configure pad 3 for SCK */
    config_spi_master.pinmux_pad3 = EXT2_SPI_SERCOM_PINMUX_PAD3;
    spi_init(&spi_master_instance, EXT2_SPI_MODULE, &config_spi_master);

    spi_enable(&spi_master_instance);

}

static void configure_spi_slave(void)
{
    struct spi_config config_spi_slave;

    /* Configure, initialize and enable SERCOM SPI module */
    spi_get_config_defaults(&config_spi_slave);
    config_spi_slave.mode = SPI_MODE_SLAVE;
    config_spi_slave.mode_specific.slave.preload_enable = true;
    config_spi_slave.mode_specific.slave.frame_format = SPI_FRAME_FORMAT_SPI_FRAME;
    config_spi_slave.mux_setting = EXT1_SPI_SERCOM_MUX_SETTING;
    /* Configure pad 0 for data in */
    config_spi_slave.pinmux_pad0 = EXT1_SPI_SERCOM_PINMUX_PAD0;
    /* Configure pad 1 as unused */
    config_spi_slave.pinmux_pad1 = EXT1_SPI_SERCOM_PINMUX_PAD1;
    /* Configure pad 2 for data out */
    config_spi_slave.pinmux_pad2 = EXT1_SPI_SERCOM_PINMUX_PAD2;
    /* Configure pad 3 for SCK */
    config_spi_slave.pinmux_pad3 = EXT1_SPI_SERCOM_PINMUX_PAD3;
    spi_init(&spi_slave_instance, EXT1_SPI_MODULE, &config_spi_slave);
```

```
    spi_enable(&spi_slave_instance);

}
```

Add to user application initialization (typically the start of `main()`):

```
configure_spi_master();
configure_spi_slave();

configure_dma_resource_tx(&example_resource_tx);
configure_dma_resource_rx(&example_resource_rx);

setup_transfer_descriptor_tx(&example_descriptor_tx);
setup_transfer_descriptor_rx(&example_descriptor_rx);

dma_add_descriptor(&example_resource_tx, &example_descriptor_tx);
dma_add_descriptor(&example_resource_rx, &example_descriptor_rx);

dma_register_callback(&example_resource_tx, transfer_tx_done,
        DMA_CALLBACK_TRANSFER_DONE);
dma_register_callback(&example_resource_rx, transfer_rx_done,
        DMA_CALLBACK_TRANSFER_DONE);

dma_enable_callback(&example_resource_tx, DMA_CALLBACK_TRANSFER_DONE);
dma_enable_callback(&example_resource_rx, DMA_CALLBACK_TRANSFER_DONE);
```

Workflow

1. Create a module software instance structure for the SPI module to store the SPI driver state while it is in use.

```
struct spi_module spi_master_instance;
struct spi_module spi_slave_instance;
```

Note This should never go out of scope as long as the module is in use. In most cases, this should be global.

2. Create a module software instance structure for DMA resource to store the DMA resource state while it is in use.

```
struct dma_resource example_resource_tx;
struct dma_resource example_resource_rx;
```

Note This should never go out of scope as long as the module is in use. In most cases, this should be global.

3. Create transfer done flag to indication DMA transfer done

```
static volatile bool transfer_tx_is_done = false;
static volatile bool transfer_rx_is_done = false;
```

4. Define the buffer length for tx/rx

```
#define BUF_LENGTH 20
```

5. Create buffer to store the data to be transferred

```
static const uint8_t buffer_tx[BUF_LENGTH] = {
        0x01, 0x02, 0x03, 0x04, 0x05, 0x06, 0x07, 0x08, 0x09, 0x0A,
        0x0B, 0x0C, 0x0D, 0x0E, 0x0F, 0x10, 0x11, 0x12, 0x13, 0x14,
};
static uint8_t buffer_rx[BUF_LENGTH];
```

6. Create SPI module configuration struct, which can be filled out to adjust the configuration of a physical SPI peripheral.

```
struct spi_config config_spi_master;
```

```
struct spi_config config_spi_slave;
```

7. Initialize the SPI configuration struct with the module's default values.

```
spi_get_config_defaults(&config_spi_master);
```

```
spi_get_config_defaults(&config_spi_slave);
```

Note This should always be performed before using the configuration struct to ensure that all values are initialized to known default settings.

8. Alter the SPI settings to configure the physical pinout, baud rate and other relevant parameters.

```
config_spi_master.mux_setting = EXT2_SPI_SERCOM_MUX_SETTING;
```

```
config_spi_slave.mux_setting = EXT1_SPI_SERCOM_MUX_SETTING;
```

9. Configure the SPI module with the desired settings, retrying while the driver is busy until the configuration is stressfully set.

```
spi_init(&spi_master_instance, EXT2_SPI_MODULE, &config_spi_master);
```

```
spi_init(&spi_slave_instance, EXT1_SPI_MODULE, &config_spi_slave);
```

10. Enable the SPI module.

```
spi_enable(&spi_master_instance);
```

```
spi_enable(&spi_slave_instance);
```

11. Create DMA resource configuration structure, which can be filled out to adjust the configuration of a single DMA transfer.

```
struct dma_resource_config tx_config;
```

```
struct dma_resource_config rx_config;
```

12. Initialize the DMA resource configuration struct with the module's default values.

```
dma_get_config_defaults(&tx_config);
```

```
dma_get_config_defaults(&rx_config);
```

Note This should always be performed before using the configuration struct to ensure that all values are initialized to known default settings.

13. Set extra configurations for the DMA resource. It is using peripheral trigger, SERCOM Tx empty and RX complete trigger causes a beat transfer in this example.

```
tx_config.peripheral_trigger = PERIPHERAL_TRIGGER_SERCOM_TX;
tx_config.trigger_action = DMA_TRIGGER_ACTON_BEAT;
```

```
rx_config.peripheral_trigger = PERIPHERAL_TRIGGER_SERCOM_RX;
rx_config.trigger_action = DMA_TRIGGER_ACTON_BEAT;
```

14. Allocate a DMA resource with the configurations.

```
dma_allocate(tx_resource, &tx_config);
```

```
dma_allocate(rx_resource, &rx_config);
```

15. Create a DMA transfer descriptor configuration structure, which can be filled out to adjust the configuration of a single DMA transfer.

```
struct dma_descriptor_config tx_descriptor_config;
```

```
struct dma_descriptor_config rx_descriptor_config;
```

16. Initialize the DMA transfer descriptor configuration struct with the module's default values.

```
dma_descriptor_get_config_defaults(&tx_descriptor_config);
```

```
dma_descriptor_get_config_defaults(&rx_descriptor_config);
```

Note This should always be performed before using the configuration struct to ensure that all values are initialized to known default settings.

17. Set the specific parameters for a DMA transfer with transfer size, source address, destination address.

```
tx_descriptor_config.beat_size = DMA_BEAT_SIZE_BYTE;
tx_descriptor_config.dst_increment_enable = false;
tx_descriptor_config.block_transfer_count = sizeof(buffer_tx)/sizeof(uint8_t);
tx_descriptor_config.source_address = (uint32_t)buffer_tx + sizeof(buffer_tx);
tx_descriptor_config.destination_address =
    (uint32_t)(&spi_master_instance.hw->SPI.DATA.reg);
```

```
rx_descriptor_config.beat_size = DMA_BEAT_SIZE_BYTE;
rx_descriptor_config.src_increment_enable = false;
rx_descriptor_config.block_transfer_count = sizeof(buffer_rx)/sizeof(uint8_t);
rx_descriptor_config.source_address =
    (uint32_t)(&spi_slave_instance.hw->SPI.DATA.reg);
rx_descriptor_config.destination_address =
    (uint32_t)buffer_rx + sizeof(buffer_rx);
```

18. Create the DMA transfer descriptor.

```
dma_descriptor_create(tx_descriptor, &tx_descriptor_config);
```

```
dma_descriptor_create(rx_descriptor, &rx_descriptor_config);
```

14.9.5.2 Use Case

Code

Copy-paste the following code to your user application:

```
spi_select_slave(&spi_master_instance, &slave, true);

dma_start_transfer_job(&example_resource_rx);
dma_start_transfer_job(&example_resource_tx);

while (!transfer_rx_is_done) {
    /* Wait for transfer done */
}

spi_select_slave(&spi_master_instance, &slave, false);

while (true) {
}
```

Workflow

1. Select the slave.

```
spi_select_slave(&spi_master_instance, &slave, true);
```

2. Start the transfer job.

```
dma_start_transfer_job(&example_resource_rx);
dma_start_transfer_job(&example_resource_tx);
```

3. Wait for transfer done.

```
while (!transfer_rx_is_done) {
    /* Wait for transfer done */
}
```

4. Deselect the slave.

```
spi_select_slave(&spi_master_instance, &slave, false);
```

5. enter endless loop

```
while (true) {
}
```

15. SAM D20/D21 Serial USART Driver (SERCOM USART)

This driver for SAM D20/D21 devices provides an interface for the configuration and management of the SERCOM module in its USART mode to transfer or receive USART data frames. The following driver API modes are covered by this manual:

- Polled APIs
- Callback APIs

The following peripherals are used by this module:

- SERCOM (Serial Communication Interface)

The outline of this documentation is as follows:

- Prerequisites
- Module Overview
- Special Considerations
- Extra Information
- Examples
- API Overview

15.1 Prerequisites

To use the USART you need to have a GCLK generator enabled and running that can be used as the SERCOM clock source. This can either be configured in conf_clocks.h or by using the system clock driver.

15.2 Module Overview

This driver will use one (or more) SERCOM interfaces on the system and configure it to run as a USART interface in either synchronous or asynchronous mode.

15.2.1 Driver Feature Macro Definition

Driver Feature Macro	Supported devices
FEATURE_USART_OVER_SAMPLE	SAMD21
FEATURE_USART_HARDWARE_FLOW_CONTROL	SAMD21
FEATURE_USART_IRDA	SAMD21
FEATURE_USART_LIN_SLAVE	SAMD21
FEATURE_USART_COLLISION_DECTION	SAMD21
FEATURE_USART_START_FRAME_DECTION	SAMD21
FEATURE_USART_IMMEDIATE_BUFFER_OVERFLOV	SAMD21

Note The specific features are only available in the driver when the selected device supports those features.

15.2.2 Frame Format

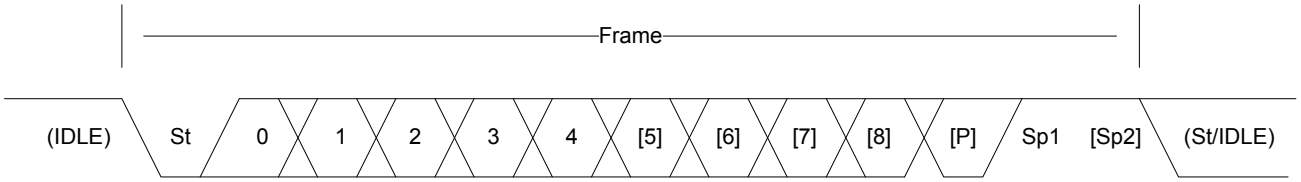
Communication is based on frames, where the frame format can be customized to accommodate a wide range of standards. A frame consists of a start bit, a number of data bits, an optional parity bit for error detection as well as

a configurable length stop bit(s) - see Figure 15-1: USART Frame overview on page 369. Table 15-1: USART Frame Parameters on page 369 shows the available parameters you can change in a frame.

Table 15-1. USART Frame Parameters

Parameter	Options
Start bit	1
Data bits	5, 6, 7, 8, 9
Parity bit	None, Even, Odd
Stop bits	1, 2

Figure 15-1. USART Frame overview



15.2.3 Synchronous mode

In synchronous mode a dedicated clock line is provided; either by the USART itself if in master mode, or by an external master if in slave mode. Maximum transmission speed is the same as the GCLK clocking the USART peripheral when in slave mode, and the GCLK divided by two if in master mode. In synchronous mode the interface needs three lines to communicate:

- TX (Transmit pin)
- RX (Receive pin)
- XCK (Clock pin)

15.2.3.1 Data sampling

In synchronous mode the data is sampled on either the rising or falling edge of the clock signal. This is configured by setting the clock polarity in the configuration struct.

15.2.4 Asynchronous mode

In asynchronous mode no dedicated clock line is used, and the communication is based on matching the clock speed on the transmitter and receiver. The clock is generated from the internal SERCOM baudrate generator, and the frames are synchronized by using the frame start bits. Maximum transmission speed is limited to the SERCOM GCLK divided by 16. In asynchronous mode the interface only needs two lines to communicate:

- TX (Transmit pin)
- RX (Receive pin)

15.2.4.1 Transmitter/receiver clock matching

For successful transmit and receive using the asynchronous mode the receiver and transmitter clocks needs to be closely matched. When receiving a frame that does not match the selected baud rate closely enough the receiver will be unable to synchronize the frame(s), and garbage transmissions will result.

15.2.5 Parity

Parity can be enabled to detect if a transmission was in error. This is done by counting the number of "1" bits in the frame. When using Even parity the parity bit will be set if the total number of "1"s in the frame are an even number. If using Odd parity the parity bit will be set if the total number of "1"s are Odd.

When receiving a character the receiver will count the number of "1"s in the frame and give an error if the received frame and parity bit disagree.

15.2.6 GPIO configuration

The SERCOM module has four internal pads; the RX pin can be placed freely on any one of the four pads, and the TX and XCK pins have two predefined positions that can be selected as a pair. The pads can then be routed to an external GPIO pin using the normal pin multiplexing scheme on the SAM D20/D21.

15.3 Special Considerations

Never execute large portions of code in the callbacks. These are run from the interrupt routine, and thus having long callbacks will keep the processor in the interrupt handler for an equally long time. A common way to handle this is to use global flags signaling the main application that an interrupt event has happened, and only do the minimal needed processing in the callback.

15.4 Extra Information

For extra information see Extra Information for SERCOM USART Driver. This includes:

- Acronyms
- Dependencies
- Errata
- Module History

15.5 Examples

For a list of examples related to this driver, see Examples for SERCOM USART Driver.

15.6 API Overview

15.6.1 Variable and Type Definitions

15.6.1.1 Type usart_callback_t

```
typedef void(* usart_callback_t )(const struct usart_module *const module)
```

Type of the callback functions

15.6.2 Structure Definitions

15.6.2.1 Struct usart_config

Configuration options for USART

Table 15-2. Members

Type	Name	Description
uint32_t	baudrate	USART baud rate
enum usart_character_size	character_size	USART character size
bool	clock_polarity_inverted	USART Clock Polarity. If true, data changes on falling XCK edge and is sampled at rising edge. If false, data changes on rising XCK edge and is sampled at falling edge.
enum usart_dataorder	data_order	USART bit order (MSB or LSB first)

Type	Name	Description
uint32_t	ext_clock_freq	External clock frequency in synchronous mode. This must be set if use_external_clock is true.
enum gclk_generator	generator_source	GCLK generator source
enum usart_signal_mux_settings	mux_setting	USART pin out
enum usart_parity	parity	USART parity
uint32_t	pinmux_pad0	PAD0 pinmux
uint32_t	pinmux_pad1	PAD1 pinmux
uint32_t	pinmux_pad2	PAD2 pinmux
uint32_t	pinmux_pad3	PAD3 pinmux
bool	receiver_enable	Enable receiver
bool	run_in_standby	If true the USART will be kept running in Standby sleep mode
enum usart_stopbits	stopbits	Number of stop bits
enum usart_transfer_mode	transfer_mode	USART in asynchronous or synchronous mode
bool	transmitter_enable	Enable transmitter
bool	use_external_clock	States whether to use the external clock applied to the XCK pin. In synchronous mode the shift register will act directly on the XCK clock. In asynchronous mode the XCK will be the input to the USART hardware module.

15.6.2.2 Struct usart_module

SERCOM USART driver software instance structure, used to retain software state information of an associated hardware module instance.

Note The fields of this structure should not be altered by the user application; they are reserved for module-internal use only.

15.6.3 Macro Definitions

15.6.3.1 Macro PINMUX_DEFAULT

```
#define PINMUX_DEFAULT 0
```

Default pin mux.

15.6.3.2 Macro PINMUX_UNUSED

```
#define PINMUX_UNUSED 0xFFFFFFFF
```

Unused PIN mux.

15.6.3.3 Macro USART_TIMEOUT

```
#define USART_TIMEOUT 0xFFFF
```

USART timeout value.

15.6.4 Function Definitions

15.6.4.1 Lock/Unlock

Function usart_lock()

Attempt to get lock on driver instance.

```
enum status_code usart_lock(
  struct usart_module *const module)
```

This function checks the instance's lock, which indicates whether or not it is currently in use, and sets the lock if it was not already set.

The purpose of this is to enable exclusive access to driver instances, so that, e.g., transactions by different services will not interfere with each other.

Table 15-3. Parameters

Data direction	Parameter name	Description
[in, out]	module	Pointer to the driver instance to lock.

Table 15-4. Return Values

Return value	Description
STATUS_OK	if the module was locked.
STATUS_BUSY	if the module was already locked.

Function usart_unlock()

Unlock driver instance.

```
void usart_unlock(
  struct usart_module *const module)
```

This function clears the instance lock, indicating that it is available for use.

Table 15-5. Parameters

Data direction	Parameter name	Description
[in, out]	module	Pointer to the driver instance to lock.

15.6.4.2 Writing and reading

Function usart_write_wait()

Transmit a character via the USART.

```
enum status_code usart_write_wait(
  struct usart_module *const module,
  const uint16_t tx_data)
```

This blocking function will transmit a single character via the USART.

Table 15-6. Parameters

Data direction	Parameter name	Description
[in]	module	Pointer to the software instance struct
[in]	tx_data	Data to transfer

Returns Status of the operation

Table 15-7. Return Values

Return value	Description
STATUS_OK	If the operation was completed
STATUS_BUSY	If the operation was not completed, due to the USART module being busy.
STATUS_ERR_DENIED	If the transmitter is not enabled

Function usart_read_wait()

Receive a character via the USART.

```
enum status_code usart_read_wait(
  struct usart_module *const module,
  uint16_t *const rx_data)
```

This blocking function will receive a character via the USART.

Table 15-8. Parameters

Data direction	Parameter name	Description
[in]	module	Pointer to the software instance struct
[out]	rx_data	Pointer to received data

Returns Status of the operation

Table 15-9. Return Values

Return value	Description
STATUS_OK	If the operation was completed
STATUS_BUSY	If the operation was not completed, due to the USART module being busy

Return value	Description
STATUS_ERR_BAD_FORMAT	If the operation was not completed, due to configuration mismatch between USART and the sender
STATUS_ERR_BAD_OVERFLOW	If the operation was not completed, due to the baud rate being too low or the system frequency being too high
STATUS_ERR_BAD_DATA	If the operation was not completed, due to data being corrupted
STATUS_ERR_DENIED	If the receiver is not enabled

Function usart_write_buffer_wait()

Transmit a buffer of characters via the USART.

```
enum status_code usart_write_buffer_wait(
  struct usart_module *const module,
  const uint8_t * tx_data,
  uint16_t length)
```

This blocking function will transmit a block of `length` characters via the USART

Note

Using this function in combination with the interrupt (`_job`) functions is not recommended as it has no functionality to check if there is an ongoing interrupt driven operation running or not.

Table 15-10. Parameters

Data direction	Parameter name	Description
[in]	module	Pointer to USART software instance struct
[in]	tx_data	Pointer to data to transmit
[in]	length	Number of characters to transmit

Returns

Status of the operation

Table 15-11. Return Values

Return value	Description
STATUS_OK	If operation was completed
STATUS_ERR_INVALID_ARG	If operation was not completed, due to invalid arguments
STATUS_ERR_TIMEOUT	If operation was not completed, due to USART module timing out
STATUS_ERR_DENIED	If the transmitter is not enabled

Function usart_read_buffer_wait()

Receive a buffer of length characters via the USART.

```
enum status_code usart_read_buffer_wait(
  struct usart_module *const module,
  uint8_t * rx_data,
  uint16_t length)
```

This blocking function will receive a block of `length` characters via the USART.

Note Using this function in combination with the interrupt (`*_job`) functions is not recommended as it has no functionality to check if there is an ongoing interrupt driven operation running or not.

Table 15-12. Parameters

Data direction	Parameter name	Description
[in]	module	Pointer to USART software instance struct
[out]	rx_data	Pointer to receive buffer
[in]	length	Number of characters to receive

Returns Status of the operation.

Table 15-13. Return Values

Return value	Description
STATUS_OK	If operation was completed
STATUS_ERR_INVALID_ARG	If operation was not completed, due to an invalid argument being supplied
STATUS_ERR_TIMEOUT	If operation was not completed, due to USART module timing out
STATUS_ERR_BAD_FORMAT	If the operation was not completed, due to a configuration mismatch between USART and the sender
STATUS_ERR_BAD_OVERFLOW	If the operation was not completed, due to the baud rate being too low or the system frequency being too high
STATUS_ERR_DENIED	If the receiver is not enabled

15.6.4.3 Enabling/Disabling receiver and transmitter

Function usart_enable_transceiver()

Enable Transceiver.

```
void usart_enable_transceiver(
  struct usart_module *const module,
  enum usart_transceiver_type transceiver_type)
```

Enable the given transceiver. Either RX or TX.

Table 15-14. Parameters

Data direction	Parameter name	Description
[in]	module	Pointer to USART software instance struct
[in]	transceiver_type	Transceiver type.

Function usart_disable_transceiver()

Disable Transceiver.

```
void usart_disable_transceiver(
  struct usart_module *const module,
  enum usart_transceiver_type transceiver_type)
```

Disable the given transceiver (RX or TX).

Table 15-15. Parameters

Data direction	Parameter name	Description
[in]	module	Pointer to USART software instance struct
[in]	transceiver_type	Transceiver type.

15.6.4.4 Callback Management

Function usart_register_callback()

Registers a callback.

```
void usart_register_callback(
  struct usart_module *const module,
  usart_callback_t callback_func,
  enum usart_callback callback_type)
```

Registers a callback function which is implemented by the user.

Note The callback must be enabled by usart_enable_callback, in order for the interrupt handler to call it when the conditions for the callback type are met.

Table 15-16. Parameters

Data direction	Parameter name	Description
[in]	module	Pointer to USART software instance struct
[in]	callback_func	Pointer to callback function
[in]	callback_type	Callback type given by an enum

Function usart_unregister_callback()

Unregisters a callback.

```
void usart_unregister_callback(
  struct usart_module * module,
  enum usart_callback callback_type)
```

Unregisters a callback function which is implemented by the user.

Table 15-17. Parameters

Data direction	Parameter name	Description
[in, out]	module	Pointer to USART software instance struct
[in]	callback_type	Callback type given by an enum

Function usart_enable_callback()

Enables callback.

```
void usart_enable_callback(
  struct usart_module *const module,
  enum usart_callback callback_type)
```

Enables the callback function registered by the usart_register_callback. The callback function will be called from the interrupt handler when the conditions for the callback type are met.

Table 15-18. Parameters

Data direction	Parameter name	Description
[in]	module	Pointer to USART software instance struct
[in]	callback_type	Callback type given by an enum

Function usart_disable_callback()

Disable callback.

```
void usart_disable_callback(
  struct usart_module *const module,
  enum usart_callback callback_type)
```

Disables the callback function registered by the usart_register_callback, and the callback will not be called from the interrupt routine.

Table 15-19. Parameters

Data direction	Parameter name	Description
[in]	module	Pointer to USART software instance struct
[in]	callback_type	Callback type given by an enum

15.6.4.5 Writing and reading

Function usart_write_job()

Asynchronous write a single char.

```
enum status_code usart_write_job(
  struct usart_module *const module,
  const uint16_t tx_data)
```

Sets up the driver to write the data given. If registered and enabled, a callback function will be called when the transmit is completed.

Table 15-20. Parameters

Data direction	Parameter name	Description
[in]	module	Pointer to USART software instance struct
[in]	tx_data	Data to transfer

Returns Status of the operation

Table 15-21. Return Values

Return value	Description
STATUS_OK	If operation was completed
STATUS_BUSY	If operation was not completed, due to the USART module being busy
STATUS_ERR_DENIED	If the transmitter is not enabled

Function usart_read_job()

Asynchronous read a single char.

```
enum status_code usart_read_job(
  struct usart_module *const module,
  uint16_t *const rx_data)
```

Sets up the driver to read data from the USART module to the data pointer given. If registered and enabled, a callback will be called when the receiving is completed.

Table 15-22. Parameters

Data direction	Parameter name	Description
[in]	module	Pointer to USART software instance struct
[out]	rx_data	Pointer to where received data should be put

Returns Status of the operation

Table 15-23. Return Values

Return value	Description
STATUS_OK	If operation was completed

Return value	Description
STATUS_BUSY	If operation was not completed,

Function usart_write_buffer_job()

Asynchronous buffer write.

```
enum status_code usart_write_buffer_job(
  struct usart_module *const module,
  uint8_t * tx_data,
  uint16_t length)
```

Sets up the driver to write a given buffer over the USART. If registered and enabled, a callback function will be called.

Table 15-24. Parameters

Data direction	Parameter name	Description
[in]	module	Pointer to USART software instance struct
[in]	tx_data	Pointer do data buffer to transmit
[in]	length	Length of the data to transmit

Returns Status of the operation

Table 15-25. Return Values

Return value	Description
STATUS_OK	If operation was completed successfully.
STATUS_BUSY	If operation was not completed, due to the USART module being busy
STATUS_ERR_INVALID_ARG	If operation was not completed, due to invalid arguments
STATUS_ERR_DENIED	If the transmitter is not enabled

Function usart_read_buffer_job()

Asynchronous buffer read.

```
enum status_code usart_read_buffer_job(
  struct usart_module *const module,
  uint8_t * rx_data,
  uint16_t length)
```

Sets up the driver to read from the USART to a given buffer. If registered and enabled, a callback function will be called.

Table 15-26. Parameters

Data direction	Parameter name	Description
[in]	module	Pointer to USART software instance struct

Data direction	Parameter name	Description
[out]	rx_data	Pointer to data buffer to receive
[in]	length	Data buffer length

Returns Status of the operation

Table 15-27. Return Values

Return value	Description
STATUS_OK	If operation was completed
STATUS_BUSY	If operation was not completed, due to the USART module being busy
STATUS_ERR_INVALID_ARG	If operation was not completed, due to invalid arguments
STATUS_ERR_DENIED	If the transmitter is not enabled

Function usart_abort_job()

Cancels ongoing read/write operation.

```
void usart_abort_job(
  struct usart_module *const module,
  enum usart_transceiver_type transceiver_type)
```

Cancels the ongoing read/write operation modifying parameters in the USART software struct.

Table 15-28. Parameters

Data direction	Parameter name	Description
[in]	module	Pointer to USART software instance struct
[in]	transceiver_type	Transfer type to cancel

Function usart_get_job_status()

Get status from the ongoing or last asynchronous transfer operation.

```
enum status_code usart_get_job_status(
  struct usart_module *const module,
  enum usart_transceiver_type transceiver_type)
```

Returns the error from a given ongoing or last asynchronous transfer operation. Either from a read or write transfer.

Table 15-29. Parameters

Data direction	Parameter name	Description
[in]	module	Pointer to USART software instance struct
[in]	transceiver_type	Transfer type to check

Returns Status of the given job.

Table 15-30. Return Values

Return value	Description
STATUS_OK	No error occurred during the last transfer
STATUS_BUSY	A transfer is ongoing
STATUS_ERR_BAD_DATA	The last operation was aborted due to a parity error. The transfer could be affected by external noise.
STATUS_ERR_BAD_FORMAT	The last operation was aborted due to a frame error.
STATUS_ERR_OVERFLOW	The last operation was aborted due to a buffer overflow.
STATUS_ERR_INVALID_ARG	An invalid transceiver enum given.

15.6.4.6 Function usart_disable()

Disable module.

```
void usart_disable(
  const struct usart_module *const module)
```

Disables the USART module

Table 15-31. Parameters

Data direction	Parameter name	Description
[in]	module	Pointer to USART software instance struct

15.6.4.7 Function usart_enable()

Enable the module.

```
void usart_enable(
  const struct usart_module *const module)
```

Enables the USART module

Table 15-32. Parameters

Data direction	Parameter name	Description
[in]	module	Pointer to USART software instance struct

15.6.4.8 Function usart_get_config_defaults()

Initializes the device to predefined defaults.

```
void usart_get_config_defaults(
  struct usart_config *const config)
```

Initialize the USART device to predefined defaults:

- 8-bit asynchronous USART
- No parity
- 1 stop bit
- 9600 baud
- Transmitter enabled
- Receiver enabled
- GCLK generator 0 as clock source
- Default pin configuration

The configuration struct will be updated with the default configuration.

Table 15-33. Parameters

Data direction	Parameter name	Description
[in, out]	config	Pointer to configuration struct

15.6.4.9 Function usart_init()

Initializes the device.

```
enum status_code usart_init(
  struct usart_module *const module,
  Sercom *const hw,
  const struct usart_config *const config)
```

Initializes the USART device based on the setting specified in the configuration struct.

Table 15-34. Parameters

Data direction	Parameter name	Description
[out]	module	Pointer to USART device
[in]	hw	Pointer to USART hardware instance
[in]	config	Pointer to configuration struct

Returns Status of the initialization

Table 15-35. Return Values

Return value	Description
STATUS_OK	The initialization was successful
STATUS_BUSY	The USART module is busy resetting
STATUS_ERR_DENIED	The USART have not been disabled in advance of initialization
STATUS_ERR_INVALID_ARG	The configuration struct contains invalid configuration

Return value	Description
STATUS_ERR_ALREADY_INITIALIZED	The SERCOM instance has already been initialized with different clock configuration
STATUS_ERR_BAUD_UNAVAILABLE	The BAUD rate given by the configuration struct cannot be reached with the current clock configuration

15.6.4.10 Function usart_is_syncing()

Check if peripheral is busy syncing registers across clock domains.

```
bool usart_is_syncing(
  const struct usart_module *const module)
```

Return peripheral synchronization status. If doing a non-blocking implementation this function can be used to check the sync state and hold of any new actions until sync is complete. If this functions is not run; the functions will block until the sync has completed.

Table 15-36. Parameters

Data direction	Parameter name	Description
[in]	module	Pointer to peripheral module

Returns Peripheral sync status

Table 15-37. Return Values

Return value	Description
true	Peripheral is busy syncing
false	Peripheral is not busy syncing and can be read/written without stalling the bus.

15.6.4.11 Function usart_reset()

Resets the USART module.

```
void usart_reset(
  const struct usart_module *const module)
```

Disables and resets the USART module.

Table 15-38. Parameters

Data direction	Parameter name	Description
[in]	module	Pointer to the USART software instance struct

15.6.5 Enumeration Definitions

15.6.5.1 Enum usart_callback

Callbacks for the Asynchronous USART driver

Table 15-39. Members

Enum value	Description
USART_CALLBACK_BUFFER_TRANSMITTED	Callback for buffer transmitted
USART_CALLBACK_BUFFER_RECEIVED	Callback for buffer received
USART_CALLBACK_ERROR	Callback for error

15.6.5.2 Enum usart_character_size

Number of bits for the character sent in a frame.

Table 15-40. Members

Enum value	Description
USART_CHARACTER_SIZE_5BIT	The char being sent in a frame is 5 bits long
USART_CHARACTER_SIZE_6BIT	The char being sent in a frame is 6 bits long
USART_CHARACTER_SIZE_7BIT	The char being sent in a frame is 7 bits long
USART_CHARACTER_SIZE_8BIT	The char being sent in a frame is 8 bits long
USART_CHARACTER_SIZE_9BIT	The char being sent in a frame is 9 bits long

15.6.5.3 Enum usart_dataorder

The data order decides which of MSB or LSB is shifted out first when data is transferred

Table 15-41. Members

Enum value	Description
USART_DATAORDER_MSB	The MSB will be shifted out first during transmission, and shifted in first during reception
USART_DATAORDER_LSB	The LSB will be shifted out first during transmission, and shifted in first during reception

15.6.5.4 Enum usart_parity

Select parity USART parity mode

Table 15-42. Members

Enum value	Description
USART_PARITY_ODD	For odd parity checking, the parity bit will be set if number of ones being transferred is even
USART_PARITY_EVEN	For even parity checking, the parity bit will be set if number of ones being received is odd
USART_PARITY_NONE	No parity checking will be executed, and there will be no parity bit in the received frame

15.6.5.5 Enum usart_signal_mux_settings

Set the functionality of the SERCOM pins.

See SERCOM USART MUX Settings for a description of the various MUX setting options.

Table 15-43. Members

Enum value	Description
USART_RX_0_TX_0_XCK_1	MUX setting RX_0_TX_0_XCK_1
USART_RX_0_TX_2_XCK_3	MUX setting RX_0_TX_2_XCK_3
USART_RX_1_TX_0_XCK_1	MUX setting RX_1_TX_0_XCK_1
USART_RX_1_TX_2_XCK_3	MUX setting RX_1_TX_2_XCK_3
USART_RX_2_TX_0_XCK_1	MUX setting RX_2_TX_0_XCK_1
USART_RX_2_TX_2_XCK_3	MUX setting RX_2_TX_2_XCK_3
USART_RX_3_TX_0_XCK_1	MUX setting RX_3_TX_0_XCK_1
USART_RX_3_TX_2_XCK_3	MUX setting RX_3_TX_2_XCK_3

15.6.5.6 Enum usart_stopbits

Number of stop bits for a frame.

Table 15-44. Members

Enum value	Description
USART_STOPBITS_1	Each transferred frame contains 1 stop bit
USART_STOPBITS_2	Each transferred frame contains 2 stop bits

15.6.5.7 Enum usart_transceiver_type

Select Receiver or Transmitter

Table 15-45. Members

Enum value	Description
USART_TRANSCEIVER_RX	The parameter is for the Receiver
USART_TRANSCEIVER_TX	The parameter is for the Transmitter

15.6.5.8 Enum usart_transfer_mode

Select USART transfer mode

Table 15-46. Members

Enum value	Description
USART_TRANSFER_SYNCHRONOUSLY	Transfer of data is done synchronously
USART_TRANSFER_ASYNCHRONOUSLY	Transfer of data is done asynchronously

15.7 SERCOM USART MUX Settings

The following lists the possible internal SERCOM module pad function assignments, for the four SERCOM pads when in USART mode. Note that this is in addition to the physical GPIO pin MUX of the device, and can be used in conjunction to optimize the serial data pin-out.

When TX and RX are connected to the same pin, the USART will operate in half-duplex mode if both the transmitter and receivers are enabled.

Note When RX and XCK are connected to the same pin, the receiver must not be enabled if the USART is configured to use an external clock.

Mux/Pad	PAD 0	PAD 1	PAD 2	PAD 3
RX_0_TX_0_XCK_1	TX / RX	XCK	-	-
RX_0_TX_2_XCK_3	RX	-	TX	XCK
RX_1_TX_0_XCK_1	TX	RX / XCK	-	-
RX_1_TX_2_XCK_3	-	RX	TX	XCK
RX_2_TX_0_XCK_1	TX	XCK	RX	-
RX_2_TX_2_XCK_3	-	-	TX / RX	XCK
RX_3_TX_0_XCK_1	TX	XCK	-	RX
RX_3_TX_2_XCK_3	-	-	TX	RX / XCK

15.8 Extra Information for SERCOM USART Driver

15.8.1 Acronyms

Below is a table listing the acronyms used in this module, along with their intended meanings.

Acronym	Description
SERCOM	Serial Communication Interface
USART	Universal Synchronous and Asynchronous Serial Receiver and Transmitter
LSB	Least Significant Bit
MSB	Most Significant Bit
DMA	Direct Memory Access

15.8.2 Dependencies

This driver has the following dependencies:

- System Pin Multiplexer Driver
- System clock configuration

15.8.3 Errata

There are no errata related to this driver.

15.8.4 Module History

An overview of the module history is presented in the table below, with details on the enhancements and fixes made to the module since its first release. The current version of this corresponds to the newest version in the table.

Changelog
Add support for SAMD21 and added new feature as below:

Changelog
• Oversample • Buffer overflow notification • Irda • Lin slave • Start frame detection • Hardware flow control • Collision detection • DMA support
• Added new `transmitter_enable` and `receiver_enable` boolean values to `struct` usart_config. • Altered `usart_write_*` and usart_read_* functions to abort with an error code if the relevant transceiver is not enabled. • Fixed `usart_write_buffer_wait()` and `usart_read_buffer_wait()` not aborting correctly when a timeout condition occurs.
Initial Release

15.9 Examples for SERCOM USART Driver

This is a list of the available Quick Start guides (QSGs) and example applications for SAM D20/D21 Serial USART Driver (SERCOM USART). QSGs are simple examples with step-by-step instructions to configure and use this driver in a selection of use cases. Note that QSGs can be compiled as a standalone application or be added to the user application.

- Quick Start Guide for SERCOM USART - Basic
- Quick Start Guide for SERCOM USART - Callback
- Quick Start Guide for Using DMA with SERCOM USART

15.9.1 Quick Start Guide for SERCOM USART - Basic

This quick start will echo back characters typed into the terminal. In this use case the USART will be configured with the following settings:

- Asynchronous mode
- 9600 Baudrate
- 8-bits, No Parity and 1 Stop Bit
- TX and RX enabled and connected to the Xplained Pro Embedded Debugger virtual COM port

15.9.1.1 Setup

Prerequisites

There are no special setup requirements for this use-case.

Code

Add to the main application source file, outside of any functions:

```
struct usart_module usart_instance;
```

Copy-paste the following setup code to your user application:

```
void configure_usart(void)
{
    struct usart_config config_usart;
    usart_get_config_defaults(&config_usart);

    config_usart.baudrate    = 9600;
    config_usart.mux_setting = EDBG_CDC_SERCOM_MUX_SETTING;
    config_usart.pinmux_pad0 = EDBG_CDC_SERCOM_PINMUX_PAD0;
    config_usart.pinmux_pad1 = EDBG_CDC_SERCOM_PINMUX_PAD1;
    config_usart.pinmux_pad2 = EDBG_CDC_SERCOM_PINMUX_PAD2;
    config_usart.pinmux_pad3 = EDBG_CDC_SERCOM_PINMUX_PAD3;

    while (usart_init(&usart_instance,
            EDBG_CDC_MODULE, &config_usart) != STATUS_OK) {
    }

    usart_enable(&usart_instance);
}
```

Add to user application initialization (typically the start of `main()`):

```
configure_usart();
```

Workflow

1. Create a module software instance structure for the USART module to store the USART driver state while it is in use.

   ```
   struct usart_module usart_instance;
   ```

Note This should never go out of scope as long as the module is in use. In most cases, this should be global.

2. Configure the USART module.

   a. Create a USART module configuration struct, which can be filled out to adjust the configuration of a physical USART peripheral.

      ```
      struct usart_config config_usart;
      ```

   b. Initialize the USART configuration struct with the module's default values.

      ```
      usart_get_config_defaults(&config_usart);
      ```

Note This should always be performed before using the configuration struct to ensure that all values are initialized to known default settings.

   c. Alter the USART settings to configure the physical pinout, baud rate and other relevant parameters.

```
config_usart.baudrate    = 9600;
config_usart.mux_setting = EDBG_CDC_SERCOM_MUX_SETTING;
config_usart.pinmux_pad0 = EDBG_CDC_SERCOM_PINMUX_PAD0;
config_usart.pinmux_pad1 = EDBG_CDC_SERCOM_PINMUX_PAD1;
config_usart.pinmux_pad2 = EDBG_CDC_SERCOM_PINMUX_PAD2;
config_usart.pinmux_pad3 = EDBG_CDC_SERCOM_PINMUX_PAD3;
```

d. Configure the USART module with the desired settings, retrying while the driver is busy until the configuration is stressfully set.

```
while (usart_init(&usart_instance,
        EDBG_CDC_MODULE, &config_usart) != STATUS_OK) {
}
```

e. Enable the USART module.

```
usart_enable(&usart_instance);
```

15.9.1.2 Use Case

Code

Copy-paste the following code to your user application:

```
uint8_t string[] = "Hello World!\r\n";
usart_write_buffer_wait(&usart_instance, string, sizeof(string));

uint16_t temp;

while (true) {
    if (usart_read_wait(&usart_instance, &temp) == STATUS_OK) {
        while (usart_write_wait(&usart_instance, temp) != STATUS_OK) {
        }
    }
}
```

Workflow

1. Send a string to the USART to show the demo is running, blocking until all characters have been sent.

```
uint8_t string[] = "Hello World!\r\n";
usart_write_buffer_wait(&usart_instance, string, sizeof(string));
```

2. Enter an infinite loop to continuously echo received values on the USART.

```
while (true) {
    if (usart_read_wait(&usart_instance, &temp) == STATUS_OK) {
        while (usart_write_wait(&usart_instance, temp) != STATUS_OK) {
        }
    }
}
```

3. Perform a blocking read of the USART, storing the received character into the previously declared temporary variable.

```
if (usart_read_wait(&usart_instance, &temp) == STATUS_OK) {
```

4. Echo the received variable back to the USART via a blocking write.

```
while (usart_write_wait(&usart_instance, temp) != STATUS_OK) {
}
```

15.9.2 Quick Start Guide for SERCOM USART - Callback

This quick start will echo back characters typed into the terminal, using asynchronous TX and RX callbacks from the USART peripheral. In this use case the USART will be configured with the following settings:

- Asynchronous mode
- 9600 Baudrate
- 8-bits, No Parity and 1 Stop Bit
- TX and RX enabled and connected to the Xplained Pro Embedded Debugger virtual COM port

15.9.2.1 Setup

Prerequisites

There are no special setup requirements for this use-case.

Code

Add to the main application source file, outside of any functions:

```
struct usart_module usart_instance;
```

```
#define MAX_RX_BUFFER_LENGTH   5

volatile uint8_t rx_buffer[MAX_RX_BUFFER_LENGTH];
```

Copy-paste the following callback function code to your user application:

```
void usart_read_callback(const struct usart_module *const usart_module)
{
    usart_write_buffer_job(&usart_instance,
            (uint8_t *)rx_buffer, MAX_RX_BUFFER_LENGTH);
}

void usart_write_callback(const struct usart_module *const usart_module)
{
    port_pin_toggle_output_level(LED_0_PIN);
}
```

Copy-paste the following setup code to your user application:

```
void configure_usart(void)
{
    struct usart_config config_usart;
    usart_get_config_defaults(&config_usart);

    config_usart.baudrate    = 9600;
```

```
    config_usart.mux_setting = EDBG_CDC_SERCOM_MUX_SETTING;
    config_usart.pinmux_pad0 = EDBG_CDC_SERCOM_PINMUX_PAD0;
    config_usart.pinmux_pad1 = EDBG_CDC_SERCOM_PINMUX_PAD1;
    config_usart.pinmux_pad2 = EDBG_CDC_SERCOM_PINMUX_PAD2;
    config_usart.pinmux_pad3 = EDBG_CDC_SERCOM_PINMUX_PAD3;

    while (usart_init(&usart_instance,
            EDBG_CDC_MODULE, &config_usart) != STATUS_OK) {
    }

    usart_enable(&usart_instance);
}

void configure_usart_callbacks(void)
{
    usart_register_callback(&usart_instance,
            usart_write_callback, USART_CALLBACK_BUFFER_TRANSMITTED);
    usart_register_callback(&usart_instance,
            usart_read_callback, USART_CALLBACK_BUFFER_RECEIVED);

    usart_enable_callback(&usart_instance, USART_CALLBACK_BUFFER_TRANSMITTED);
    usart_enable_callback(&usart_instance, USART_CALLBACK_BUFFER_RECEIVED);
}
```

Add to user application initialization (typically the start of `main()`):

```
configure_usart();
configure_usart_callbacks();
```

Workflow

1. Create a module software instance structure for the USART module to store the USART driver state while it is in use.

   ```
   struct usart_module usart_instance;
   ```

Note This should never go out of scope as long as the module is in use. In most cases, this should be global.

2. Configure the USART module.

   a. Create a USART module configuration struct, which can be filled out to adjust the configuration of a physical USART peripheral.

      ```
      struct usart_config config_usart;
      ```

   b. Initialize the USART configuration struct with the module's default values.

      ```
      usart_get_config_defaults(&config_usart);
      ```

Note This should always be performed before using the configuration struct to ensure that all values are initialized to known default settings.

   c. Alter the USART settings to configure the physical pinout, baud rate and other relevant parameters.

```
config_usart.baudrate    = 9600;
config_usart.mux_setting = EDBG_CDC_SERCOM_MUX_SETTING;
config_usart.pinmux_pad0 = EDBG_CDC_SERCOM_PINMUX_PAD0;
config_usart.pinmux_pad1 = EDBG_CDC_SERCOM_PINMUX_PAD1;
config_usart.pinmux_pad2 = EDBG_CDC_SERCOM_PINMUX_PAD2;
config_usart.pinmux_pad3 = EDBG_CDC_SERCOM_PINMUX_PAD3;
```

d. Configure the USART module with the desired settings, retrying while the driver is busy until the configuration is stressfully set.

```
while (usart_init(&usart_instance,
        EDBG_CDC_MODULE, &config_usart) != STATUS_OK) {
}
```

e. Enable the USART module.

```
usart_enable(&usart_instance);
```

3. Configure the USART callbacks.

a. Register the TX and RX callback functions with the driver.

```
usart_register_callback(&usart_instance,
        usart_write_callback, USART_CALLBACK_BUFFER_TRANSMITTED);
usart_register_callback(&usart_instance,
        usart_read_callback, USART_CALLBACK_BUFFER_RECEIVED);
```

b. Enable the TX and RX callbacks so that they will be called by the driver when appropriate.

```
usart_enable_callback(&usart_instance, USART_CALLBACK_BUFFER_TRANSMITTED);
usart_enable_callback(&usart_instance, USART_CALLBACK_BUFFER_RECEIVED);
```

15.9.2.2 Use Case

Code

Copy-paste the following code to your user application:

```
system_interrupt_enable_global();

uint8_t string[] = "Hello World!\r\n";
usart_write_buffer_job(&usart_instance, string, sizeof(string));

while (true) {
    usart_read_buffer_job(&usart_instance,
            (uint8_t *)rx_buffer, MAX_RX_BUFFER_LENGTH);
}
```

Workflow

1. Enable global interrupts, so that the callbacks can be fired.

```
system_interrupt_enable_global();
```

2. Send a string to the USART to show the demo is running, blocking until all characters have been sent.

```
uint8_t string[] = "Hello World!\r\n";
usart_write_buffer_job(&usart_instance, string, sizeof(string));
```

3. Enter an infinite loop to continuously echo received values on the USART.

```
while (true) {
```

4. Perform an asynchronous read of the USART, which will fire the registered callback when characters are received.

```
usart_read_buffer_job(&usart_instance,
        (uint8_t *)rx_buffer, MAX_RX_BUFFER_LENGTH);
```

15.9.3 Quick Start Guide for Using DMA with SERCOM USART

The supported device list:

- SAMD21

This quick start will receiving 8 bytes of data from PC terminal and transmit back the string to the terminal through DMA. In this use case the USART will be configured with the following settings:

- Asynchronous mode
- 9600 Baudrate
- 8-bits, No Parity and 1 Stop Bit
- TX and RX enabled and connected to the Xplained Pro Embedded Debugger virtual COM port

15.9.3.1 Setup

Prerequisites

There are no special setup requirements for this use-case.

Code

Add to the main application source file, outside of any functions:

```
struct usart_module usart_instance;
```

```
struct dma_resource usart_dma_resource_rx;
struct dma_resource usart_dma_resource_tx;
```

```
#define BUFFER_LEN    8
static uint16_t string[BUFFER_LEN];
```

```
COMPILER_ALIGNED(16)
DmacDescriptor example_descriptor_rx;
DmacDescriptor example_descriptor_tx;
```

Copy-paste the following setup code to your user application:

```
static void transfer_done_rx( const struct dma_resource* const resource )
{
    dma_start_transfer_job(&usart_dma_resource_tx);
}

static void transfer_done_tx( const struct dma_resource* const resource )
{
    dma_start_transfer_job(&usart_dma_resource_rx);
}

static void configure_dma_resource_rx(struct dma_resource *resource)
{
    struct dma_resource_config config;

    dma_get_config_defaults(&config);

    config.peripheral_trigger = SERCOM3_DMAC_ID_RX;
    config.trigger_action = DMA_TRIGGER_ACTON_BEAT;

    dma_allocate(resource, &config);
}

static void setup_transfer_descriptor_rx(DmacDescriptor *descriptor)
{
    struct dma_descriptor_config descriptor_config;

    dma_descriptor_get_config_defaults(&descriptor_config);

    descriptor_config.beat_size = DMA_BEAT_SIZE_HWORD;
    descriptor_config.src_increment_enable = false;
    descriptor_config.block_transfer_count = BUFFER_LEN;
    descriptor_config.destination_address =
            (uint32_t)string + sizeof(string);
    descriptor_config.source_address =
            (uint32_t)(&usart_instance.hw->USART.DATA.reg);

    dma_descriptor_create(descriptor, &descriptor_config);
}

static void configure_dma_resource_tx(struct dma_resource *resource)
{
    struct dma_resource_config config;

    dma_get_config_defaults(&config);

    config.peripheral_trigger = SERCOM3_DMAC_ID_TX;
    config.trigger_action = DMA_TRIGGER_ACTON_BEAT;

    dma_allocate(resource, &config);
}

static void setup_transfer_descriptor_tx(DmacDescriptor *descriptor)
{
    struct dma_descriptor_config descriptor_config;

    dma_descriptor_get_config_defaults(&descriptor_config);

    descriptor_config.beat_size = DMA_BEAT_SIZE_HWORD;
    descriptor_config.dst_increment_enable = false;
```

```
    descriptor_config.block_transfer_count = BUFFER_LEN;
    descriptor_config.source_address = (uint32_t)string + sizeof(string);
    descriptor_config.destination_address =
        (uint32_t)(&usart_instance.hw->USART.DATA.reg);

    dma_descriptor_create(descriptor, &descriptor_config);
}

static void configure_usart(void)
{
    struct usart_config config_usart;
    usart_get_config_defaults(&config_usart);

    config_usart.baudrate    = 9600;
    config_usart.mux_setting = EDBG_CDC_SERCOM_MUX_SETTING;
    config_usart.pinmux_pad0 = EDBG_CDC_SERCOM_PINMUX_PAD0;
    config_usart.pinmux_pad1 = EDBG_CDC_SERCOM_PINMUX_PAD1;
    config_usart.pinmux_pad2 = EDBG_CDC_SERCOM_PINMUX_PAD2;
    config_usart.pinmux_pad3 = EDBG_CDC_SERCOM_PINMUX_PAD3;

    while (usart_init(&usart_instance,
            EDBG_CDC_MODULE, &config_usart) != STATUS_OK) {
    }

    usart_enable(&usart_instance);
}
```

Add to user application initialization (typically the start of `main()`):

```
configure_usart();

configure_dma_resource_rx(&usart_dma_resource_rx);
configure_dma_resource_tx(&usart_dma_resource_tx);

setup_transfer_descriptor_rx(&example_descriptor_rx);
setup_transfer_descriptor_tx(&example_descriptor_tx);

dma_add_descriptor(&usart_dma_resource_rx, &example_descriptor_rx);
dma_add_descriptor(&usart_dma_resource_tx, &example_descriptor_tx);

dma_register_callback(&usart_dma_resource_rx, transfer_done_rx,
        DMA_CALLBACK_TRANSFER_DONE);
dma_register_callback(&usart_dma_resource_tx, transfer_done_tx,
        DMA_CALLBACK_TRANSFER_DONE);

dma_enable_callback(&usart_dma_resource_rx,
        DMA_CALLBACK_TRANSFER_DONE);
dma_enable_callback(&usart_dma_resource_tx,
        DMA_CALLBACK_TRANSFER_DONE);
```

Workflow

Create variables

1. Create a module software instance structure for the USART module to store the USART driver state while it is in use.

```
struct usart_module usart_instance;
```

Note This should never go out of scope as long as the module is in use. In most cases, this should be global.

2. Create module software instance structures for DMA resources to store the DMA resource state while it is in use.

```
struct dma_resource usart_dma_resource_rx;
struct dma_resource usart_dma_resource_tx;
```

Note This should never go out of scope as long as the module is in use. In most cases, this should be global.

3. Create a buffer to store the data to be transferred /received

```
#define BUFFER_LEN    8
static uint16_t string[BUFFER_LEN];
```

4. Create DMA transfer descriptors for RX/TX

```
COMPILER_ALIGNED(16)
DmacDescriptor example_descriptor_rx;
DmacDescriptor example_descriptor_tx;
```

Configure the USART

1. Create a USART module configuration struct, which can be filled out to adjust the configuration of a physical USART peripheral.

```
struct usart_config config_usart;
```

2. Initialize the USART configuration struct with the module's default values.

```
usart_get_config_defaults(&config_usart);
```

Note This should always be performed before using the configuration struct to ensure that all values are initialized to known default settings.

3. Alter the USART settings to configure the physical pinout, baud rate and other relevant parameters.

```
config_usart.baudrate    = 9600;
config_usart.mux_setting = EDBG_CDC_SERCOM_MUX_SETTING;
config_usart.pinmux_pad0 = EDBG_CDC_SERCOM_PINMUX_PAD0;
config_usart.pinmux_pad1 = EDBG_CDC_SERCOM_PINMUX_PAD1;
config_usart.pinmux_pad2 = EDBG_CDC_SERCOM_PINMUX_PAD2;
config_usart.pinmux_pad3 = EDBG_CDC_SERCOM_PINMUX_PAD3;
```

4. Configure the USART module with the desired settings, retrying while the driver is busy until the configuration is stressfully set.

```
while (usart_init(&usart_instance,
```

```
        EDBG_CDC_MODULE, &config_usart) != STATUS_OK) {
}
```

5. Enable the USART module.

```
usart_enable(&usart_instance);
```

Configure DMA

1. Create a callback function of receiver done

```
static void transfer_done_rx( const struct dma_resource* const resource )
{
    dma_start_transfer_job(&usart_dma_resource_tx);
}
```

2. Create a callback function of transmission done

```
static void transfer_done_tx( const struct dma_resource* const resource )
{
    dma_start_transfer_job(&usart_dma_resource_rx);
}
```

3. Create a DMA resource configuration structure, which can be filled out to adjust the configuration of a single DMA transfer.

```
struct dma_resource_config config;
```

4. Initialize the DMA resource configuration struct with the module's default values.

```
dma_get_config_defaults(&config);
```

Note

This should always be performed before using the configuration struct to ensure that all values are initialized to known default settings.

5. Set extra configurations for the DMA resource. It is using peripheral trigger, SERCOM Tx empty trigger and trigger causes a beat transfer in this example.

```
config.peripheral_trigger = SERCOM3_DMAC_ID_RX;
config.trigger_action = DMA_TRIGGER_ACTON_BEAT;
```

6. Allocate a DMA resource with the configurations.

```
dma_allocate(resource, &config);
```

7. Create a DMA transfer descriptor configuration structure, which can be filled out to adjust the configuration of a single DMA transfer.

```
struct dma_descriptor_config descriptor_config;
```

8. Initialize the DMA transfer descriptor configuration struct with the module's default values.

```
dma_descriptor_get_config_defaults(&descriptor_config);
```

Note This should always be performed before using the configuration struct to ensure that all values are initialized to known default settings.

9. Set the specific parameters for a DMA transfer with transfer size, source address, destination address.

```
descriptor_config.beat_size = DMA_BEAT_SIZE_HWORD;
descriptor_config.src_increment_enable = false;
descriptor_config.block_transfer_count = BUFFER_LEN;
descriptor_config.destination_address =
        (uint32_t)string + sizeof(string);
descriptor_config.source_address =
        (uint32_t)(&usart_instance.hw->USART.DATA.reg);
```

10. Create the DMA transfer descriptor.

```
dma_descriptor_create(descriptor, &descriptor_config);
```

11. Create a DMA resource configuration structure for tx, which can be filled out to adjust the configuration of a single DMA transfer.

```
struct dma_resource_config config;
```

12. Initialize the DMA resource configuration struct with the module's default values.

```
dma_get_config_defaults(&config);
```

Note This should always be performed before using the configuration struct to ensure that all values are initialized to known default settings.

13. Set extra configurations for the DMA resource. It is using peripheral trigger, SERCOM Rx Ready trigger and trigger causes a beat transfer in this example.

```
config.peripheral_trigger = SERCOM3_DMAC_ID_TX;
config.trigger_action = DMA_TRIGGER_ACTON_BEAT;
```

14. Allocate a DMA resource with the configurations.

```
dma_allocate(resource, &config);
```

15. Create a DMA transfer descriptor configuration structure, which can be filled out to adjust the configuration of a single DMA transfer.

```
struct dma_descriptor_config descriptor_config;
```

16. Initialize the DMA transfer descriptor configuration struct with the module's default values.

```
dma_descriptor_get_config_defaults(&descriptor_config);
```

Note This should always be performed before using the configuration struct to ensure that all values are initialized to known default settings.

17. Set the specific parameters for a DMA transfer with transfer size, source address, destination address.

```
descriptor_config.beat_size = DMA_BEAT_SIZE_HWORD;
descriptor_config.dst_increment_enable = false;
descriptor_config.block_transfer_count = BUFFER_LEN;
descriptor_config.source_address = (uint32_t)string + sizeof(string);
descriptor_config.destination_address =
    (uint32_t)(&usart_instance.hw->USART.DATA.reg);
```

18. Create the DMA transfer descriptor.

```
dma_descriptor_create(descriptor, &descriptor_config);
```

15.9.3.2 Use Case

Code

Copy-paste the following code to your user application:

```
dma_start_transfer_job(&usart_dma_resource_rx);

while (true) {
}
```

Workflow

1. Wait for receiving data.

```
dma_start_transfer_job(&usart_dma_resource_rx);
```

2. enter endless loop

```
while (true) {
}
```

16. SAM D20/D21 System Clock Management Driver (SYSTEM CLOCK)

This driver for SAM D20/D21 devices provides an interface for the configuration and management of the device's clocking related functions. This includes the various clock sources, bus clocks and generic clocks within the device, with functions to manage the enabling, disabling, source selection and prescaling of clocks to various internal peripherals.

The following peripherals are used by this module:

- GCLK (Generic Clock Management)
- PM (Power Management)
- SYSCTRL (Clock Source Control)

The outline of this documentation is as follows:

16.1 Prerequisites

There are no prerequisites for this module.

16.2 Module Overview

The SAM D20/D21 devices contain a sophisticated clocking system, which is designed to give the maximum flexibility to the user application. This system allows a system designer to tune the performance and power consumption of the device in a dynamic manner, to achieve the best trade-off between the two for a particular application.

This driver provides a set of functions for the configuration and management of the various clock related functionality within the device.

16.2.1 Driver Feature Macro Definition

Driver Feature Macro	Supported devices
FEATURE_SYSTEM_CLOCK_DPLL	SAMD21

Note The specific features are only available in the driver when the selected device supports those features.

16.2.2 Clock Sources

The SAM D20/D21 devices have a number of master clock source modules, each of which being capable of producing a stabilized output frequency which can then be fed into the various peripherals and modules within the device.

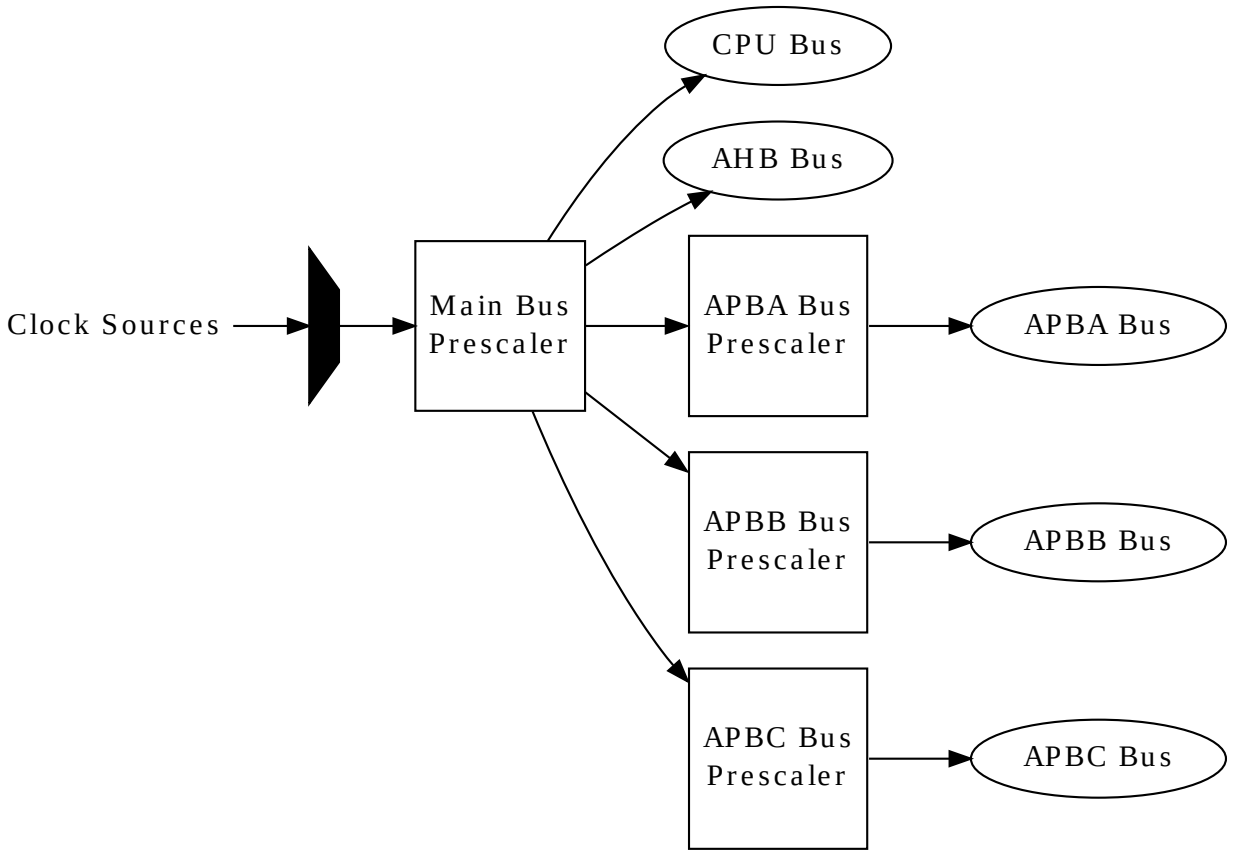
Possible clock source modules include internal R/C oscillators, internal DFLL modules, as well as external crystal oscillators and/or clock inputs.

16.2.3 CPU / Bus Clocks

The CPU and AHB/APBx buses are clocked by the same physical clock source (referred in this module as the Main Clock), however the APBx buses may have additional prescaler division ratios set to give each peripheral bus a different clock speed.

The general main clock tree for the CPU and associated buses is shown in Figure 16-1: CPU / Bus Clocks on page 401.

Figure 16-1. CPU / Bus Clocks



16.2.4 Clock Masking

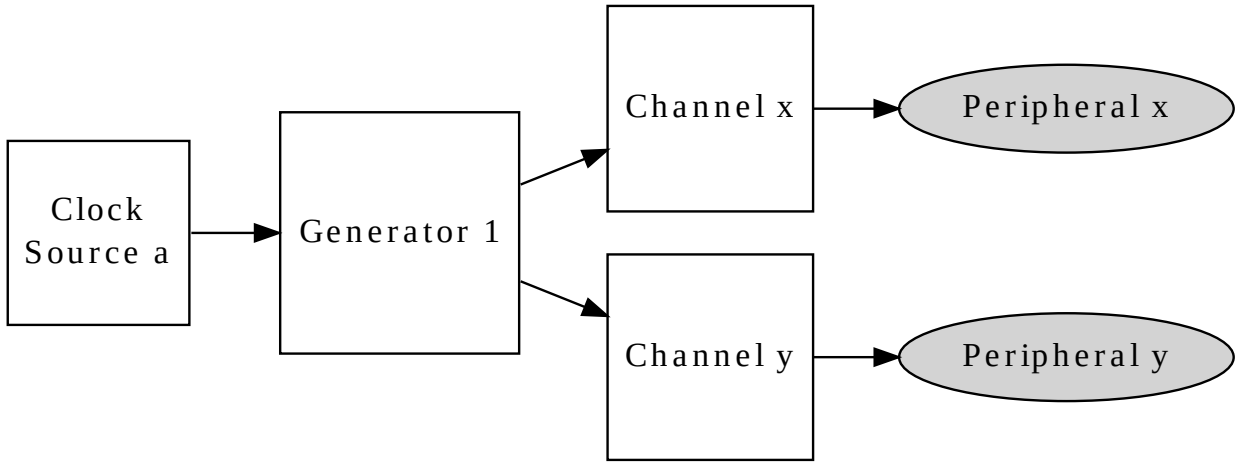
To save power, the input clock to one or more peripherals on the AHB and APBx busses can be masked away - when masked, no clock is passed into the module. Disabling of clocks of unused modules will prevent all access to the masked module, but will reduce the overall device power consumption.

16.2.5 Generic Clocks

Within the SAM D20/D21 devices are a number of Generic Clocks; these are used to provide clocks to the various peripheral clock domains in the device in a standardized manner. One or more master source clocks can be selected as the input clock to a Generic Clock Generator, which can prescale down the input frequency to a slower rate for use in a peripheral.

Additionally, a number of individually selectable Generic Clock Channels are provided, which multiplex and gate the various generator outputs for one or more peripherals within the device. This setup allows for a single common generator to feed one or more channels, which can then be enabled or disabled individually as required.

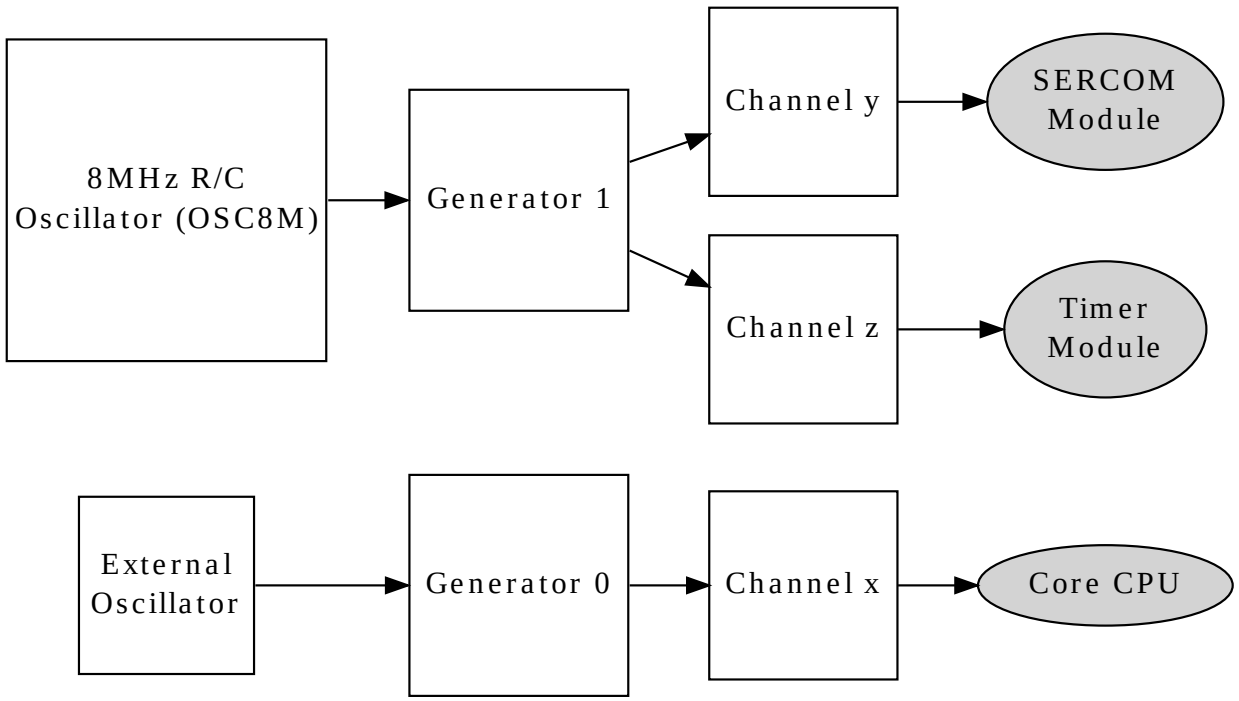
Figure 16-2. Generic Clocks



16.2.5.1 Clock Chain Example

An example setup of a complete clock chain within the device is shown in Figure 16-3: Clock Chain Example on page 402.

Figure 16-3. Clock Chain Example



16.2.5.2 Generic Clock Generators

Each Generic Clock generator within the device can source its input clock from one of the provided Source Clocks, and prescale the output for one or more Generic Clock Channels in a one-to-many relationship. The generators thus allow for several clocks to be generated of different frequencies, power usages and accuracies, which can be turned on and off individually to disable the clocks to multiple peripherals as a group.

16.2.5.3 Generic Clock Channels

To connect a Generic Clock Generator to a peripheral within the device, a Generic Clock Channel is used. Each peripheral or peripheral group has an associated Generic Clock Channel, which serves as the clock input for

the peripheral(s). To supply a clock to the peripheral module(s), the associated channel must be connected to a running Generic Clock Generator and the channel enabled.

16.3 Special Considerations

There are no special considerations for this module.

16.4 Extra Information

For extra information see Extra Information for SYSTEM CLOCK Driver. This includes:

- Acronyms
- Dependencies
- Errata
- Module History

16.5 Examples

For a list of examples related to this driver, see Examples for System Clock Driver.

16.6 API Overview

16.6.1 Structure Definitions

16.6.1.1 Struct system_clock_source_dfll_config

DFLL oscillator configuration structure.

Table 16-1. Members

Type	Name	Description
enum system_clock_dfll_chill_cycle	chill_cycle	Enable Chill Cycle
uint8_t	coarse_max_step	Coarse adjustment max step size (Closed loop mode)
uint8_t	coarse_value	Coarse calibration value (Open loop mode)
uint16_t	fine_max_step	Fine adjustment max step size (Closed loop mode)
uint16_t	fine_value	Fine calibration value (Open loop mode)
enum system_clock_dfll_loop_mode	loop_mode	Loop mode
uint16_t	multiply_factor	DFLL multiply factor (Closed loop mode
bool	on_demand	Run On Demand. If this is set the DFLL won't run until requested by a peripheral
enum system_clock_dfll_quick_lock	quick_lock	Enable Quick Lock
enum system_clock_dfll_stable_tracking	stable_tracking	DFLL tracking after fine lock
enum system_clock_dfll_wakeup_lock	wakeup_lock	DFLL lock state on wakeup

16.6.1.2 Struct system_clock_source_osc32k_config

Internal 32KHz (nominal) oscillator configuration structure.

Table 16-2. Members

Type	Name	Description
bool	enable_1khz_output	Enable 1kHz output
bool	enable_32khz_output	Enable 32kHz output
bool	on_demand	Run On Demand. If this is set the OSC32K won't run until requested by a peripheral
bool	run_in_standby	Keep the OSC32K enabled in standby sleep mode
enum system_osc32k_startup	startup_time	Startup time
bool	write_once	Lock configuration after it has been written, a device reset will release the lock

16.6.1.3 Struct system_clock_source_osc8m_config

Internal 8MHz (nominal) oscillator configuration structure.

Table 16-3. Members

Type	Name	Description
bool	on_demand	Run On Demand. If this is set the OSC8M won't run until requested by a peripheral
enum system_osc8m_div	prescaler	
bool	run_in_standby	Keep the OSC8M enabled in standby sleep mode

16.6.1.4 Struct system_clock_source_xosc32k_config

External 32KHz oscillator clock configuration structure.

Table 16-4. Members

Type	Name	Description
bool	auto_gain_control	Enable automatic amplitude control
bool	enable_1khz_output	Enable 1kHz output
bool	enable_32khz_output	Enable 32kHz output
enum system_clock_external	external_clock	External clock type
uint32_t	frequency	External clock/crystal frequency
bool	on_demand	Run On Demand. If this is set the XOSC32K won't run until requested by a peripheral
bool	run_in_standby	Keep the XOSC32K enabled in standby sleep mode

Type	Name	Description
enum system_xosc32k_startup	startup_time	Crystal oscillator start-up time
bool	write_once	Lock configuration after it has been written, a device reset will release the lock

16.6.1.5 Struct system_clock_source_xosc_config

External oscillator clock configuration structure.

Table 16-5. Members

Type	Name	Description
bool	auto_gain_control	Enable automatic amplitude gain control
enum system_clock_external	external_clock	External clock type
uint32_t	frequency	External clock/crystal frequency
bool	on_demand	Run On Demand. If this is set the XOSC won't run until requested by a peripheral
bool	run_in_standby	Keep the XOSC enabled in standby sleep mode
enum system_xosc_startup	startup_time	Crystal oscillator start-up time

16.6.1.6 Struct system_gclk_chan_config

Configuration structure for a Generic Clock channel. This structure should be initialized by the system_gclk_chan_get_config_defaults() function before being modified by the user application.

Table 16-6. Members

Type	Name	Description
enum gclk_generator	source_generator	Generic Clock Generator source channel.

16.6.1.7 Struct system_gclk_gen_config

Configuration structure for a Generic Clock Generator channel. This structure should be initialized by the system_gclk_gen_get_config_defaults() function before being modified by the user application.

Table 16-7. Members

Type	Name	Description
uint32_t	division_factor	Integer division factor of the clock output compared to the input.
bool	high_when_disabled	If true, the generator output level is high when disabled.
bool	output_enable	If true, enables GCLK generator clock output to a GPIO pin.
bool	run_in_standby	If true, the clock is kept enabled during device standby mode.

Type	Name	Description
uint8_t	source_clock	Source clock input channel index.

16.6.2 Function Definitions

16.6.2.1 External Oscillator management

Function system_clock_source_xosc_get_config_defaults()

Retrieve the default configuration for XOSC.

```
void system_clock_source_xosc_get_config_defaults(
  struct system_clock_source_xosc_config *const config)
```

Fills a configuration structure with the default configuration for an external oscillator module:

- External Crystal
- Start-up time of 16384 external clock cycles
- Automatic crystal gain control mode enabled
- Frequency of 12MHz
- Don't run in STANDBY sleep mode
- Run only when requested by peripheral (on demand)

Table 16-8. Parameters

Data direction	Parameter name	Description
[out]	config	Configuration structure to fill with default values

Function system_clock_source_xosc_set_config()

Configure the external oscillator clock source.

```
void system_clock_source_xosc_set_config(
  struct system_clock_source_xosc_config *const config)
```

Configures the external oscillator clock source with the given configuration settings.

Table 16-9. Parameters

Data direction	Parameter name	Description
[in]	config	External oscillator configuration structure containing the new config

16.6.2.2 External 32KHz Oscillator management

Function system_clock_source_xosc32k_get_config_defaults()

Retrieve the default configuration for XOSC32K.

```
void system_clock_source_xosc32k_get_config_defaults(
  struct system_clock_source_xosc32k_config *const config)
```

Fills a configuration structure with the default configuration for an external 32KHz oscillator module:

- External Crystal
- Start-up time of 16384 external clock cycles
- Automatic crystal gain control mode disabled
- Frequency of 32.768KHz
- 1KHz clock output disabled
- 32KHz clock output enabled
- Don't run in STANDBY sleep mode
- Run only when requested by peripheral (on demand)
- Don't lock registers after configuration has been written

Table 16-10. Parameters

Data direction	Parameter name	Description
[out]	config	Configuration structure to fill with default values

Function system_clock_source_xosc32k_set_config()

Configure the XOSC32K external 32KHz oscillator clock source.

```
void system_clock_source_xosc32k_set_config(
  struct system_clock_source_xosc32k_config *const config)
```

Configures the external 32KHz oscillator clock source with the given configuration settings.

Table 16-11. Parameters

Data direction	Parameter name	Description
[in]	config	XOSC32K configuration structure containing the new config

16.6.2.3 Internal 32KHz Oscillator management

Function system_clock_source_osc32k_get_config_defaults()

Retrieve the default configuration for OSC32K.

```
void system_clock_source_osc32k_get_config_defaults(
  struct system_clock_source_osc32k_config *const config)
```

Fills a configuration structure with the default configuration for an internal 32KHz oscillator module:

- 1KHz clock output enabled
- 32KHz clock output enabled
- Don't run in STANDBY sleep mode
- Run only when requested by peripheral (on demand)
- Set startup time to 130 cycles
- Don't lock registers after configuration has been written

Table 16-12. Parameters

Data direction	Parameter name	Description
[out]	config	Configuration structure to fill with default values

Function system_clock_source_osc32k_set_config()

Configure the internal OSC32K oscillator clock source.

```
void system_clock_source_osc32k_set_config(
  struct system_clock_source_osc32k_config *const config)
```

Configures the 32KHz (nominal) internal RC oscillator with the given configuration settings.

Table 16-13. Parameters

Data direction	Parameter name	Description
[in]	config	OSC32K configuration structure containing the new config

16.6.2.4 Internal 8MHz Oscillator management

Function system_clock_source_osc8m_get_config_defaults()

Retrieve the default configuration for OSC8M.

```
void system_clock_source_osc8m_get_config_defaults(
  struct system_clock_source_osc8m_config *const config)
```

Fills a configuration structure with the default configuration for an internal 8MHz (nominal) oscillator module:

- Clock output frequency divided by a factor of 8
- Don't run in STANDBY sleep mode
- Run only when requested by peripheral (on demand)

Table 16-14. Parameters

Data direction	Parameter name	Description
[out]	config	Configuration structure to fill with default values

Function system_clock_source_osc8m_set_config()

Configure the internal OSC8M oscillator clock source.

```
void system_clock_source_osc8m_set_config(
  struct system_clock_source_osc8m_config *const config)
```

Configures the 8MHz (nominal) internal RC oscillator with the given configuration settings.

Table 16-15. Parameters

Data direction	Parameter name	Description
[in]	config	OSC8M configuration structure containing the new config

16.6.2.5 Internal DFLL management

Function system_clock_source_dfll_get_config_defaults()

Retrieve the default configuration for DFLL.

```
void system_clock_source_dfll_get_config_defaults(
  struct system_clock_source_dfll_config *const config)
```

Fills a configuration structure with the default configuration for a DFLL oscillator module:

- Open loop mode
- QuickLock mode enabled
- Chill cycle enabled
- Output frequency lock maintained during device wake-up
- Continuous tracking of the output frequency
- Default tracking values at the mid-points for both coarse and fine tracking parameters
- Don't run in STANDBY sleep mode
- Run only when requested by peripheral (on demand)

Table 16-16. Parameters

Data direction	Parameter name	Description
[out]	config	Configuration structure to fill with default values

Function system_clock_source_dfll_set_config()

Configure the DFLL clock source.

```
void system_clock_source_dfll_set_config(
  struct system_clock_source_dfll_config *const config)
```

Configures the Digital Frequency Locked Loop clock source with the given configuration settings.

Note The DFLL will be running when this function returns, as the DFLL module needs to be enabled in order to perform the module configuration.

Table 16-17. Parameters

Data direction	Parameter name	Description
[in]	config	DFLL configuration structure containing the new config

16.6.2.6 Clock source management

Function system_clock_source_write_calibration()

```
enum status_code system_clock_source_write_calibration(
  const enum system_clock_source system_clock_source,
  const uint16_t calibration_value,
  const uint8_t freq_range)
```

Function system_clock_source_enable()

```
enum status_code system_clock_source_enable(
  const enum system_clock_source system_clock_source)
```

Function system_clock_source_disable()

Disables a clock source.

```
enum status_code system_clock_source_disable(
  const enum system_clock_source clk_source)
```

Disables a clock source that was previously enabled.

Table 16-18. Parameters

Data direction	Parameter name	Description
[in]	clock_source	Clock source to disable

Table 16-19. Return Values

Return value	Description
STATUS_OK	Clock source was disabled successfully
STATUS_ERR_INVALID_ARG	An invalid or unavailable clock source was given

Function system_clock_source_is_ready()

Checks if a clock source is ready.

```
bool system_clock_source_is_ready(
```

```
  const enum system_clock_source clk_source)
```

Checks if a given clock source is ready to be used.

Table 16-20. Parameters

Data direction	Parameter name	Description
[in]	clock_source	Clock source to check if ready

Returns Ready state of the given clock source.

Table 16-21. Return Values

Return value	Description
true	Clock source is enabled and ready
false	Clock source is disabled or not yet ready

Function system_clock_source_get_hz()

Retrieve the frequency of a clock source.

```
uint32_t system_clock_source_get_hz(
  const enum system_clock_source clk_source)
```

Determines the current operating frequency of a given clock source.

Table 16-22. Parameters

Data direction	Parameter name	Description
[in]	clock_source	Clock source to get the frequency of

Returns Frequency of the given clock source, in Hz

16.6.2.7 Main clock management

Function system_main_clock_set_failure_detect()

Enable or disable the main clock failure detection.

```
void system_main_clock_set_failure_detect(
  const bool enable)
```

This mechanism allows switching automatically the main clock to the safe RCSYS clock, when the main clock source is considered off.

This may happen for instance when an external crystal is selected as the clock source of the main clock and the crystal dies. The mechanism is to detect, during a RCSYS period, at least one rising edge of the main clock. If no rising edge is seen the clock is considered failed. As soon as the detector is enabled, the clock failure detector CFD) will monitor the divided main clock. When a clock failure is detected, the main clock automatically switches to the RCSYS clock and the CFD interrupt is generated if enabled.

Note The failure detect must be disabled if the system clock is the same or slower than 32kHz as it will believe the system clock has failed with a too-slow clock.

Table 16-23. Parameters

Data direction	Parameter name	Description
[in]	enable	Boolean `true` to enable, `false` to disable detection

Function system_cpu_clock_set_divider()

Set main CPU clock divider.

```
void system_cpu_clock_set_divider(
  const enum system_main_clock_div divider)
```

Sets the clock divider used on the main clock to provide the CPU clock.

Table 16-24. Parameters

Data direction	Parameter name	Description
[in]	divider	CPU clock divider to set

Function system_cpu_clock_get_hz()

Retrieves the current frequency of the CPU core.

```
uint32_t system_cpu_clock_get_hz(void)
```

Retrieves the operating frequency of the CPU core, obtained from the main generic clock and the set CPU bus divider.

Returns Current CPU frequency in Hz.

Function system_apb_clock_set_divider()

Set APBx clock divider.

```
enum status_code system_apb_clock_set_divider(
  const enum system_clock_apb_bus bus,
  const enum system_main_clock_div divider)
```

Set the clock divider used on the main clock to provide the clock for the given APBx bus.

Table 16-25. Parameters

Data direction	Parameter name	Description
[in]	divider	APBx bus divider to set

Data direction	Parameter name	Description
[in]	bus	APBx bus to set divider for

Returns Status of the clock division change operation.

Table 16-26. Return Values

Return value	Description
STATUS_ERR_INVALID_ARG	Invalid bus ID was given
STATUS_OK	The APBx clock was set successfully

Function system_apb_clock_get_hz()

Retrieves the current frequency of a ABPx.

```
uint32_t system_apb_clock_get_hz(
  const enum system_clock_apb_bus bus)
```

Retrieves the operating frequency of an APBx bus, obtained from the main generic clock and the set APBx bus divider.

Returns Current APBx bus frequency in Hz.

16.6.2.8 Bus clock masking

Function system_ahb_clock_set_mask()

Set bits in the clock mask for the AHB bus.

```
void system_ahb_clock_set_mask(
  const uint32_t ahb_mask)
```

This function will set bits in the clock mask for the AHB bus. Any bits set to 1 will enable that clock, 0 bits in the mask will be ignored

Table 16-27. Parameters

Data direction	Parameter name	Description
[in]	ahb_mask	AHB clock mask to enable

Function system_ahb_clock_clear_mask()

Clear bits in the clock mask for the AHB bus.

```
void system_ahb_clock_clear_mask(
  const uint32_t ahb_mask)
```

This function will clear bits in the clock mask for the AHB bus. Any bits set to 1 will disable that clock, 0 bits in the mask will be ignored.

Table 16-28. Parameters

Data direction	Parameter name	Description
[in]	ahb_mask	AHB clock mask to disable

Function system_apb_clock_set_mask()

Set bits in the clock mask for an APBx bus.

```
enum status_code system_apb_clock_set_mask(
  const enum system_clock_apb_bus bus,
  const uint32_t mask)
```

This function will set bits in the clock mask for an APBx bus. Any bits set to 1 will enable the corresponding module clock, zero bits in the mask will be ignored.

Table 16-29. Parameters

Data direction	Parameter name	Description
[in]	mask	APBx clock mask, a SYSTEM_CLOCK_APB_APBx constant from the device header files
[in]	bus	Bus to set clock mask bits for, a mask of PM_APBxMASK_* constants from the device header files

Returns Status indicating the result of the clock mask change operation.

Table 16-30. Return Values

Return value	Description
STATUS_ERR_INVALID_ARG	Invalid bus given
STATUS_OK	The clock mask was set successfully

Function system_apb_clock_clear_mask()

Clear bits in the clock mask for an APBx bus.

```
enum status_code system_apb_clock_clear_mask(
  const enum system_clock_apb_bus bus,
  const uint32_t mask)
```

This function will clear bits in the clock mask for an APBx bus. Any bits set to 1 will disable the corresponding module clock, zero bits in the mask will be ignored.

Table 16-31. Parameters

Data direction	Parameter name	Description
[in]	mask	APBx clock mask, a SYSTEM_CLOCK_APB_APBx

Data direction	Parameter name	Description
		constant from the device header files
[in]	bus	Bus to clear clock mask bits for

Returns Status indicating the result of the clock mask change operation.

Table 16-32. Return Values

Return value	Description
STATUS_ERR_INVALID_ARG	Invalid bus ID was given.
STATUS_OK	The clock mask was changed successfully.

16.6.2.9 System Clock Initialization

Function system_clock_init()

Initialize clock system based on the configuration in conf_clocks.h.

```
void system_clock_init(void)
```

This function will apply the settings in conf_clocks.h when run from the user application. All clock sources and GCLK generators are running when this function returns.

16.6.2.10 System Flash Wait States

Function system_flash_set_waitstates()

Set flash controller wait states.

```
void system_flash_set_waitstates(
  uint8_t wait_states)
```

Will set the number of wait states that are used by the onboard flash memory. The number of wait states depend on both device supply voltage and CPU speed. The required number of wait states can be found in the electrical characteristics of the device.

Table 16-33. Parameters

Data direction	Parameter name	Description
[in]	wait_states	Number of wait states to use for internal flash

16.6.2.11 Generic Clock management

Function system_gclk_is_syncing()

Determines if the hardware module(s) are currently synchronizing to the bus.

```
bool system_gclk_is_syncing(void)
```

Checks to see if the underlying hardware peripheral module(s) are currently synchronizing across multiple clock domains to the hardware bus, This function can be used to delay further operations on a module until such time that it is ready, to prevent blocking delays for synchronization in the user application.

Returns Synchronization status of the underlying hardware module(s).

Table 16-34. Return Values

Return value	Description
true	if the module has completed synchronization
false	if the module synchronization is ongoing

Function system_gclk_init()

Initializes the GCLK driver.

```
void system_gclk_init(void)
```

Initializes the Generic Clock module, disabling and resetting all active Generic Clock Generators and Channels to their power-on default values.

16.6.2.12 Generic Clock management (Generators)

Function system_gclk_gen_get_config_defaults()

Initializes a Generic Clock Generator configuration structure to defaults.

```
void system_gclk_gen_get_config_defaults(
  struct system_gclk_gen_config *const config)
```

Initializes a given Generic Clock Generator configuration structure to a set of known default values. This function should be called on all new instances of these configuration structures before being modified by the user application.

The default configuration is as follows:

- Clock is generated undivided from the source frequency
- Clock generator output is low when the generator is disabled
- The input clock is sourced from input clock channel 0
- Clock will be disabled during sleep
- The clock output will not be routed to a physical GPIO pin

Table 16-35. Parameters

Data direction	Parameter name	Description
[out]	config	Configuration structure to initialize to default values

Function system_gclk_gen_set_config()

Writes a Generic Clock Generator configuration to the hardware module.

```
void system_gclk_gen_set_config(
  const uint8_t generator,
  struct system_gclk_gen_config *const config)
```

Writes out a given configuration of a Generic Clock Generator configuration to the hardware module.

Note

Changing the clock source on the fly (on a running generator) can take additional time if the clock source is configured to only run on-demand (ONDEMAND bit is set) and it is not currently running (no peripheral is requesting the clock source). In this case the GCLK will request the new clock while still keeping a request to the old clock source until the new clock source is ready.

This function will not start a generator that is not already running; to start the generator, call system_gclk_gen_enable() after configuring a generator.

Table 16-36. Parameters

Data direction	Parameter name	Description
[in]	generator	Generic Clock Generator index to configure
[in]	config	Configuration settings for the generator

Function system_gclk_gen_enable()

Enables a Generic Clock Generator that was previously configured.

```
void system_gclk_gen_enable(
  const uint8_t generator)
```

Starts the clock generation of a Generic Clock Generator that was previously configured via a call to system_gclk_gen_set_config().

Table 16-37. Parameters

Data direction	Parameter name	Description
[in]	generator	Generic Clock Generator index to enable

Function system_gclk_gen_disable()

Disables a Generic Clock Generator that was previously enabled.

```
void system_gclk_gen_disable(
  const uint8_t generator)
```

Stops the clock generation of a Generic Clock Generator that was previously started via a call to system_gclk_gen_enable().

Table 16-38. Parameters

Data direction	Parameter name	Description
[in]	generator	Generic Clock Generator index to disable

Function system_gclk_gen_is_enabled()

Determins if the specified Generic Clock Generator is enabled.

```
bool system_gclk_gen_is_enabled(
  const uint8_t generator)
```

Table 16-39. Parameters

Data direction	Parameter name	Description
[in]	generator	Generic Clock Generator index to check

Returns The enabled status.

Table 16-40. Return Values

Return value	Description
true	The Generic Clock Generator is enabled;
false	The Generic Clock Generator is disabled.

16.6.2.13 Generic Clock management (Channels)

Function system_gclk_chan_get_config_defaults()

Initializes a Generic Clock configuration structure to defaults.

```
void system_gclk_chan_get_config_defaults(
  struct system_gclk_chan_config *const config)
```

Initializes a given Generic Clock configuration structure to a set of known default values. This function should be called on all new instances of these configuration structures before being modified by the user application.

The default configuration is as follows:

- Clock is sourced from the Generic Clock Generator channel 0
- Clock configuration will not be write-locked when set

Table 16-41. Parameters

Data direction	Parameter name	Description
[out]	config	Configuration structure to initialize to default values

Function system_gclk_chan_set_config()

Writes a Generic Clock configuration to the hardware module.

```
void system_gclk_chan_set_config(
  const uint8_t channel,
  struct system_gclk_chan_config *const config)
```

Writes out a given configuration of a Generic Clock configuration to the hardware module. If the clock is currently running, it will be stopped.

Note Once called the clock will not be running; to start the clock, call system_gclk_chan_enable() after configuring a clock channel.

Table 16-42. Parameters

Data direction	Parameter name	Description
[in]	channel	Generic Clock channel to configure
[in]	config	Configuration settings for the clock

Function system_gclk_chan_enable()

Enables a Generic Clock that was previously configured.

```
void system_gclk_chan_enable(
  const uint8_t channel)
```

Starts the clock generation of a Generic Clock that was previously configured via a call to system_gclk_chan_set_config().

Table 16-43. Parameters

Data direction	Parameter name	Description
[in]	channel	Generic Clock channel to enable

Function system_gclk_chan_disable()

Disables a Generic Clock that was previously enabled.

```
void system_gclk_chan_disable(
  const uint8_t channel)
```

Stops the clock generation of a Generic Clock that was previously started via a call to system_gclk_chan_enable().

Table 16-44. Parameters

Data direction	Parameter name	Description
[in]	channel	Generic Clock channel to disable

Function system_gclk_chan_is_enabled()

Determins if the specified Generic Clock channel is enabled.

```
bool system_gclk_chan_is_enabled(
  const uint8_t channel)
```

Table 16-45. Parameters

Data direction	Parameter name	Description
[in]	channel	Generic Clock Channel index

Returns The enabled status.

Table 16-46. Return Values

Return value	Description
true	The Generic Clock channel is enabled;
false	The Generic Clock channel is disabled.

Function system_gclk_chan_lock()

Locks a Generic Clock channel from further configuration writes.

```
void system_gclk_chan_lock(
  const uint8_t channel)
```

Locks a generic clock channel from further configuration writes. It is only possible to unlock the channel configuration through a power on reset.

Table 16-47. Parameters

Data direction	Parameter name	Description
[in]	channel	Generic Clock channel to enable

Function system_gclk_chan_is_locked()

Determins if the specified Generic Clock channel is locked.

```
bool system_gclk_chan_is_locked(
  const uint8_t channel)
```

Table 16-48. Parameters

Data direction	Parameter name	Description
[in]	channel	Generic Clock Channel index

Returns The lock status.

Table 16-49. Return Values

Return value	Description
true	The Generic Clock channel is locked;
false	The Generic Clock channel is not locked.

16.6.2.14 Generic Clock frequency retrieval

Function system_gclk_gen_get_hz()

Retrieves the clock frequency of a Generic Clock generator.

```
uint32_t system_gclk_gen_get_hz(
```

```
  const uint8_t generator)
```

Determines the clock frequency (in Hz) of a specified Generic Clock generator, used as a source to a Generic Clock Channel module.

Table 16-50. Parameters

Data direction	Parameter name	Description
[in]	generator	Generic Clock Generator index

Returns The frequency of the generic clock generator, in Hz.

Function system_gclk_chan_get_hz()

Retrieves the clock frequency of a Generic Clock channel.

```
uint32_t system_gclk_chan_get_hz(
  const uint8_t channel)
```

Determines the clock frequency (in Hz) of a specified Generic Clock channel, used as a source to a device peripheral module.

Table 16-51. Parameters

Data direction	Parameter name	Description
[in]	channel	Generic Clock Channel index

Returns The frequency of the generic clock channel, in Hz.

16.6.3 Enumeration Definitions

16.6.3.1 Enum gclk_generator

List of Available GCLK generators. This enum is used in the peripheral device drivers to select the GCLK generator to be used for its operation.

The number of GCLK generators available is device dependent.

Table 16-52. Members

Enum value	Description
GCLK_GENERATOR_0	GCLK generator channel 0.
GCLK_GENERATOR_1	GCLK generator channel 1.
GCLK_GENERATOR_2	GCLK generator channel 2.
GCLK_GENERATOR_3	GCLK generator channel 3.
GCLK_GENERATOR_4	GCLK generator channel 4.
GCLK_GENERATOR_5	GCLK generator channel 5.
GCLK_GENERATOR_6	GCLK generator channel 6.
GCLK_GENERATOR_7	GCLK generator channel 7.

Enum value	Description
GCLK_GENERATOR_8	GCLK generator channel 8.
GCLK_GENERATOR_9	GCLK generator channel 9.
GCLK_GENERATOR_10	GCLK generator channel 10.
GCLK_GENERATOR_11	GCLK generator channel 11.
GCLK_GENERATOR_12	GCLK generator channel 12.
GCLK_GENERATOR_13	GCLK generator channel 13.
GCLK_GENERATOR_14	GCLK generator channel 14.
GCLK_GENERATOR_15	GCLK generator channel 15.
GCLK_GENERATOR_16	GCLK generator channel 16.

16.6.3.2 Enum system_clock_apb_bus

Available bus clock domains on the APB bus.

Table 16-53. Members

Enum value	Description
SYSTEM_CLOCK_APB_APBA	Peripheral bus A on the APB bus.
SYSTEM_CLOCK_APB_APBB	Peripheral bus B on the APB bus.
SYSTEM_CLOCK_APB_APBC	Peripheral bus C on the APB bus.

16.6.3.3 Enum system_clock_dfll_chill_cycle

DFLL chill-cycle behavior modes of the DFLL module. A chill cycle is a period of time when the DFLL output frequency is not measured by the unit, to allow the output to stabilize after a change in the input clock source.

Table 16-54. Members

Enum value	Description
SYSTEM_CLOCK_DFLL_CHILL_CYCLE_ENABLE	Enable a chill cycle, where the DFLL output frequency is not measured
SYSTEM_CLOCK_DFLL_CHILL_CYCLE_DISABLE	Disable a chill cycle, where the DFLL output frequency is not measured

16.6.3.4 Enum system_clock_dfll_loop_mode

Available operating modes of the DFLL clock source module,

Table 16-55. Members

Enum value	Description
SYSTEM_CLOCK_DFLL_LOOP_MODE_OPEN	The DFLL is operating in open loop mode with no feedback
SYSTEM_CLOCK_DFLL_LOOP_MODE_CLOSED	The DFLL is operating in closed loop mode with frequency feedback from a low frequency reference clock
SYSTEM_CLOCK_DFLL_LOOP_MODE_USB_RECOVERY	The DFLL is operating in USB recovery mode with frequency feedback from USB SOF

16.6.3.5 Enum system_clock_dfll_quick_lock

DFLL QuickLock settings for the DFLL module, to allow for a faster lock of the DFLL output frequency at the expense of accuracy.

Table 16-56. Members

Enum value	Description
SYSTEM_CLOCK_DFLL_QUICK_LOCK_ENABLE	Enable the QuickLock feature for looser lock requirements on the DFLL
SYSTEM_CLOCK_DFLL_QUICK_LOCK_DISABLE	Disable the QuickLock feature for strict lock requirements on the DFLL

16.6.3.6 Enum system_clock_dfll_stable_tracking

DFLL fine tracking behavior modes after a lock has been acquired.

Table 16-57. Members

Enum value	Description
SYSTEM_CLOCK_DFLL_STABLE_TRACKING_TRACK_AFTI	Keep tracking after the DFLL has gotten a fine lock
SYSTEM_CLOCK_DFLL_STABLE_TRACKING_FIX_AFTER_	Stop tracking after the DFLL has gotten a fine lock

16.6.3.7 Enum system_clock_dfll_wakeup_lock

DFLL lock behavior modes on device wake-up from sleep.

Table 16-58. Members

Enum value	Description
SYSTEM_CLOCK_DFLL_WAKEUP_LOCK_KEEP	Keep DFLL lock when the device wakes from sleep
SYSTEM_CLOCK_DFLL_WAKEUP_LOCK_LOSE	Lose DFLL lock when the devices wakes from sleep

16.6.3.8 Enum system_clock_external

Available external clock source types.

Table 16-59. Members

Enum value	Description
SYSTEM_CLOCK_EXTERNAL_CRYSTAL	The external clock source is a crystal oscillator
SYSTEM_CLOCK_EXTERNAL_CLOCK	The connected clock source is an external logic level clock signal

16.6.3.9 Enum system_clock_source

Clock sources available to the GCLK generators

Table 16-60. Members

Enum value	Description
SYSTEM_CLOCK_SOURCE_OSC8M	Internal 8MHz RC oscillator
SYSTEM_CLOCK_SOURCE_OSC32K	Internal 32kHz RC oscillator
SYSTEM_CLOCK_SOURCE_XOSC	External oscillator
SYSTEM_CLOCK_SOURCE_XOSC32K	External 32kHz oscillator
SYSTEM_CLOCK_SOURCE_DFLL	Digital Frequency Locked Loop (DFLL)
SYSTEM_CLOCK_SOURCE_ULP32K	Internal Ultra Low Power 32kHz oscillator

16.6.3.10 Enum system_main_clock_div

Available division ratios for the CPU and APB/AHB bus clocks.

Table 16-61. Members

Enum value	Description
SYSTEM_MAIN_CLOCK_DIV_1	Divide Main clock by 1
SYSTEM_MAIN_CLOCK_DIV_2	Divide Main clock by 2
SYSTEM_MAIN_CLOCK_DIV_4	Divide Main clock by 4
SYSTEM_MAIN_CLOCK_DIV_8	Divide Main clock by 8
SYSTEM_MAIN_CLOCK_DIV_16	Divide Main clock by 16
SYSTEM_MAIN_CLOCK_DIV_32	Divide Main clock by 32
SYSTEM_MAIN_CLOCK_DIV_64	Divide Main clock by 64
SYSTEM_MAIN_CLOCK_DIV_128	Divide Main clock by 128

16.6.3.11 Enum system_osc32k_startup

Available internal 32KHz oscillator start-up times, as a number of internal OSC32K clock cycles.

Table 16-62. Members

Enum value	Description
SYSTEM_OSC32K_STARTUP_3	Wait 3 clock cycles until the clock source is considered stable
SYSTEM_OSC32K_STARTUP_4	Wait 4 clock cycles until the clock source is considered stable
SYSTEM_OSC32K_STARTUP_6	Wait 6 clock cycles until the clock source is considered stable
SYSTEM_OSC32K_STARTUP_10	Wait 10 clock cycles until the clock source is considered stable
SYSTEM_OSC32K_STARTUP_18	Wait 18 clock cycles until the clock source is considered stable
SYSTEM_OSC32K_STARTUP_34	Wait 34 clock cycles until the clock source is considered stable
SYSTEM_OSC32K_STARTUP_66	Wait 66 clock cycles until the clock source is considered stable

Enum value	Description
SYSTEM_OSC32K_STARTUP_130	Wait 130 clock cycles until the clock source is considered stable

16.6.3.12 Enum system_osc8m_div

Available prescalers for the internal 8MHz (nominal) system clock.

Table 16-63. Members

Enum value	Description
SYSTEM_OSC8M_DIV_1	Do not divide the 8MHz RC oscillator output
SYSTEM_OSC8M_DIV_2	Divide the 8MHz RC oscillator output by 2
SYSTEM_OSC8M_DIV_4	Divide the 8MHz RC oscillator output by 4
SYSTEM_OSC8M_DIV_8	Divide the 8MHz RC oscillator output by 8

16.6.3.13 Enum system_osc8m_frequency_range

Internal 8Mhz RC oscillator freqency range setting

Table 16-64. Members

Enum value	Description
SYSTEM_OSC8M_FREQUENCY_RANGE_4_TO_6	Frequency range 4 Mhz to 6 Mhz
SYSTEM_OSC8M_FREQUENCY_RANGE_6_TO_8	Frequency range 6 Mhz to 8 Mhz
SYSTEM_OSC8M_FREQUENCY_RANGE_8_TO_11	Frequency range 8 Mhz to 11 Mhz
SYSTEM_OSC8M_FREQUENCY_RANGE_11_TO_15	Frequency range 11 Mhz to 15 Mhz

16.6.3.14 Enum system_xosc32k_startup

Available external 32KHz oscillator start-up times, as a number of external clock cycles.

Table 16-65. Members

Enum value	Description
SYSTEM_XOSC32K_STARTUP_0	Wait 0 clock cycles until the clock source is considered stable
SYSTEM_XOSC32K_STARTUP_32	Wait 32 clock cycles until the clock source is considered stable
SYSTEM_XOSC32K_STARTUP_2048	Wait 2048 clock cycles until the clock source is considered stable
SYSTEM_XOSC32K_STARTUP_4096	Wait 4096 clock cycles until the clock source is considered stable
SYSTEM_XOSC32K_STARTUP_16384	Wait 16384 clock cycles until the clock source is considered stable
SYSTEM_XOSC32K_STARTUP_32768	Wait 32768 clock cycles until the clock source is considered stable
SYSTEM_XOSC32K_STARTUP_65536	Wait 65536 clock cycles until the clock source is considered stable

Enum value	Description
SYSTEM_XOSC32K_STARTUP_131072	Wait 131072 clock cycles until the clock source is considered stable

16.6.3.15 Enum system_xosc_startup

Available external oscillator start-up times, as a number of external clock cycles.

Table 16-66. Members

Enum value	Description
SYSTEM_XOSC_STARTUP_1	Wait 1 clock cycles until the clock source is considered stable
SYSTEM_XOSC_STARTUP_2	Wait 2 clock cycles until the clock source is considered stable
SYSTEM_XOSC_STARTUP_4	Wait 4 clock cycles until the clock source is considered stable
SYSTEM_XOSC_STARTUP_8	Wait 8 clock cycles until the clock source is considered stable
SYSTEM_XOSC_STARTUP_16	Wait 16 clock cycles until the clock source is considered stable
SYSTEM_XOSC_STARTUP_32	Wait 32 clock cycles until the clock source is considered stable
SYSTEM_XOSC_STARTUP_64	Wait 64 clock cycles until the clock source is considered stable
SYSTEM_XOSC_STARTUP_128	Wait 128 clock cycles until the clock source is considered stable
SYSTEM_XOSC_STARTUP_256	Wait 256 clock cycles until the clock source is considered stable
SYSTEM_XOSC_STARTUP_512	Wait 512 clock cycles until the clock source is considered stable
SYSTEM_XOSC_STARTUP_1024	Wait 1024 clock cycles until the clock source is considered stable
SYSTEM_XOSC_STARTUP_2048	Wait 2048 clock cycles until the clock source is considered stable
SYSTEM_XOSC_STARTUP_4096	Wait 4096 clock cycles until the clock source is considered stable
SYSTEM_XOSC_STARTUP_8192	Wait 8192 clock cycles until the clock source is considered stable
SYSTEM_XOSC_STARTUP_16384	Wait 16384 clock cycles until the clock source is considered stable
SYSTEM_XOSC_STARTUP_32768	Wait 32768 clock cycles until the clock source is considered stable

16.7 Extra Information for SYSTEM CLOCK Driver

16.7.1 Acronyms

Below is a table listing the acronyms used in this module, along with their intended meanings.

Acronym	Description
DFLL	Digital Frequency Locked Loop
MUX	Multiplexer
OSC32K	Internal 32KHz Oscillator
OSC8M	Internal 8MHz Oscillator
PLL	Phase Locked Loop
OSC	Oscillator
XOSC	External Oscillator
XOSC32K	External 32KHz Oscillator
AHB	Advanced High-performance Bus
APB	Advanced Peripheral Bus
DPLL	Digital Phase Locked Loop

16.7.2 Dependencies

This driver has the following dependencies:

- None

16.7.3 Errata

- This driver implements workaround for errata 10558

  "Several reset values of SYSCTRL.INTFLAG are wrong (BOD and DFLL)" When system_init is called it will reset these interrupts flags before they are used.

- This driver implements experimental workaround for errata 9905

  "The DFLL clock must be requested before being configured otherwise a write access to a DFLL register can freeze the device." This driver will enable and configure the DFLL before the ONDEMAND bit is set.

16.7.4 Module History

An overview of the module history is presented in the table below, with details on the enhancements and fixes made to the module since its first release. The current version of this corresponds to the newest version in the table.

Changelog
• Corrected OSC32K startup time definitions. • Support locking of OSC32K and XOSC32K config register (default: false). • Added DPLL support, functions added: `system_clock_source_dpll_get_config_defaults()` and `system_clock_source_dpll_set_config()`. • Moved gclk channel locking feature out of the config struct, functions added: `system_gclk_chan_lock()`, `system_gclk_chan_is_locked()`, `system_gclk_chan_is_enabled()` and `system_gclk_gen_is_enabled()`.
Fixed `system_gclk_chan_disable()` deadlocking if a channel is enabled and configured to a failed/not running clock generator.
• Changed default value for CONF_CLOCK_DFLL_ON_DEMAND from `true` to `false`. • Fixed system_flash_set_waitstates() failing with an assertion if an odd number of wait states provided.
• Updated dfll configuration function to implement workaround for errata 9905 in the DFLL module.

Changelog
• Updated system_clock_init() to reset interrupt flags before they are used, errata 10558. • Fixed system_clock_source_get_hz() to return correcy DFLL frequency number.
• Fixed system_clock_source_is_ready not returning the correct state for SYSTEM_CLOCK_SOURCE_OSC8M. • Renamed the various system_clock_source_*_get_default_config() functions to system_clock_source_*_get_config_defaults() to match the remainder of ASF. • Added OSC8M calibration constant loading from the device signature row when the oscillator is initialized. • Updated default configuration of the XOSC32 to disable Automatic Gain Control due to silicon errata.
Initial Release

16.8 Examples for System Clock Driver

This is a list of the available Quick Start guides (QSGs) and example applications for SAM D20/D21 System Clock Management Driver (SYSTEM CLOCK). QSGs are simple examples with step-by-step instructions to configure and use this driver in a selection of use cases. Note that QSGs can be compiled as a standalone application or be added to the user application.

- Quick Start Guide for SYSTEM CLOCK - Basic
- Quick Start Guide for SYSTEM CLOCK - GCLK Configuration

16.8.1 Quick Start Guide for SYSTEM CLOCK - Basic

In this case we apply the following configuration:

- RC8MHz (internal 8MHz RC oscillator)
  - Divide by 4, giving a frequency of 2MHz
- DFLL (Digital frequency locked loop)
  - Open loop mode
  - 48MHz frequency
- CPU clock
  - Use two wait states when reading from flash memory
  - Use the DFLL, configured to 48MHz

16.8.1.1 Setup

Prerequisites

There are no special setup requirements for this use-case.

Code

Copy-paste the following setup code to your application:

```
void configure_extosc32k(void)
{
    struct system_clock_source_xosc32k_config config_ext32k;
    system_clock_source_xosc32k_get_config_defaults(&config_ext32k);
```

```
    config_ext32k.startup_time = SYSTEM_XOSC32K_STARTUP_4096;

    system_clock_source_xosc32k_set_config(&config_ext32k);
}

void configure_dfll_open_loop(void)
{
    struct system_clock_source_dfll_config config_dfll;
    system_clock_source_dfll_get_config_defaults(&config_dfll);

    system_clock_source_dfll_set_config(&config_dfll);
}
```

Workflow

1. Create a EXTOSC32K module configuration struct, which can be filled out to adjust the configuration of the external 32KHz oscillator channel.

```
struct system_clock_source_xosc32k_config config_ext32k;
```

2. Initialize the oscillator configuration struct with the module's default values.

```
system_clock_source_xosc32k_get_config_defaults(&config_ext32k);
```

Note This should always be performed before using the configuration struct to ensure that all values are initialized to known default settings.

3. Alter the EXTOSC32K module configuration struct to require a start-up time of 4096 clock cycles.

```
config_ext32k.startup_time = SYSTEM_XOSC32K_STARTUP_4096;
```

4. Write the new configuration to the EXTOSC32K module.

```
system_clock_source_xosc32k_set_config(&config_ext32k);
```

5. Create a DFLL module configuration struct, which can be filled out to adjust the configuration of the external 32KHz oscillator channel.

```
struct system_clock_source_dfll_config config_dfll;
```

6. Initialize the DFLL oscillator configuration struct with the module's default values.

```
system_clock_source_dfll_get_config_defaults(&config_dfll);
```

Note This should always be performed before using the configuration struct to ensure that all values are initialized to known default settings.

7. Write the new configuration to the DFLL module.

```
system_clock_source_dfll_set_config(&config_dfll);
```

16.8.1.2 Use Case

Code

Copy-paste the following code to your user application:

```
/* Configure the external 32KHz oscillator */
configure_extosc32k();

/* Enable the external 32KHz oscillator */
enum status_code osc32k_status =
        system_clock_source_enable(SYSTEM_CLOCK_SOURCE_XOSC32K);

if (osc32k_status != STATUS_OK) {
    /* Error enabling the clock source */
}

/* Configure the DFLL in open loop mode using default values */
configure_dfll_open_loop();

/* Enable the DFLL oscillator */
enum status_code dfll_status =
        system_clock_source_enable(SYSTEM_CLOCK_SOURCE_DFLL);

if (dfll_status != STATUS_OK) {
    /* Error enabling the clock source */
}

/* Configure flash wait states before switching to high frequency clock */
system_flash_set_waitstates(2);

/* Change system clock to DFLL */
struct system_gclk_gen_config config_gclock_gen;
system_gclk_gen_get_config_defaults(&config_gclock_gen);
config_gclock_gen.source_clock    = SYSTEM_CLOCK_SOURCE_DFLL;
config_gclock_gen.division_factor = 1;
system_gclk_gen_set_config(GCLK_GENERATOR_0, &config_gclock_gen);
```

Workflow

1. Configure the external 32KHz oscillator source using the previously defined setup function.

   ```
   configure_extosc32k();
   ```

2. Enable the configured external 32KHz oscillator source.

   ```
   enum status_code osc32k_status =
           system_clock_source_enable(SYSTEM_CLOCK_SOURCE_XOSC32K);

   if (osc32k_status != STATUS_OK) {
       /* Error enabling the clock source */
   }
   ```

3. Configure the DFLL oscillator source using the previously defined setup function.

   ```
   configure_dfll_open_loop();
   ```

4. Enable the configured DFLL oscillator source.

```
enum status_code dfll_status =
        system_clock_source_enable(SYSTEM_CLOCK_SOURCE_DFLL);

if (dfll_status != STATUS_OK) {
    /* Error enabling the clock source */
}
```

5. Configure the flash wait states to have two wait states per read, as the high speed DFLL will be used as the system clock. If insufficient wait states are used, the device may crash randomly due to misread instructions.

```
system_flash_set_waitstates(2);
```

6. Switch the system clock source to the DFLL, by reconfiguring the main clock generator.

```
struct system_gclk_gen_config config_gclock_gen;
system_gclk_gen_get_config_defaults(&config_gclock_gen);
config_gclock_gen.source_clock    = SYSTEM_CLOCK_SOURCE_DFLL;
config_gclock_gen.division_factor = 1;
system_gclk_gen_set_config(GCLK_GENERATOR_0, &config_gclock_gen);
```

16.8.2 Quick Start Guide for SYSTEM CLOCK - GCLK Configuration

In this use case, the GCLK module is configured for:

- One generator attached to the internal 8MHz RC oscillator clock source
- Generator output equal to input frequency divided by a factor of 128
- One channel (connected to the TC0 module) enabled with the enabled generator selected

This use case configures a clock channel to output a clock for a peripheral within the device, by first setting up a clock generator from a master clock source, and then linking the generator to the desired channel. This clock can then be used to clock a module within the device.

16.8.2.1 Setup

Prerequisites

There are no special setup requirements for this use-case.

Code

Copy-paste the following setup code to your user application:

```
void configure_gclock_generator(void)
{
    struct system_gclk_gen_config gclock_gen_conf;
    system_gclk_gen_get_config_defaults(&gclock_gen_conf);

    gclock_gen_conf.source_clock    = SYSTEM_CLOCK_SOURCE_OSC8M;
    gclock_gen_conf.division_factor = 128;
    system_gclk_gen_set_config(GCLK_GENERATOR_1, &gclock_gen_conf);

    system_gclk_gen_enable(GCLK_GENERATOR_1);
}

void configure_gclock_channel(void)
{
```

```
    struct system_gclk_chan_config gclk_chan_conf;
    system_gclk_chan_get_config_defaults(&gclk_chan_conf);

    gclk_chan_conf.source_generator = GCLK_GENERATOR_1;
    system_gclk_chan_set_config(TC3_GCLK_ID, &gclk_chan_conf);

    system_gclk_chan_enable(TC3_GCLK_ID);
}
```

Add to user application initialization (typically the start of `main()`):

```
configure_gclock_generator();
configure_gclock_channel();
```

Workflow

1. Create a GCLK generator configuration struct, which can be filled out to adjust the configuration of a single clock generator.

   ```
   struct system_gclk_gen_config gclock_gen_conf;
   ```

2. Initialize the generator configuration struct with the module's default values.

   ```
   system_gclk_gen_get_config_defaults(&gclock_gen_conf);
   ```

Note This should always be performed before using the configuration struct to ensure that all values are initialized to known default settings.

3. Adjust the configuration struct to request that the master clock source channel 0 be used as the source of the generator, and set the generator output prescaler to divide the input clock by a factor of 128.

   ```
   gclock_gen_conf.source_clock    = SYSTEM_CLOCK_SOURCE_OSC8M;
   gclock_gen_conf.division_factor = 128;
   ```

4. Configure the generator using the configuration structure.

   ```
   system_gclk_gen_set_config(GCLK_GENERATOR_1, &gclock_gen_conf);
   ```

Note The existing configuration struct may be re-used, as long as any values that have been altered from the default settings are taken into account by the user application.

5. Enable the generator once it has been properly configured, to begin clock generation.

   ```
   system_gclk_gen_enable(GCLK_GENERATOR_1);
   ```

6. Create a GCLK channel configuration struct, which can be filled out to adjust the configuration of a single generic clock channel.

   ```
   struct system_gclk_chan_config gclk_chan_conf;
   ```

7. Initialize the channel configuration struct with the module's default values.

```
system_gclk_chan_get_config_defaults(&gclk_chan_conf);
```

Note This should always be performed before using the configuration struct to ensure that all values are initialized to known default settings.

8. Adjust the configuration struct to request that the previously configured and enabled clock generator be used as the clock source for the channel.

```
gclk_chan_conf.source_generator = GCLK_GENERATOR_1;
```

9. Configure the channel using the configuration structure.

```
system_gclk_chan_set_config(TC3_GCLK_ID, &gclk_chan_conf);
```

Note The existing configuration struct may be re-used, as long as any values that have been altered from the default settings are taken into account by the user application.

10. Enable the channel once it has been properly configured, to output the clock to the channel's peripheral module consumers.

```
system_gclk_chan_enable(TC3_GCLK_ID);
```

16.8.2.2 Use Case

Code

Copy-paste the following code to your user application:

```
while (true) {
    /* Nothing to do */
}
```

Workflow

1. As the clock is generated asynchronously to the system core, no special extra application code is required.

17. SAM D20/D21 System Driver (SYSTEM)

This driver for SAM D20/D21 devices provides an interface for the configuration and management of the device's system relation functionality, necessary for the basic device operation. This is not limited to a single peripheral, but extends across multiple hardware peripherals,

The following peripherals are used by this module:

- SYSCTRL (System Control)
- PM (Power Manager)

The outline of this documentation is as follows:

- Prerequisites
- Module Overview
- Special Considerations
- Extra Information
- Examples
- API Overview

17.1 Prerequisites

There are no prerequisites for this module.

17.2 Module Overview

The System driver provides a collection of interfaces between the user application logic, and the core device functionality (such as clocks, reset cause determination, etc.) that is required for all applications. It contains a number of sub-modules that control one specific aspect of the device:

- System Core (this module)
- System Clock Control (sub-module)
- System Interrupt Control (sub-module)
- System Pin Multiplexer Control (sub-module)

17.2.1 Voltage References

The various analog modules within the SAM D20/D21 devices (such as AC, ADC and DAC) require a voltage reference to be configured to act as a reference point for comparisons and conversions.

The SAM D20/D21 devices contain multiple references, including an internal temperature sensor, and a fixed band-gap voltage source. When enabled, the associated voltage reference can be selected within the desired peripheral where applicable.

17.2.2 System Reset Cause

In some application there may be a need to execute a different program flow based on how the device was reset. For example, if the cause of reset was the Watchdog timer (WDT), this might indicate an error in the application and a form of error handling or error logging might be needed.

For this reason, an API is provided to retrieve the cause of the last system reset, so that appropriate action can be taken.

17.2.3 Sleep Modes

The SAM D20/D21 devices have several sleep modes, where the sleep mode controls which clock systems on the device will remain enabled or disabled when the device enters a low power sleep mode. Table 17-1: SAM D20/D21 Device Sleep Modes on page 435 lists the clock settings of the different sleep modes.

Table 17-1. SAM D20/D21 Device Sleep Modes

Sleep mode	CPU clock	AHB clock	APB clocks	Clock sources	System clock	32KHz	Reg mode	RAM mode
IDLE 0	Stop	Run	Run	Run	Run	Run	Normal	Normal
IDLE 1	Stop	Stop	Run	Run	Run	Run	Normal	Normal
IDLE 2	Stop	Stop	Stop	Run	Run	Run	Normal	Normal
STANDBY	Stop	Stop	Stop	Stop	Stop	Stop	Low Power	Source/ Drain biasing

To enter device sleep, one of the available sleep modes must be set, and the function to enter sleep called. The device will automatically wake up in response to an interrupt being generated or other device event.

Some peripheral clocks will remain enabled during sleep, depending on their configuration; if desired, modules can remain clocked during sleep to allow them to continue to operate while other parts of the system are powered down to save power.

17.3 Special Considerations

Most of the functions in this driver have device specific restrictions and caveats; refer to your device datasheet.

17.4 Extra Information

For extra information see Extra Information for SYSTEM Driver. This includes:

- Acronyms
- Dependencies
- Errata
- Module History

17.5 Examples

For SYSTEM module related examples, please refer to the sub-modules listed in the system module overview.

17.6 API Overview

17.6.1 Function Definitions

17.6.1.1 System identification

Function system_get_device_id()

Retrieve the device identification signature.

```
uint32_t system_get_device_id(void)
```

Retrieves the signature of the current device.

Returns Device ID signature as a 32-bit integer.

17.6.1.2 Voltage references

Function system_voltage_reference_enable()

Enable the selected voltage reference.

```
void system_voltage_reference_enable(
  const enum system_voltage_reference vref)
```

Enables the selected voltage reference source, making the voltage reference available on a pin as well as an input source to the analog peripherals.

Table 17-2. Parameters

Data direction	Parameter name	Description
[in]	vref	Voltage reference to enable

Function system_voltage_reference_disable()

Disable the selected voltage reference.

```
void system_voltage_reference_disable(
  const enum system_voltage_reference vref)
```

Disables the selected voltage reference source.

Table 17-3. Parameters

Data direction	Parameter name	Description
[in]	vref	Voltage reference to disable

17.6.1.3 Device sleep

Function system_set_sleepmode()

Set the sleep mode of the device.

```
enum status_code system_set_sleepmode(
  const enum system_sleepmode sleep_mode)
```

Sets the sleep mode of the device; the configured sleep mode will be entered upon the next call of the system_sleep() function.

For an overview of which systems are disabled in sleep for the different sleep modes, see Sleep Modes.

Table 17-4. Parameters

Data direction	Parameter name	Description
[in]	sleep_mode	Sleep mode to configure for the next sleep operation

Table 17-5. Return Values

Return value	Description
STATUS_OK	Operation completed successfully
STATUS_ERR_INVALID_ARG	The requested sleep mode was invalid or not available

Function system_sleep()

Put the system to sleep waiting for interrupt.

```
void system_sleep(void)
```

Executes a device DSB (Data Synchronization Barrier) instruction to ensure all ongoing memory accesses have completed, then a WFI (Wait For Interrupt) instruction to place the device into the sleep mode specified by system_set_sleepmode until woken by an interrupt.

17.6.1.4 Reset control

Function system_is_debugger_present()

Check if bugger is present.

```
bool system_is_debugger_present(void)
```

Check if debugger is connected to the onboard debug system (DAP)

Returns A bool identifying if a debugger is present

Table 17-6. Return Values

Return value	Description
true	Debugger is connected to the system
false	Debugger is not connected to the system

Function system_reset()

Reset the MCU.

```
void system_reset(void)
```

Resets the MCU and all associated peripherals and registers, except RTC, all 32kHz sources, WDT (if ALWAYSON is set) and GCLK (if WRTLOCK is set).

Function system_get_reset_cause()

Return the reset cause.

```
enum system_reset_cause system_get_reset_cause(void)
```

Retrieves the cause of the last system reset.

Returns An enum value indicating the cause of the last system reset.

17.6.1.5 System initialization

Function system_init()

Initialize system.

```
void system_init(void)
```

This function will call the various initialization functions within the system namespace. If a given optional system module is not available, the associated call will effectively be a NOP (No Operation).

Currently the following initialization functions are supported:

- System clock initialization (via the SYSTEM CLOCK sub-module)
- Board hardware initialization (via the Board module)
- Event system driver initialization (via the EVSYS module)
- External Interrupt driver initialization (via the EXTINT module)

17.6.2 Enumeration Definitions

17.6.2.1 Enum system_reset_cause

List of possible reset causes of the system.

Table 17-7. Members

Enum value	Description
SYSTEM_RESET_CAUSE_SOFTWARE	The system was last reset by a software reset.
SYSTEM_RESET_CAUSE_WDT	The system was last reset by the watchdog timer.
SYSTEM_RESET_CAUSE_EXTERNAL_RESET	The system was last reset because the external reset line was pulled low.
SYSTEM_RESET_CAUSE_BOD33	The system was last reset by the BOD33.
SYSTEM_RESET_CAUSE_BOD12	The system was last reset by the BOD12.
SYSTEM_RESET_CAUSE_POR	The system was last reset by the POR (Power on reset).

17.6.2.2 Enum system_sleepmode

List of available sleep modes in the device. A table of clocks available in different sleep modes can be found in Sleep Modes.

Table 17-8. Members

Enum value	Description
SYSTEM_SLEEPMODE_IDLE_0	IDLE 0 sleep mode.

Enum value	Description
SYSTEM_SLEEPMODE_IDLE_1	IDLE 1 sleep mode.
SYSTEM_SLEEPMODE_IDLE_2	IDLE 2 sleep mode.
SYSTEM_SLEEPMODE_STANDBY	Standby sleep mode.

17.6.2.3 Enum system_voltage_reference

List of available voltage references (VREF) that may be used within the device.

Table 17-9. Members

Enum value	Description
SYSTEM_VOLTAGE_REFERENCE_TEMPSENSE	Temperature sensor voltage reference.
SYSTEM_VOLTAGE_REFERENCE_BANDGAP	Bandgap voltage reference.

17.7 Extra Information for SYSTEM Driver

17.7.1 Acronyms

Below is a table listing the acronyms used in this module, along with their intended meanings.

Acronym	Definition
PM	Power Manager
SYSCTRL	System control interface

17.7.2 Dependencies

This driver has the following dependencies:

- None

17.7.3 Errata

There are no errata related to this driver.

17.7.4 Module History

An overview of the module history is presented in the table below, with details on the enhancements and fixes made to the module since its first release. The current version of this corresponds to the newest version in the table.

Changelog
Added support for SAMD21
Added new `system_reset()` to reset the complete MCU with some exceptions
Added new `system_get_device_id()` function to retrieved the device ID.
Initial Release

18. SAM D20/D21 System Interrupt Driver (SYSTEM INTERRUPT)

This driver for SAM D20/D21 devices provides an interface for the configuration and management of internal software and hardware interrupts/exceptions.

The following peripherals are used by this module:

- NVIC (Nested Vector Interrupt Controller)

The outline of this documentation is as follows:

- Prerequisites
- Module Overview
- Special Considerations
- Extra Information
- Examples
- API Overview

18.1 Prerequisites

There are no prerequisites for this module.

18.2 Module Overview

The ARM® Cortex® M0+ core contains an interrupt an exception vector table, which can be used to configure the device's interrupt handlers; individual interrupts and exceptions can be enabled and disabled, as well as configured with a variable priority.

This driver provides a set of wrappers around the core interrupt functions, to expose a simple API for the management of global and individual interrupts within the device.

18.2.1 Critical Sections

In some applications it is important to ensure that no interrupts may be executed by the system whilst a critical portion of code is being run; for example, a buffer may be copied from one context to another - during which interrupts must be disabled to avoid corruption of the source buffer contents until the copy has completed. This driver provides a basic API to enter and exit nested critical sections, so that global interrupts can be kept disabled for as long as necessary to complete a critical application code section.

18.2.2 Software Interrupts

For some applications, it may be desirable to raise a module or core interrupt via software. For this reason, a set of APIs to set an interrupt or exception as pending are provided to the user application.

18.3 Special Considerations

Interrupts from peripherals in the SAM D20/D21 devices are on a per-module basis; an interrupt raised from any source within a module will cause a single, module-common handler to execute. It is the user application or driver's responsibility to de-multiplex the module-common interrupt to determine the exact interrupt cause.

18.4 Extra Information

For extra information see Extra Information for SYSTEM INTERRUPT Driver. This includes:

- Acronyms
- Dependencies
- Errata

- Module History

18.5 Examples

For a list of examples related to this driver, see Examples for SYSTEM INTERRUPT Driver.

18.6 API Overview

18.6.1 Function Definitions

18.6.1.1 Critical Section Management

Function system_interrupt_enter_critical_section()

Enters a critical section.

```
void system_interrupt_enter_critical_section(void)
```

Disables global interrupts. To support nested critical sections, an internal count of the critical section nesting will be kept, so that global interrupts are only re-enabled upon leaving the outermost nested critical section.

Function system_interrupt_leave_critical_section()

Leaves a critical section.

```
void system_interrupt_leave_critical_section(void)
```

Enables global interrupts. To support nested critical sections, an internal count of the critical section nesting will be kept, so that global interrupts are only re-enabled upon leaving the outermost nested critical section.

18.6.1.2 Interrupt Enabling/Disabling

Function system_interrupt_is_global_enabled()

Check if global interrupts are enabled.

```
bool system_interrupt_is_global_enabled(void)
```

Checks if global interrupts are currently enabled.

Returns A boolean that identifies if the global interrupts are enabled or not.

Table 18-1. Return Values

Return value	Description
true	Global interrupts are currently enabled
false	Global interrupts are currently disabled

Function system_interrupt_enable_global()

Enables global interrupts.

```
void system_interrupt_enable_global(void)
```

Enables global interrupts in the device to fire any enabled interrupt handlers.

Function system_interrupt_disable_global()

Disables global interrupts.

```
void system_interrupt_disable_global(void)
```

Disabled global interrupts in the device, preventing any enabled interrupt handlers from executing.

Function system_interrupt_is_enabled()

Checks if an interrupt vector is enabled or not.

```
bool system_interrupt_is_enabled(
  const enum system_interrupt_vector vector)
```

Checks if a specific interrupt vector is currently enabled.

Table 18-2. Parameters

Data direction	Parameter name	Description
[in]	vector	Interrupt vector number to check

Returns A variable identifying if the requested interrupt vector is enabled

Table 18-3. Return Values

Return value	Description
true	Specified interrupt vector is currently enabled
false	Specified interrupt vector is currently disabled

Function system_interrupt_enable()

Enable interrupt vector.

```
void system_interrupt_enable(
  const enum system_interrupt_vector vector)
```

Enables execution of the software handler for the requested interrupt vector.

Table 18-4. Parameters

Data direction	Parameter name	Description
[in]	vector	Interrupt vector to enable

Function system_interrupt_disable()

Disable interrupt vector.

```
void system_interrupt_disable(
  const enum system_interrupt_vector vector)
```

Disables execution of the software handler for the requested interrupt vector.

Table 18-5. Parameters

Data direction	Parameter name	Description
[in]	vector	Interrupt vector to disable

18.6.1.3 Interrupt State Management

Function system_interrupt_get_active()

Get active interrupt (if any)

```
enum system_interrupt_vector system_interrupt_get_active(void)
```

Return the vector number for the current executing software handler, if any.

Returns Interrupt number that is currently executing.

Function system_interrupt_is_pending()

Check if a interrupt line is pending.

```
bool system_interrupt_is_pending(
  const enum system_interrupt_vector vector)
```

Checks if the requested interrupt vector is pending.

Table 18-6. Parameters

Data direction	Parameter name	Description
[in]	vector	Interrupt vector number to check

Returns A boolean identifying if the requested interrupt vector is pending.

Table 18-7. Return Values

Return value	Description
true	Specified interrupt vector is pending
false	Specified interrupt vector is not pending

Function system_interrupt_set_pending()

Set a interrupt vector as pending.

```
enum status_code system_interrupt_set_pending(
  const enum system_interrupt_vector vector)
```

Set the requested interrupt vector as pending (i.e issues a software interrupt request for the specified vector). The software handler will be handled (if enabled) in a priority order based on vector number and configured priority settings.

Table 18-8. Parameters

Data direction	Parameter name	Description
[in]	vector	Interrupt vector number which is set as pending

Returns Status code identifying if the vector was successfully set as pending.

Table 18-9. Return Values

Return value	Description
STATUS_OK	If no error was detected
STATUS_INVALID_ARG	If an unsupported interrupt vector number was given

Function system_interrupt_clear_pending()

Clear pending interrupt vector.

```
enum status_code system_interrupt_clear_pending(
  const enum system_interrupt_vector vector)
```

Clear a pending interrupt vector, so the software handler is not executed.

Table 18-10. Parameters

Data direction	Parameter name	Description
[in]	vector	Interrupt vector number to clear

Returns A status code identifying if the interrupt pending state was successfully cleared.

Table 18-11. Return Values

Return value	Description
STATUS_OK	If no error was detected
STATUS_INVALID_ARG	If an unsupported interrupt vector number was given

18.6.1.4 Interrupt Priority Management

Function system_interrupt_set_priority()

Set interrupt vector priority level.

```
enum status_code system_interrupt_set_priority(
  const enum system_interrupt_vector vector,
```

```
  const enum system_interrupt_priority_level priority_level)
```

Set the priority level of an external interrupt or exception.

Table 18-12. Parameters

Data direction	Parameter name	Description
[in]	vector	Interrupt vector to change
[in]	priority_level	New vector priority level to set

Returns Status code indicating if the priority level of the interrupt was successfully set.

Table 18-13. Return Values

Return value	Description
STATUS_OK	If no error was detected
STATUS_INVALID_ARG	If an unsupported interrupt vector number was given

Function system_interrupt_get_priority()

Get interrupt vector priority level.

```
enum system_interrupt_priority_level system_interrupt_get_priority(
  const enum system_interrupt_vector vector)
```

Retrieves the priority level of the requested external interrupt or exception.

Table 18-14. Parameters

Data direction	Parameter name	Description
[in]	vector	Interrupt vector of which the priority level will be read

Returns Currently configured interrupt priority level of the given interrupt vector.

18.6.2 Enumeration Definitions

18.6.2.1 Enum system_interrupt_priority_level

Table of all possible interrupt and exception vector priorities within the device.

Table 18-15. Members

Enum value	Description
SYSTEM_INTERRUPT_PRIORITY_LEVEL_0	Priority level 0, the highest possible interrupt priority.
SYSTEM_INTERRUPT_PRIORITY_LEVEL_1	Priority level 1.
SYSTEM_INTERRUPT_PRIORITY_LEVEL_2	Priority level 2.
SYSTEM_INTERRUPT_PRIORITY_LEVEL_3	Priority level 3, the lowest possible interrupt priority.

18.6.2.2 Enum system_interrupt_vector_samd21

Table of all possible interrupt and exception vector indexes within the SAMD21 device.

Note The actual enumeration name is "system_interrupt_vector".

Table 18-16. Members

Enum value	Description
SYSTEM_INTERRUPT_NON_MASKABLE	Interrupt vector index for a NMI interrupt.
SYSTEM_INTERRUPT_HARD_FAULT	Interrupt vector index for a Hard Fault memory access exception.
SYSTEM_INTERRUPT_SV_CALL	Interrupt vector index for a Supervisor Call exception.
SYSTEM_INTERRUPT_PENDING_SV	Interrupt vector index for a Pending Supervisor interrupt.
SYSTEM_INTERRUPT_SYSTICK	Interrupt vector index for a System Tick interrupt.
SYSTEM_INTERRUPT_MODULE_PM	Interrupt vector index for a Power Manager peripheral interrupt.
SYSTEM_INTERRUPT_MODULE_SYSCTRL	Interrupt vector index for a System Control peripheral interrupt.
SYSTEM_INTERRUPT_MODULE_WDT	Interrupt vector index for a Watch Dog peripheral interrupt.
SYSTEM_INTERRUPT_MODULE_RTC	Interrupt vector index for a Real Time Clock peripheral interrupt.
SYSTEM_INTERRUPT_MODULE_EIC	Interrupt vector index for an External Interrupt peripheral interrupt.
SYSTEM_INTERRUPT_MODULE_NVMCTRL	Interrupt vector index for a Non Volatile Memory Controller interrupt.
SYSTEM_INTERRUPT_MODULE_DMA	Interrupt vector index for a Direct Memory Access interrupt.
SYSTEM_INTERRUPT_MODULE_USB	Interrupt vector index for a Universal Serial Bus interrupt.
SYSTEM_INTERRUPT_MODULE_EVSYS	Interrupt vector index for an Event System interrupt.
SYSTEM_INTERRUPT_MODULE_SERCOMn	Interrupt vector index for a SERCOM peripheral interrupt. Each specific device may contain several SERCOM peripherals; each module instance will have its own entry in the table, with the instance number substituted for "n" in the entry name (e.g. `SYSTEM_INTERRUPT_MODULE_SERCOM0`).
SYSTEM_INTERRUPT_MODULE_TCCn	Interrupt vector index for a Timer/Counter Control peripheral interrupt. Each specific device may contain several TCC peripherals; each module instance will have its own entry in the table, with the instance

Enum value	Description
	number substituted for "n" in the entry name (e.g. SYSTEM_INTERRUPT_MODULE_TCC0).
SYSTEM_INTERRUPT_MODULE_TCn	Interrupt vector index for a Timer/Counter peripheral interrupt. Each specific device may contain several TC peripherals; each module instance will have its own entry in the table, with the instance number substituted for "n" in the entry name (e.g. SYSTEM_INTERRUPT_MODULE_TC3).
SYSTEM_INTERRUPT_MODULE_AC	Interrupt vector index for an Analog Comparator peripheral interrupt.
SYSTEM_INTERRUPT_MODULE_ADC	Interrupt vector index for an Analog-to-Digital peripheral interrupt.
SYSTEM_INTERRUPT_MODULE_DAC	Interrupt vector index for a Digital-to-Analog peripheral interrupt.
SYSTEM_INTERRUPT_MODULE_PTC	Interrupt vector index for a Peripheral Touch Controller peripheral interrupt.
SYSTEM_INTERRUPT_MODULE_I2S	Interrupt vector index for a Inter-IC Sound Interface peripheral interrupt.

18.7 Extra Information for SYSTEM INTERRUPT Driver

18.7.1 Acronyms

The table below presents the acronyms used in this module:

Acronym	Description
ISR	Interrupt Service Routine
NMI	Non-maskable interrupt
SERCOM	Serial Communication Interface

18.7.2 Dependencies

This driver has the following dependencies:

- None

18.7.3 Errata

There are no errata related to this driver.

18.7.4 Module History

An overview of the module history is presented in the table below, with details on the enhancements and fixes made to the module since its first release. The current version of this corresponds to the newest version in the table.

Changelog
Added support for SAMD21
Initial Release

18.8 Examples for SYSTEM INTERRUPT Driver

This is a list of the available Quick Start guides (QSGs) and example applications for SAM D20/D21 System Interrupt Driver (SYSTEM INTERRUPT). QSGs are simple examples with step-by-step instructions to configure and use this driver in a selection of use cases. Note that QSGs can be compiled as a standalone application or be added to the user application.

- Quick Start Guide for SYSTEM INTERRUPT - Critical Section Use Case
- Quick Start Guide for SYSTEM INTERRUPT - Enable Module Interrupt Use Case

18.8.1 Quick Start Guide for SYSTEM INTERRUPT - Critical Section Use Case

In this case we perform a critical piece of code, disabling all interrupts while a global shared flag is read. During the critical section, no interrupts may occur.

18.8.1.1 Setup

Prerequisites

There are no special setup requirements for this use-case.

18.8.1.2 Use Case

Code

Copy-paste the following code to your user application:

```
system_interrupt_enter_critical_section();

if (is_ready == true) {
    /* Do something in response to the global shared flag */
    is_ready = false;
}

system_interrupt_leave_critical_section();
```

Workflow

1. Enter a critical section to disable global interrupts.

   ```
   system_interrupt_enter_critical_section();
   ```

Note Critical sections *may* be nested if desired; if nested, global interrupts will only be re-enabled once the outer-most critical section has completed.

2. Check a global shared flag and perform a response. This code may be any critical code that requires exclusive access to all resources without the possibility of interruption.

   ```
   if (is_ready == true) {
       /* Do something in response to the global shared flag */
       is_ready = false;
   }
   ```

3. Exit the critical section to re-enable global interrupts.

   ```
   system_interrupt_leave_critical_section();
   ```

18.8.2 Quick Start Guide for SYSTEM INTERRUPT - Enable Module Interrupt Use Case

In this case we enable interrupt handling for a specific module, as well as enable interrupts globally for the device.

18.8.2.1 Setup

Prerequisites

There are no special setup requirements for this use-case.

18.8.2.2 Use Case

Code

Copy-paste the following code to your user application:

```
system_interrupt_enable(SYSTEM_INTERRUPT_MODULE_RTC);

system_interrupt_enable_global();
```

Workflow

1. Enable interrupt handling for the device's RTC peripheral.

   ```
   system_interrupt_enable(SYSTEM_INTERRUPT_MODULE_RTC);
   ```

2. Enable global interrupts, so that any enabled and active interrupt sources can trigger their respective handler functions.

   ```
   system_interrupt_enable_global();
   ```

19. SAM D20/D21 System Pin Multiplexer Driver (SYSTEM PINMUX)

This driver for SAM D20/D21 devices provides an interface for the configuration and management of the device's physical I/O Pins, to alter the direction and input/drive characteristics as well as to configure the pin peripheral multiplexer selection.

The following peripherals are used by this module:

- PORT (Port I/O Management)

Physically, the modules are interconnected within the device as shown in the following diagram:

The outline of this documentation is as follows:

- Prerequisites
- Module Overview
- Special Considerations
- Extra Information
- Examples
- API Overview

19.1 Prerequisites

There are no prerequisites for this module.

19.2 Module Overview

The SAM D20/D21 devices contain a number of General Purpose I/O pins, used to interface the user application logic and internal hardware peripherals to an external system. The Pin Multiplexer (PINMUX) driver provides a method of configuring the individual pin peripheral multiplexers to select alternate pin functions.

19.2.1 Physical and Logical GPIO Pins

SAM D20/D21 devices use two naming conventions for the I/O pins in the device; one physical, and one logical. Each physical pin on a device package is assigned both a physical port and pin identifier (e.g. "PORTA.0") as well as a monotonically incrementing logical GPIO number (e.g. "GPIO0"). While the former is used to map physical pins to their physical internal device module counterparts, for simplicity the design of this driver uses the logical GPIO numbers instead.

19.2.2 Peripheral Multiplexing

SAM D20/D21 devices contain a peripheral MUX, which is individually controllable for each I/O pin of the device. The peripheral MUX allows you to select the function of a physical package pin - whether it will be controlled as a user controllable GPIO pin, or whether it will be connected internally to one of several peripheral modules (such as an I^2C module). When a pin is configured in GPIO mode, other peripherals connected to the same pin will be disabled.

19.2.3 Special Pad Characteristics

There are several special modes that can be selected on one or more I/O pins of the device, which alter the input and output characteristics of the pad:

19.2.3.1 Drive Strength

The Drive Strength configures the strength of the output driver on the pad. Normally, there is a fixed current limit that each I/O pin can safely drive, however some I/O pads offer a higher drive mode which increases this limit for that I/O pin at the expense of an increased power consumption.

19.2.3.2 Slew Rate

The Slew Rate configures the slew rate of the output driver, limiting the rate at which the pad output voltage can change with time.

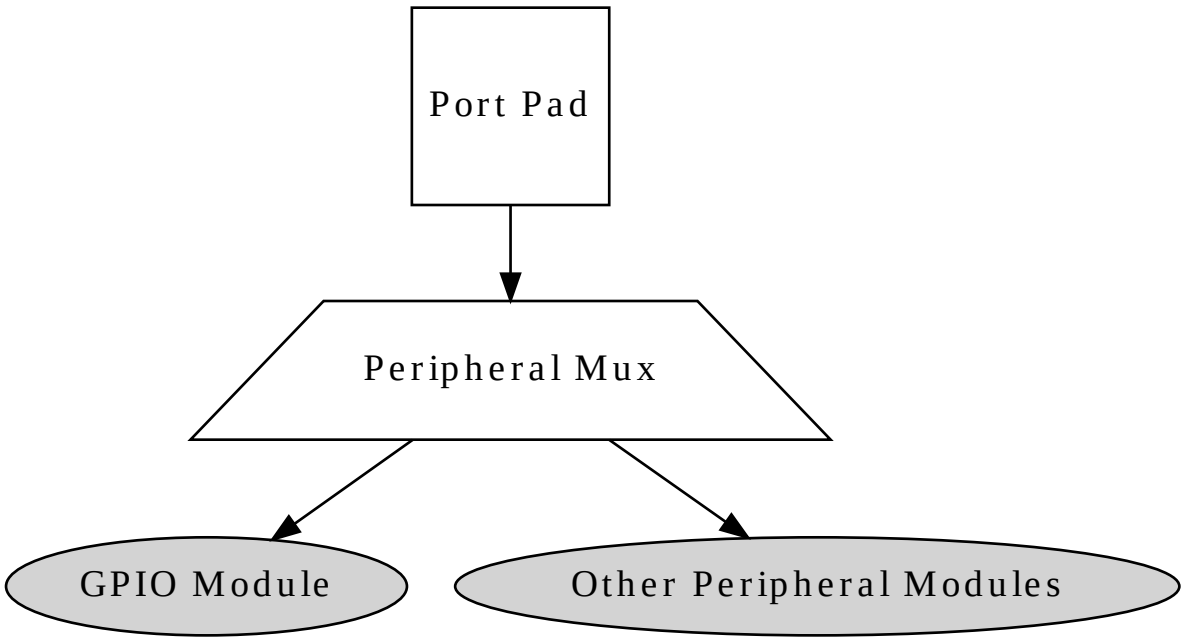
19.2.3.3 Input Sample Mode

The Input Sample Mode configures the input sampler buffer of the pad. By default, the input buffer is only sampled "on-demand", i.e. when the user application attempts to read from the input buffer. This mode is the most power efficient, but increases the latency of the input sample by two clock cycles of the port clock. To reduce latency, the input sampler can instead be configured to always sample the input buffer on each port clock cycle, at the expense of an increased power consumption.

19.2.4 Physical Connection

Figure 19-1: Physical Connection on page 451 shows how this module is interconnected within the device:

Figure 19-1. Physical Connection



19.3 Special Considerations

The SAM D20/D21 port pin input sampling mode is set in groups of four physical pins; setting the sampling mode of any pin in a sub-group of eight I/O pins will configure the sampling mode of the entire sub-group.

High Drive Strength output driver mode is not available on all device pins - refer to your device specific datasheet.

19.4 Extra Information

For extra information see Extra Information for SYSTEM PINMUX Driver. This includes:

- Acronyms
- Dependencies
- Errata
- Module History

19.5 Examples

For a list of examples related to this driver, see Examples for SYSTEM PINMUX Driver.

19.6 API Overview

19.6.1 Structure Definitions

19.6.1.1 Struct system_pinmux_config

Configuration structure for a port pin instance. This structure should be structure should be initialized by the system_pinmux_get_config_defaults() function before being modified by the user application.

Table 19-1. Members

Type	Name	Description
enum system_pinmux_pin_dir	direction	Port buffer input/output direction.
enum system_pinmux_pin_pull	input_pull	Logic level pull of the input buffer.
uint8_t	mux_position	MUX index of the peripheral that should control the pin, if peripheral control is desired. For GPIO use, this should be set to SYSTEM_PINMUX_GPIO.
bool	powersave	Enable lowest possible powerstate on the pin[1]

Notes: [1]All other configurations will be ignored, the pin will be disabled

19.6.2 Macro Definitions

19.6.2.1 Macro SYSTEM_PINMUX_GPIO

```
#define SYSTEM_PINMUX_GPIO (1 << 7)
```

Peripheral multiplexer index to select GPIO mode for a pin.

19.6.3 Function Definitions

19.6.3.1 Configuration and initialization

Function system_pinmux_get_config_defaults()

Initializes a Port pin configuration structure to defaults.

```
void system_pinmux_get_config_defaults(
  struct system_pinmux_config *const config)
```

Initializes a given Port pin configuration structure to a set of known default values. This function should be called on all new instances of these configuration structures before being modified by the user application.

The default configuration is as follows:

- Non peripheral (i.e. GPIO) controlled
- Input mode with internal pull-up enabled

Table 19-2. Parameters

Data direction	Parameter name	Description
[out]	config	Configuration structure to initialize to default values

Function system_pinmux_pin_set_config()

Writes a Port pin configuration to the hardware module.

```
void system_pinmux_pin_set_config(
  const uint8_t gpio_pin,
  const struct system_pinmux_config *const config)
```

Writes out a given configuration of a Port pin configuration to the hardware module.

Note If the pin direction is set as an output, the pull-up/pull-down input configuration setting is ignored.

Table 19-3. Parameters

Data direction	Parameter name	Description
[in]	gpio_pin	Index of the GPIO pin to configure.
[in]	config	Configuration settings for the pin.

Function system_pinmux_group_set_config()

Writes a Port pin group configuration to the hardware module.

```
void system_pinmux_group_set_config(
  PortGroup *const port,
  const uint32_t mask,
  const struct system_pinmux_config *const config)
```

Writes out a given configuration of a Port pin group configuration to the hardware module.

Note If the pin direction is set as an output, the pull-up/pull-down input configuration setting is ignored.

Table 19-4. Parameters

Data direction	Parameter name	Description
[in]	port	Base of the PORT module to configure.
[in]	mask	Mask of the port pin(s) to configure.
[in]	config	Configuration settings for the pin.

19.6.3.2 Special mode configuration (physical group orientated)

Function system_pinmux_get_group_from_gpio_pin()

Retrieves the PORT module group instance from a given GPIO pin number.

```
PortGroup * system_pinmux_get_group_from_gpio_pin(
  const uint8_t gpio_pin)
```

Retrieves the PORT module group instance associated with a given logical GPIO pin number.

Table 19-5. Parameters

Data direction	Parameter name	Description
[in]	gpio_pin	Index of the GPIO pin to convert.

Returns Base address of the associated PORT module.

Function system_pinmux_group_set_input_sample_mode()

Configures the input sampling mode for a group of pins.

```
void system_pinmux_group_set_input_sample_mode(
  PortGroup *const port,
  const uint32_t mask,
  const enum system_pinmux_pin_sample mode)
```

Configures the input sampling mode for a group of pins, to control when the physical I/O pin value is sampled and stored inside the microcontroller.

Table 19-6. Parameters

Data direction	Parameter name	Description
[in]	port	Base of the PORT module to configure.
[in]	mask	Mask of the port pin(s) to configure.
[in]	mode	New pin sampling mode to configure.

19.6.3.3 Special mode configuration (logical pin orientated)

Function system_pinmux_pin_get_mux_position()

Retrieves the currently selected MUX position of a logical pin.

```
uint8_t system_pinmux_pin_get_mux_position(
  const uint8_t gpio_pin)
```

Retrieves the selected MUX peripheral on a given logical GPIO pin.

Table 19-7. Parameters

Data direction	Parameter name	Description
[in]	gpio_pin	Index of the GPIO pin to configure.

Returns Currently selected peripheral index on the specified pin.

Function system_pinmux_pin_set_input_sample_mode()

Configures the input sampling mode for a GPIO pin.

```
void system_pinmux_pin_set_input_sample_mode(
  const uint8_t gpio_pin,
  const enum system_pinmux_pin_sample mode)
```

Configures the input sampling mode for a GPIO input, to control when the physical I/O pin value is sampled and stored inside the microcontroller.

Table 19-8. Parameters

Data direction	Parameter name	Description
[in]	gpio_pin	Index of the GPIO pin to configure.
[in]	mode	New pin sampling mode to configure.

19.6.4 Enumeration Definitions

19.6.4.1 Enum system_pinmux_pin_dir

Enum for the possible pin direction settings of the port pin configuration structure, to indicate the direction the pin should use.

Table 19-9. Members

Enum value	Description
SYSTEM_PINMUX_PIN_DIR_INPUT	The pin's input buffer should be enabled, so that the pin state can be read.
SYSTEM_PINMUX_PIN_DIR_OUTPUT	The pin's output buffer should be enabled, so that the pin state can be set (but not read back).
SYSTEM_PINMUX_PIN_DIR_OUTPUT_WITH_READBACK	The pin's output and input buffers should both be enabled, so that the pin state can be set and read back.

19.6.4.2 Enum system_pinmux_pin_pull

Enum for the possible pin pull settings of the port pin configuration structure, to indicate the type of logic level pull the pin should use.

Table 19-10. Members

Enum value	Description
SYSTEM_PINMUX_PIN_PULL_NONE	No logical pull should be applied to the pin.
SYSTEM_PINMUX_PIN_PULL_UP	Pin should be pulled up when idle.
SYSTEM_PINMUX_PIN_PULL_DOWN	Pin should be pulled down when idle.

19.6.4.3 Enum system_pinmux_pin_sample

Enum for the possible input sampling modes for the port pin configuration structure, to indicate the type of sampling a port pin should use.

Table 19-11. Members

Enum value	Description
SYSTEM_PINMUX_PIN_SAMPLE_CONTINUOUS	Pin input buffer should continuously sample the pin state.
SYSTEM_PINMUX_PIN_SAMPLE_ONDEMAND	Pin input buffer should be enabled when the IN register is read.

19.7 Extra Information for SYSTEM PINMUX Driver

19.7.1 Acronyms

The table below presents the acronyms used in this module:

Acronym	Description
GPIO	General Purpose Input/Output
MUX	Multiplexer

19.7.2 Dependencies

This driver has the following dependencies:

- None

19.7.3 Errata

There are no errata related to this driver.

19.7.4 Module History

An overview of the module history is presented in the table below, with details on the enhancements and fixes made to the module since its first release. The current version of this corresponds to the newest version in the table.

Changelog
Removed code of open drain, slew limit and drive strength features.
Fixed broken sampling mode function implementations, which wrote corrupt configuration values to the device registers.
Added missing NULL pointer asserts to the PORT driver functions.
Initial Release

19.8 Examples for SYSTEM PINMUX Driver

This is a list of the available Quick Start guides (QSGs) and example applications for SAM D20/D21 System Pin Multiplexer Driver (SYSTEM PINMUX). QSGs are simple examples with step-by-step instructions to configure and use this driver in a selection of use cases. Note that QSGs can be compiled as a standalone application or be added to the user application.

- Quick Start Guide for SYSTEM PINMUX - Basic

19.8.1 Quick Start Guide for SYSTEM PINMUX - Basic

In this use case, the PINMUX module is configured for:

- One pin in input mode, with pull-up enabled, connected to the GPIO module
- Sampling mode of the pin changed to sample on demand

This use case sets up the PINMUX to configure a physical I/O pin set as an input with pull-up. and changes the sampling mode of the pin to reduce power by only sampling the physical pin state when the user application attempts to read it.

19.8.1.1 Setup

Prerequisites

There are no special setup requirements for this use-case.

Code

Copy-paste the following setup code to your application:

```
struct system_pinmux_config config_pinmux;
system_pinmux_get_config_defaults(&config_pinmux);

config_pinmux.mux_position = SYSTEM_PINMUX_GPIO;
config_pinmux.direction    = SYSTEM_PINMUX_PIN_DIR_INPUT;
config_pinmux.input_pull   = SYSTEM_PINMUX_PIN_PULL_UP;

system_pinmux_pin_set_config(10, &config_pinmux);
```

Workflow

1. Create a PINMUX module pin configuration struct, which can be filled out to adjust the configuration of a single port pin.

   ```
   struct system_pinmux_config config_pinmux;
   ```

2. Initialize the pin configuration struct with the module's default values.

   ```
   system_pinmux_get_config_defaults(&config_pinmux);
   ```

Note This should always be performed before using the configuration struct to ensure that all values are initialized to known default settings.

3. Adjust the configuration struct to request an input pin with pullup connected to the GPIO peripheral.

   ```
   config_pinmux.mux_position = SYSTEM_PINMUX_GPIO;
   config_pinmux.direction    = SYSTEM_PINMUX_PIN_DIR_INPUT;
   config_pinmux.input_pull   = SYSTEM_PINMUX_PIN_PULL_UP;
   ```

4. Configure GPIO10 with the initialized pin configuration struct, to enable the input sampler on the pin.

   ```
   system_pinmux_pin_set_config(10, &config_pinmux);
   ```

19.8.1.2 Use Case

Code

Copy-paste the following code to your user application:

```
system_pinmux_pin_set_input_sample_mode(10,
        SYSTEM_PINMUX_PIN_SAMPLE_ONDEMAND);
```

```
while (true) {
    /* Infinite loop */
}
```

Workflow

1. Adjust the configuration of the pin to enable on-demand sampling mode.

```
system_pinmux_pin_set_input_sample_mode(10,
        SYSTEM_PINMUX_PIN_SAMPLE_ONDEMAND);
```

20. SAM D20/D21 Timer/Counter Driver (TC)

This driver for SAM D20/D21 devices provides an interface for the configuration and management of the timer modules within the device, for waveform generation and timing operations. The following driver API modes are covered by this manual:

- Polled APIs
- Callback APIs

The following peripherals are used by this module:

- TC (Timer/Counter)

The outline of this documentation is as follows:

- Prerequisites
- Module Overview
- Special Considerations
- Extra Information
- Examples
- API Overview

20.1 Prerequisites

There are no prerequisites for this module.

20.2 Module Overview

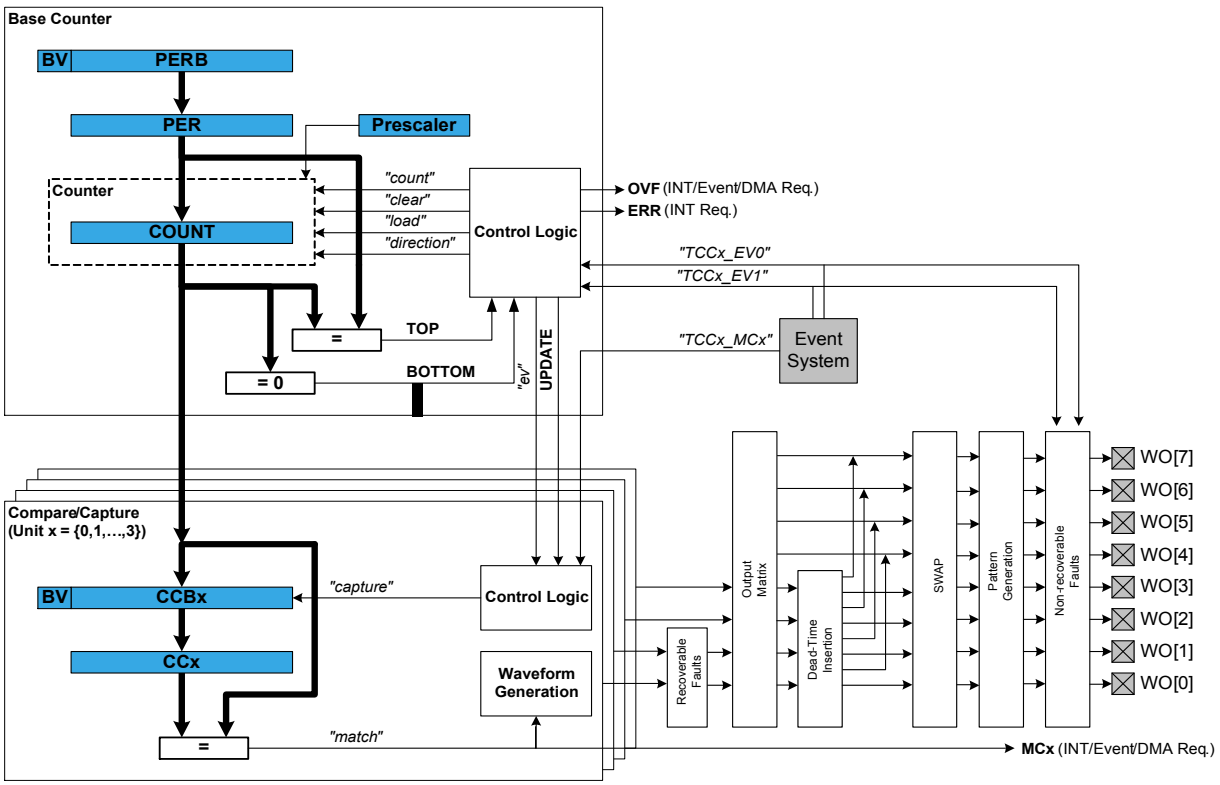
The Timer/Counter (TC) module provides a set of timing and counting related functionality, such as the generation of periodic waveforms, the capturing of a periodic waveform's frequency/duty cycle, and software timekeeping for periodic operations. TC modules can be configured to use an 8-, 16-, or 32-bit counter size.

This TC module for the SAM D20/D21 is capable of the following functions:

- Generation of PWM signals
- Generation of timestamps for events
- General time counting
- Waveform period capture
- Waveform frequency capture

Figure 20-1: Basic overview of the TC module on page 460 shows the overview of the TC module design.

Figure 20-1. Basic overview of the TC module



20.2.1 Functional Description

Independent of the configured counter size, each TC module can be set up in one of two different modes; capture and compare.

In capture mode, the counter value is stored when a configurable event occurs. This mode can be used to generate timestamps used in event capture, or it can be used for the measurement of a periodic input signal's frequency/duty cycle.

In compare mode, the counter value is compared against one or more of the configured channel compare values. When the counter value coincides with a compare value an action can be taken automatically by the module, such as generating an output event or toggling a pin when used for frequency or PWM signal generation.

Note The connection of events between modules requires the use of the SAM D20/D21 Event System Driver (EVENTS) to route output event of one module to the the input event of another. For more information on event routing, refer to the event driver documentation.

20.2.2 Timer/Counter Size

Each timer module can be configured in one of three different counter sizes; 8-, 16-, and 32-bits. The size of the counter determines the maximum value it can count to before an overflow occurs and the count is reset back to zero. Table 20-1: Timer counter sizes and their maximum count values on page 460 shows the maximum values for each of the possible counter sizes.

Table 20-1. Timer counter sizes and their maximum count values

Counter Size	Max (Hexadecimal)	Max (Decimal)
8-bit	0xFF	255
16-bit	0xFFFF	65,535
32-bit	0xFFFFFFFF	4,294,967,295

When using the counter in 16- or 32-bit count mode, Compare Capture register 0 (CC0) is used to store the period value when running in PWM generation match mode.

When using 32-bit counter size, two 16-bit counters are chained together in a cascade formation. Even numbered TC modules (e.g. TC0, TC2) can be configured as 32-bit counters. The odd numbered counters will act as slaves to the even numbered masters, and will not be reconfigurable until the master timer is disabled. The pairing of timer modules for 32-bit mode is shown in Table 20-2: TC master and slave module pairings on page 461.

Table 20-2. TC master and slave module pairings

Master TC Module	Slave TC Module
TC0	TC1
TC2	TC3
...	...
TCn-1	TCn

20.2.3 Clock Settings

20.2.3.1 Clock Selection

Each TC peripheral is clocked asynchronously to the system clock by a GCLK (Generic Clock) channel. The GCLK channel connects to any of the GCLK generators. The GCLK generators are configured to use one of the available clock sources on the system such as internal oscillator, external crystals etc. - see the Generic Clock driver for more information.

20.2.3.2 Prescaler

Each TC module in the SAM D20/D21 has its own individual clock prescaler, which can be used to divide the input clock frequency used in the counter. This prescaler only scales the clock used to provide clock pulses for the counter to count, and does not affect the digital register interface portion of the module, thus the timer registers will synchronized to the raw GCLK frequency input to the module.

As a result of this, when selecting a GCLK frequency and timer prescaler value the user application should consider both the timer resolution required and the synchronization frequency, to avoid lengthy synchronization times of the module if a very slow GCLK frequency is fed into the TC module. It is preferable to use a higher module GCLK frequency as the input to the timer and prescale this down as much as possible to obtain a suitable counter frequency in latency-sensitive applications.

20.2.3.3 Reloading

Timer modules also contain a configurable reload action, used when a re-trigger event occurs. Examples of a re-trigger event are the counter reaching the max value when counting up, or when an event from the event system tells the counter to re-trigger. The reload action determines if the prescaler should be reset, and when this should happen. The counter will always be reloaded with the value it is set to start counting from. The user can choose between three different reload actions, described in Table 20-3: TC module reload actions on page 461.

Table 20-3. TC module reload actions

Reload Action	Description
TC_RELOAD_ACTION_GCLK on page 478	Reload TC counter value on next GCLK cycle. Leave prescaler as-is.
TC_RELOAD_ACTION_PRESC on page 478	Reloads TC counter value on next prescaler clock. Leave prescaler as-is.
TC_RELOAD_ACTION_RESYNC on page 478	Reload TC counter value on next GCLK cycle. Clear prescaler to zero.

The reload action to use will depend on the specific application being implemented. One example is when an external trigger for a reload occurs; if the TC uses the prescaler, the counter in the prescaler should not have a value between zero and the division factor. The TC counter and the counter in the prescaler should both start at zero. When the counter is set to re-trigger when it reaches the max value on the other hand, this is not the right

option to use. In such a case it would be better if the prescaler is left unaltered when the re-trigger happens, letting the counter reset on the next GCLK cycle.

20.2.4 Compare Match Operations

In compare match operation, Compare/Capture registers are used in comparison with the counter value. When the timer's count value matches the value of a compare channel, a user defined action can be taken.

20.2.4.1 Basic Timer

A Basic Timer is a simple application where compare match operations is used to determine when a specific period has elapsed. In Basic Timer operations, one or more values in the module's Compare/Capture registers are used to specify the time (as a number of prescaled GCLK cycles) when an action should be taken by the microcontroller. This can be an Interrupt Service Routine (ISR), event generator via the event system, or a software flag that is polled via the user application.

20.2.4.2 Waveform Generation

Waveform generation enables the TC module to generate square waves, or if combined with an external passive low-pass filter, analog waveforms.

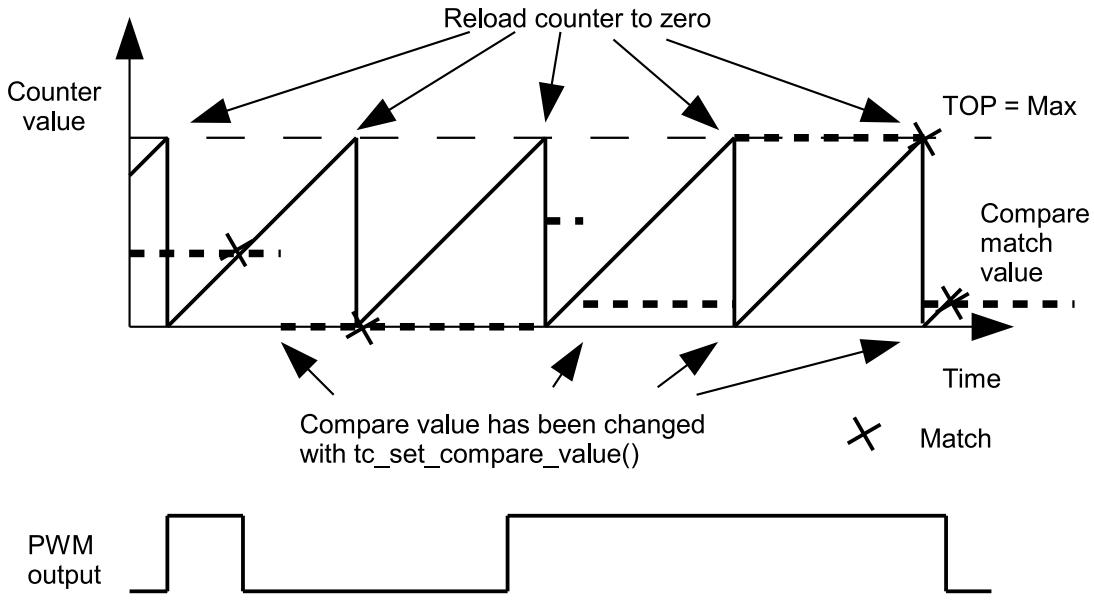
20.2.4.3 Waveform Generation - PWM

Pulse width modulation is a form of waveform generation and a signalling technique that can be useful in many situations. When PWM mode is used, a digital pulse train with a configurable frequency and duty cycle can be generated by the TC module and output to a GPIO pin of the device.

Often PWM is used to communicate a control or information parameter to an external circuit or component. Differing impedances of the source generator and sink receiver circuits is less of an issue when using PWM compared to using an analog voltage value, as noise will not generally affect the signal's integrity to a meaningful extent.

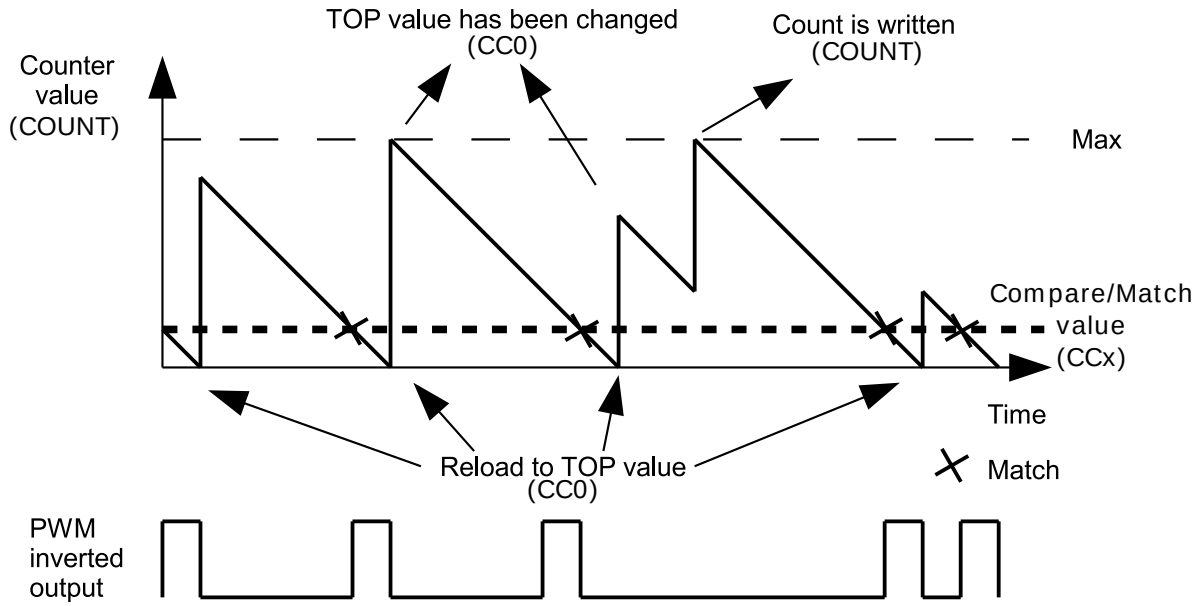
Figure 20-2: Example of PWM in normal mode, and different counter operations on page 462 illustrates operations and different states of the counter and its output when running the counter in PWM normal mode. As can be seen, the TOP value is unchanged and is set to MAX. The compare match value is changed at several points to illustrate the resulting waveform output changes. The PWM output is set to normal (i.e. non-inverted) output mode.

Figure 20-2. Example of PWM in normal mode, and different counter operations



In Figure 20-3: Example of PWM in match mode, and different counter operations on page 463, the counter is set to generate PWM in Match mode. The PWM output is inverted via the appropriate configuration option in the TC driver configuration structure. In this example, the counter value is changed once, but the compare match value is kept unchanged. As can be seen, it is possible to change the TOP value when running in PWM match mode.

Figure 20-3. Example of PWM in match mode, and different counter operations



20.2.4.4 Waveform Generation - Frequency

Frequency Generation mode is in many ways identical to PWM generation. However, in Frequency Generation a toggle only occurs on the output when a match on a capture channels occurs. When the match is made, the timer value is reset, resulting in a variable frequency square wave with a fixed 50% duty cycle.

20.2.4.5 Capture Operations

In capture operations, any event from the event system or a pin change can trigger a capture of the counter value. This captured counter value can be used as a timestamp for the event, or it can be used in frequency and pulse width capture.

20.2.4.6 Capture Operations - Event

Event capture is a simple use of the capture functionality, designed to create timestamps for specific events. When the TC module's input capture pin is externally toggled, the current timer count value is copied into a buffered register which can then be read out by the user application.

Note that when performing any capture operation, there is a risk that the counter reaches its top value (MAX) when counting up, or the bottom value (zero) when counting down, before the capture event occurs. This can distort the result, making event timestamps to appear shorter than reality; the user application should check for timer overflow when reading a capture result in order to detect this situation and perform an appropriate adjustment.

Before checking for a new capture, TC_STATUS_COUNT_OVERFLOW should be checked. The response to an overflow error is left to the user application, however it may be necessary to clear both the capture overflow flag and the capture flag upon each capture reading.

20.2.4.7 Capture Operations - Pulse Width

Pulse Width Capture mode makes it possible to measure the pulse width and period of PWM signals. This mode uses two capture channels of the counter. This means that the counter module used for Pulse Width Capture can not be used for any other purpose. There are two modes for pulse width capture; Pulse Width Period (PWP)

and Period Pulse Width (PPW). In PWP mode, capture channel 0 is used for storing the pulse width and capture channel 1 stores the observed period. While in PPW mode, the roles of the two capture channels is reversed.

As in the above example it is necessary to poll on interrupt flags to see if a new capture has happened and check that a capture overflow error has not occurred.

20.2.5 One-shot Mode

TC modules can be configured into a one-shot mode. When configured in this manner, starting the timer will cause it to count until the next overflow or underflow condition before automatically halting, waiting to be manually triggered by the user application software or an event signal from the event system.

20.2.5.1 Wave Generation Output Inversion

The output of the wave generation can be inverted by hardware if desired, resulting in the logically inverted value being output to the configured device GPIO pin.

20.3 Special Considerations

The number of capture compare registers in each TC module is dependent on the specific SAM D20/D21 device being used, and in some cases the counter size.

The maximum amount of capture compare registers available in any SAM D20/D21 device is two when running in 32-bit mode and four in 8-, and 16-bit modes.

20.4 Extra Information

For extra information see Extra Information for TC Driver. This includes:

- Acronyms
- Dependencies
- Errata
- Module History

20.5 Examples

For a list of examples related to this driver, see Examples for TC Driver.

20.6 API Overview

20.6.1 Variable and Type Definitions

20.6.1.1 Type tc_callback_t

```
typedef void(* tc_callback_t )(struct tc_module *const module)
```

20.6.2 Structure Definitions

20.6.2.1 Struct tc_16bit_config

Table 20-4. Members

Type	Name	Description
uint16_t	compare_capture_channel[]	Value to be used for compare match on each channel.
uint16_t	value	Initial timer count value.

20.6.2.2 Struct tc_32bit_config

Table 20-5. Members

Type	Name	Description
uint32_t	compare_capture_channel[]	Value to be used for compare match on each channel.
uint32_t	value	Initial timer count value.

20.6.2.3 Struct tc_8bit_config

Table 20-6. Members

Type	Name	Description
uint8_t	compare_capture_channel[]	Value to be used for compare match on each channel.
uint8_t	period	Where to count to or from depending on the direction on the counter.
uint8_t	value	Initial timer count value.

20.6.2.4 Struct tc_config

Configuration struct for a TC instance. This structure should be initialized by the tc_get_config_defaults function before being modified by the user application.

Table 20-7. Members

Type	Name	Description
union tc_config.@410	@410	Access the different counter size settings though this configuration member.
enum tc_clock_prescaler	clock_prescaler	Specifies the prescaler value for GCLK_TC.
enum gclk_generator	clock_source	GCLK generator used to clock the peripheral.
enum tc_count_direction	count_direction	Specifies the direction for the TC to count.
enum tc_counter_size	counter_size	Specifies either 8-, 16-, or 32-bit counter size.
bool	enable_capture_on_channel[]	Specifies which channel(s) to enable channel capture operation on.
bool	oneshot	When true, one-shot will stop the TC on next hardware or software re-trigger event or overflow/ underflow.
struct tc_pwm_channel	pwm_channel[]	Specifies the PWM channel for TC.
enum tc_reload_action	reload_action	Specifies the reload or reset time of the counter and prescaler resynchronization on a re-trigger event for the TC.

Type	Name	Description
bool	run_in_standby	When true the module is enabled during standby.
enum tc_wave_generation	wave_generation	Specifies which waveform generation mode to use.
uint8_t	waveform_invert_output	Specifies which channel(s) to invert the waveform on.

20.6.2.5 Union tc_config.__unnamed__

Access the different counter size settings though this configuration member.

Table 20-8. Members

Type	Name	Description
struct tc_16bit_config	counter_16_bit	Struct for 16-bit specific timer configuration.
struct tc_32bit_config	counter_32_bit	Struct for 32-bit specific timer configuration.
struct tc_8bit_config	counter_8_bit	Struct for 8-bit specific timer configuration.

20.6.2.6 Struct tc_events

Event flags for the tc_enable_events() and tc_disable_events().

Table 20-9. Members

Type	Name	Description
enum tc_event_action	event_action	Specifies which event to trigger if an event is triggered.
bool	generate_event_on_compare_chann	Generate an output event on a compare channel match.
bool	generate_event_on_overflow	Generate an output event on counter overflow.
bool	invert_event_input	Specifies if the input event source is inverted, when used in PWP or PPW event action modes.
bool	on_event_perform_action	Perform the configured event action when an incoming event is signalled.

20.6.2.7 Struct tc_module

TC software instance structure, used to retain software state information of an associated hardware module instance.

Note The fields of this structure should not be altered by the user application; they are reserved for module-internal use only.

20.6.2.8 Struct tc_pwm_channel

Table 20-10. Members

Type	Name	Description
bool	enabled	When true, PWM output for the given channel is enabled.
uint32_t	pin_mux	Specifies MUX setting for each output channel pin.
uint32_t	pin_out	Specifies pin output for each channel.

20.6.3 Macro Definitions

20.6.3.1 Module status flags

TC status flags, returned by tc_get_status() and cleared by tc_clear_status().

Macro TC_STATUS_CHANNEL_0_MATCH

```
#define TC_STATUS_CHANNEL_0_MATCH (1UL << 0)
```

Timer channel 0 has matched against its compare value, or has captured a new value.

Macro TC_STATUS_CHANNEL_1_MATCH

```
#define TC_STATUS_CHANNEL_1_MATCH (1UL << 1)
```

Timer channel 1 has matched against its compare value, or has captured a new value.

Macro TC_STATUS_SYNC_READY

```
#define TC_STATUS_SYNC_READY (1UL << 2)
```

Timer register synchronization has completed, and the synchronized count value may be read.

Macro TC_STATUS_CAPTURE_OVERFLOW

```
#define TC_STATUS_CAPTURE_OVERFLOW (1UL << 3)
```

A new value was captured before the previous value was read, resulting in lost data.

Macro TC_STATUS_COUNT_OVERFLOW

```
#define TC_STATUS_COUNT_OVERFLOW (1UL << 4)
```

The timer count value has overflowed from its maximum value to its minimum when counting upward, or from its minimum value to its maximum when counting downward.

20.6.4 Function Definitions

20.6.4.1 Driver Initialization and Configuration

Function tc_is_syncing()

Determines if the hardware module(s) are currently synchronizing to the bus.

```
bool tc_is_syncing(
  const struct tc_module *const module_inst)
```

Checks to see if the underlying hardware peripheral module(s) are currently synchronizing across multiple clock domains to the hardware bus, This function can be used to delay further operations on a module until such time that it is ready, to prevent blocking delays for synchronization in the user application.

Table 20-11. Parameters

Data direction	Parameter name	Description
[in]	module_inst	Pointer to the software module instance struct

Returns

Synchronization status of the underlying hardware module(s).

Table 20-12. Return Values

Return value	Description
true	if the module has completed synchronization
false	if the module synchronization is ongoing

Function tc_get_config_defaults()

Initializes config with predefined default values.

```
void tc_get_config_defaults(
  struct tc_config *const config)
```

This function will initialize a given TC configuration structure to a set of known default values. This function should be called on any new instance of the configuration structures before being modified by the user application.

The default configuration is as follows:

- GCLK generator 0 (GCLK main) clock source
- 16-bit counter size on the counter
- No prescaler
- Normal frequency wave generation
- GCLK reload action
- Don't run in standby
- No inversion of waveform output
- No capture enabled

- No event input enabled
- Count upward
- Don't perform one-shot operations
- No event action
- No channel 0 PWM output
- No channel 1 PWM output
- Counter starts on 0
- Capture compare channel 0 set to 0
- Capture compare channel 1 set to 0
- No PWM pin output enabled
- Pin and Mux configuration not set

Table 20-13. Parameters

Data direction	Parameter name	Description
[out]	config	Pointer to a TC module configuration structure to set

Function tc_init()

Initializes a hardware TC module instance.

```
enum status_code tc_init(
  struct tc_module *const module_inst,
  Tc *const hw,
  const struct tc_config *const config)
```

Enables the clock and initializes the TC module, based on the given configuration values.

Table 20-14. Parameters

Data direction	Parameter name	Description
[in, out]	module_inst	Pointer to the software module instance struct
[in]	hw	Pointer to the TC hardware module
[in]	config	Pointer to the TC configuration options struct

Returns Status of the initialization procedure.

Table 20-15. Return Values

Return value	Description
STATUS_OK	The module was initialized successfully
STATUS_BUSY	Hardware module was busy when the initialization procedure was attempted

Return value	Description
STATUS_INVALID_ARG	An invalid configuration option or argument was supplied
STATUS_ERR_DENIED	Hardware module was already enabled, or the hardware module is configured in 32 bit slave mode

20.6.4.2 Event Management

Function tc_enable_events()

Enables a TC module event input or output.

```
void tc_enable_events(
  struct tc_module *const module_inst,
  struct tc_events *const events)
```

Enables one or more input or output events to or from the TC module. See tc_events for a list of events this module supports.

Note Events cannot be altered while the module is enabled.

Table 20-16. Parameters

Data direction	Parameter name	Description
[in]	module_inst	Pointer to the software module instance struct
[in]	events	Struct containing flags of events to enable

Function tc_disable_events()

Disables a TC module event input or output.

```
void tc_disable_events(
  struct tc_module *const module_inst,
  struct tc_events *const events)
```

Disables one or more input or output events to or from the TC module. See tc_events for a list of events this module supports.

Note Events cannot be altered while the module is enabled.

Table 20-17. Parameters

Data direction	Parameter name	Description
[in]	module_inst	Pointer to the software module instance struct
[in]	events	Struct containing flags of events to disable

20.6.4.3 Enable/Disable/Reset

Function tc_reset()

Resets the TC module.

```
enum status_code tc_reset(
  const struct tc_module *const module_inst)
```

Resets the TC module, restoring all hardware module registers to their default values and disabling the module. The TC module will not be accessible while the reset is being performed.

Note When resetting a 32-bit counter only the master TC module's instance structure should be passed to the function.

Table 20-18. Parameters

Data direction	Parameter name	Description
[in]	module_inst	Pointer to the software module instance struct

Returns Status of the procedure

Table 20-19. Return Values

Return value	Description
STATUS_OK	The module was reset successfully
STATUS_ERR_UNSUPPORTED_DEV	A 32-bit slave TC module was passed to the function. Only use reset on master TC.

Function tc_enable()

Enable the TC module.

```
void tc_enable(
  const struct tc_module *const module_inst)
```

Enables a TC module that has been previously initialized. The counter will start when the counter is enabled.

Note When the counter is configured to re-trigger on an event, the counter will not start until the start function is used.

Table 20-20. Parameters

Data direction	Parameter name	Description
[in]	module_inst	Pointer to the software module instance struct

Function tc_disable()

Disables the TC module.

```
void tc_disable(
  const struct tc_module *const module_inst)
```

Disables a TC module and stops the counter.

Table 20-21. Parameters

Data direction	Parameter name	Description
[in]	module_inst	Pointer to the software module instance struct

20.6.4.4 Get/Set Count Value

Function tc_get_count_value()

Get TC module count value.

```
uint32_t tc_get_count_value(
  const struct tc_module *const module_inst)
```

Retrieves the current count value of a TC module. The specified TC module may be started or stopped.

Table 20-22. Parameters

Data direction	Parameter name	Description
[in]	module_inst	Pointer to the software module instance struct

Returns

Count value of the specified TC module.

Function tc_set_count_value()

Sets TC module count value.

```
enum status_code tc_set_count_value(
  const struct tc_module *const module_inst,
  const uint32_t count)
```

Sets the current timer count value of a initialized TC module. The specified TC module may be started or stopped.

Table 20-23. Parameters

Data direction	Parameter name	Description
[in]	module_inst	Pointer to the software module instance struct

Data direction	Parameter name	Description
[in]	count	New timer count value to set

Returns Status of the count update procedure.

Table 20-24. Return Values

Return value	Description
STATUS_OK	The timer count was updated successfully
STATUS_ERR_INVALID_ARG	An invalid timer counter size was specified

20.6.4.5 Start/Stop Counter

Function tc_stop_counter()

Stops the counter.

```
void tc_stop_counter(
  const struct tc_module *const module_inst)
```

This function will stop the counter. When the counter is stopped the value in the count value is set to 0 if the counter was counting up, or max or the top value if the counter was counting down when stopped.

Table 20-25. Parameters

Data direction	Parameter name	Description
[in]	module_inst	Pointer to the software module instance struct

Function tc_start_counter()

Starts the counter.

```
void tc_start_counter(
  const struct tc_module *const module_inst)
```

Starts or restarts an initialized TC module's counter.

Table 20-26. Parameters

Data direction	Parameter name	Description
[in]	module_inst	Pointer to the software module instance struct

20.6.4.6 Get Capture Set Compare

Function tc_get_capture_value()

Gets the TC module capture value.

```
uint32_t tc_get_capture_value(
```

```
  const struct tc_module *const module_inst,
  const enum tc_compare_capture_channel channel_index)
```

Retrieves the capture value in the indicated TC module capture channel.

Table 20-27. Parameters

Data direction	Parameter name	Description
[in]	module_inst	Pointer to the software module instance struct
[in]	channel_index	Index of the Compare Capture channel to read

Returns Capture value stored in the specified timer channel.

Function tc_set_compare_value()

Sets a TC module compare value.

```
enum status_code tc_set_compare_value(
  const struct tc_module *const module_inst,
  const enum tc_compare_capture_channel channel_index,
  const uint32_t compare_value)
```

Writes a compare value to the given TC module compare/capture channel.

Table 20-28. Parameters

Data direction	Parameter name	Description
[in]	module_inst	Pointer to the software module instance struct
[in]	channel_index	Index of the compare channel to write to
[in]	compare	New compare value to set

Returns Status of the compare update procedure.

Table 20-29. Return Values

Return value	Description
STATUS_OK	The compare value was updated successfully
STATUS_ERR_INVALID_ARG	An invalid channel index was supplied

20.6.4.7 Set Top Value

Function tc_set_top_value()

Set the timer TOP/period value.

```
enum status_code tc_set_top_value(
```

```
  const struct tc_module *const module_inst,
  const uint32_t top_value)
```

For 8-bit counter size this function writes the top value to the period register.

For 16- and 32-bit counter size this function writes the top value to Capture Compare register 0. The value in this register can not be used for any other purpose.

Note This function is designed to be used in PWM or frequency match modes only. When the counter is set to 16- or 32-bit counter size. In 8-bit counter size it will always be possible to change the top value even in normal mode.

Table 20-30. Parameters

Data direction	Parameter name	Description
[in]	module_inst	Pointer to the software module instance struct
[in]	top_value	New timer TOP value to set

Returns Status of the TOP set procedure.

Table 20-31. Return Values

Return value	Description
STATUS_OK	The timer TOP value was updated successfully
STATUS_ERR_INVALID_ARG	The configured TC module counter size in the module instance is invalid.

20.6.4.8 Status Management

Function tc_get_status()

Retrieves the current module status.

```
uint32_t tc_get_status(
  struct tc_module *const module_inst)
```

Retrieves the status of the module, giving overall state information.

Table 20-32. Parameters

Data direction	Parameter name	Description
[in]	module_inst	Pointer to the TC software instance struct

Returns Bitmask of TC_STATUS_* flags

Table 20-33. Return Values

Return value	Description
TC_STATUS_CHANNEL_0_MATCH	Timer channel 0 compare/capture match

Return value	Description
TC_STATUS_CHANNEL_1_MATCH	Timer channel 1 compare/capture match
TC_STATUS_SYNC_READY	Timer read synchronization has completed
TC_STATUS_CAPTURE_OVERFLOW	Timer capture data has overflowed
TC_STATUS_COUNT_OVERFLOW	Timer count value has overflowed

Function tc_clear_status()

Clears a module status flag.

```
void tc_clear_status(
  struct tc_module *const module_inst,
  const uint32_t status_flags)
```

Clears the given status flag of the module.

Table 20-34. Parameters

Data direction	Parameter name	Description
[in]	module_inst	Pointer to the TC software instance struct
[in]	status_flags	Bitmask of TC_STATUS_* flags to clear

20.6.5 Enumeration Definitions

20.6.5.1 Enum tc_callback

Enum for the possible callback types for the TC module.

Table 20-35. Members

Enum value	Description
TC_CALLBACK_OVERFLOW	Callback for TC overflow
TC_CALLBACK_ERROR	Callback for capture overflow error
TC_CALLBACK_CC_CHANNEL0	Callback for capture compare channel 0
TC_CALLBACK_CC_CHANNEL1	Callback for capture compare channel 1

20.6.5.2 Enum tc_clock_prescaler

This enum is used to choose the clock prescaler configuration. The prescaler divides the clock frequency of the TC module to make the counter count slower.

Table 20-36. Members

Enum value	Description
TC_CLOCK_PRESCALER_DIV1	Divide clock by 1
TC_CLOCK_PRESCALER_DIV2	Divide clock by 2
TC_CLOCK_PRESCALER_DIV4	Divide clock by 4

Enum value	Description
TC_CLOCK_PRESCALER_DIV8	Divide clock by 8
TC_CLOCK_PRESCALER_DIV16	Divide clock by 16
TC_CLOCK_PRESCALER_DIV64	Divide clock by 64
TC_CLOCK_PRESCALER_DIV256	Divide clock by 256
TC_CLOCK_PRESCALER_DIV1024	Divide clock by 1024

20.6.5.3 Enum tc_compare_capture_channel

This enum is used to specify which capture/compare channel to do operations on.

Table 20-37. Members

Enum value	Description
TC_COMPARE_CAPTURE_CHANNEL_0	Index of compare capture channel 0
TC_COMPARE_CAPTURE_CHANNEL_1	Index of compare capture channel 1

20.6.5.4 Enum tc_count_direction

Timer/Counter count direction.

Table 20-38. Members

Enum value	Description
TC_COUNT_DIRECTION_UP	Timer should count upward from zero to MAX.
TC_COUNT_DIRECTION_DOWN	Timer should count downward to zero from MAX.

20.6.5.5 Enum tc_counter_size

This enum specifies the maximum value it is possible to count to.

Table 20-39. Members

Enum value	Description
TC_COUNTER_SIZE_8BIT	The counter's max value is 0xFF, the period register is available to be used as top value.
TC_COUNTER_SIZE_16BIT	The counter's max value is 0xFFFF. There is no separate period register, to modify top one of the capture compare registers has to be used. This limits the amount of available channels.
TC_COUNTER_SIZE_32BIT	The counter's max value is 0xFFFFFFFF. There is no separate period register, to modify top one of the capture compare registers has to be used. This limits the amount of available channels.

20.6.5.6 Enum tc_event_action

Event action to perform when the module is triggered by an event.

Table 20-40. Members

Enum value	Description
TC_EVENT_ACTION_OFF	No event action.
TC_EVENT_ACTION_RETRIGGER	Re-trigger on event.
TC_EVENT_ACTION_INCREMENT_COUNTER	Increment counter on event.
TC_EVENT_ACTION_START	Start counter on event.
TC_EVENT_ACTION_PPW	Store period in capture register 0, pulse width in capture register 1.
TC_EVENT_ACTION_PWP	Store pulse width in capture register 0, period in capture register 1.

20.6.5.7 Enum tc_reload_action

This enum specify how the counter and prescaler should reload.

Table 20-41. Members

Enum value	Description
TC_RELOAD_ACTION_GCLK	The counter is reloaded/reset on the next GCLK and starts counting on the prescaler clock.
TC_RELOAD_ACTION_PRESC	The counter is reloaded/reset on the next prescaler clock
TC_RELOAD_ACTION_RESYNC	The counter is reloaded/reset on the next GCLK, and the prescaler is restarted as well.

20.6.5.8 Enum tc_wave_generation

This enum is used to select which mode to run the wave generation in.

Table 20-42. Members

Enum value	Description
TC_WAVE_GENERATION_NORMAL_FREQ	Top is max, except in 8-bit counter size where it is the PER register
TC_WAVE_GENERATION_MATCH_FREQ	Top is CC0, except in 8-bit counter size where it is the PER register
TC_WAVE_GENERATION_NORMAL_PWM	Top is max, except in 8-bit counter size where it is the PER register
TC_WAVE_GENERATION_MATCH_PWM	Top is CC0, except in 8-bit counter size where it is the PER register

20.6.5.9 Enum tc_waveform_invert_output

Output waveform inversion mode.

Table 20-43. Members

Enum value	Description
TC_WAVEFORM_INVERT_OUTPUT_NONE	No inversion of the waveform output.
TC_WAVEFORM_INVERT_OUTPUT_CHANNEL_0	Invert output from compare channel 0.

Enum value	Description
TC_WAVEFORM_INVERT_OUTPUT_CHANNEL_1	Invert output from compare channel 1.

20.7 Extra Information for TC Driver

20.7.1 Acronyms

The table below presents the acronyms used in this module:

Acronym	Description
DMA	Direct Memory Access
TC	Timer Counter
PWM	Pulse Width Modulation
PWP	Pulse Width Period
PPW	Period Pulse Width

20.7.2 Dependencies

This driver has the following dependencies:

- System Pin Multiplexer Driver

20.7.3 Errata

There are no errata related to this driver.

20.7.4 Module History

An overview of the module history is presented in the table below, with details on the enhancements and fixes made to the module since its first release. The current version of this corresponds to the newest version in the table.

Changelog
Added support for SAMD21 and do some modifications as below: • Clean up in the configuration structure, the counter size setting specific registers is accessed through the counter_8_bit, counter_16_bit and counter_32_bit structures. • All event related settings moved into the tc_event structure
Added automatic digital clock interface enable for the slave TC module when a timer is initialized in 32-bit mode.
Initial Release

20.8 Examples for TC Driver

This is a list of the available Quick Start guides (QSGs) and example applications for SAM D20/D21 Timer/Counter Driver (TC). QSGs are simple examples with step-by-step instructions to configure and use this driver in a selection of use cases. Note that QSGs can be compiled as a standalone application or be added to the user application.

- Quick Start Guide for TC - Basic
- Quick Start Guide for TC - Timer
- Quick Start Guide for TC - Callback
- Quick Start Guide for Using DMA with TC

20.8.1 Quick Start Guide for TC - Basic

In this use case, the TC will be used to generate a PWM signal. Here the pulse width is set to one quarter of the period. The TC module will be set up as follows:

- GCLK generator 0 (GCLK main) clock source
- 16 bit resolution on the counter
- No prescaler
- Normal PWM wave generation
- GCLK reload action
- Don't run in standby
- No inversion of waveform output
- No capture enabled
- Count upward
- Don't perform one-shot operations
- No event input enabled
- No event action
- No event generation enabled
- Counter starts on 0
- Capture compare channel 0 set to 0xFFFF/4

20.8.1.1 Quick Start

Prerequisites

There are no prerequisites for this use case.

Code

Add to the main application source file, before any functions:

```
#define PWM_MODULE      EXT1_PWM_MODULE

#define PWM_OUT_PIN     EXT1_PWM_0_PIN

#define PWM_OUT_MUX     EXT1_PWM_0_MUX
```

Add to the main application source file, outside of any functions:

```
struct tc_module tc_instance;
```

Copy-paste the following setup code to your user application:

```
void configure_tc(void)
{
    struct tc_config config_tc;
    tc_get_config_defaults(&config_tc);
```

```
    config_tc.counter_size    = TC_COUNTER_SIZE_16BIT;
    config_tc.wave_generation = TC_WAVE_GENERATION_NORMAL_PWM;
    config_tc.counter_16_bit.compare_capture_channel[0] = (0xFFFF / 4);

    config_tc.pwm_channel[0].enabled = true;
    config_tc.pwm_channel[0].pin_out = PWM_OUT_PIN;
    config_tc.pwm_channel[0].pin_mux = PWM_OUT_MUX;

    tc_init(&tc_instance, PWM_MODULE, &config_tc);

    tc_enable(&tc_instance);
}
```

Add to user application initialization (typically the start of `main()`):

```
configure_tc();
```

Workflow

1. Create a module software instance structure for the TC module to store the TC driver state while it is in use.

   ```
   struct tc_module tc_instance;
   ```

Note This should never go out of scope as long as the module is in use. In most cases, this should be global.

2. Configure the TC module.

   a. Create a TC module configuration struct, which can be filled out to adjust the configuration of a physical TC peripheral.

      ```
      struct tc_config config_tc;
      ```

   b. Initialize the TC configuration struct with the module's default values.

      ```
      tc_get_config_defaults(&config_tc);
      ```

Note This should always be performed before using the configuration struct to ensure that all values are initialized to known default settings.

   c. Alter the TC settings to configure the counter width, wave generation mode and the compare channel 0 value.

      ```
      config_tc.counter_size    = TC_COUNTER_SIZE_16BIT;
      config_tc.wave_generation = TC_WAVE_GENERATION_NORMAL_PWM;
      config_tc.counter_16_bit.compare_capture_channel[0] = (0xFFFF / 4);
      ```

   d. Alter the TC settings to configure the PWM output on a physical device pin.

      ```
      config_tc.pwm_channel[0].enabled = true;
      config_tc.pwm_channel[0].pin_out = PWM_OUT_PIN;
      ```

```
config_tc.pwm_channel[0].pin_mux = PWM_OUT_MUX;
```

e. Configure the TC module with the desired settings.

```
tc_init(&tc_instance, PWM_MODULE, &config_tc);
```

f. Enable the TC module to start the timer and begin PWM signal generation.

```
tc_enable(&tc_instance);
```

20.8.1.2 Use Case

Code

Copy-paste the following code to your user application:

```
while (true) {
    /* Infinite loop */
}
```

Workflow

1. Enter an infinite loop while the PWM wave is generated via the TC module.

```
while (true) {
    /* Infinite loop */
}
```

20.8.2 Quick Start Guide for TC - Timer

In this use case, the TC will be used as a timer, to generate overflow and compare match callbacks. In the callbacks the on-board LED is toggled.

The TC module will be set up as follows:

- GCLK generator 1 (GCLK 32K) clock source
- 16 bit resolution on the counter
- Prescaler is divided by 64
- GCLK reload action
- Count upward
- Don't run in standby
- No waveform outputs
- No capture enabled
- Don't perform one-shot operations
- No event input enabled
- No event action
- No event generation enabled
- Counter starts on 0

- Counter top set to 2000 (about 4s) and generate overflow callback
- Channel 0 is set to compare and match value 900 and generate callback
- Channel 1 is set to compare and match value 930 and generate callback

20.8.2.1 Quick Start

Prerequisites

For this use case, XOSC32K should be enabled and available through GCLK generator 1 clock source selection. Within Atmel Software Framework (ASF) it can be done through modifying *conf_clocks.h*. See System Clock Management Driver for more details about clock configuration.

Code

Add to the main application source file, outside of any functions:

```
struct tc_module tc_instance;
```

Copy-paste the following callback function code to your user application:

```
void tc_callback_to_toggle_led(
        struct tc_module *const module_inst)
{
    port_pin_toggle_output_level(LED0_PIN);
}
```

Copy-paste the following setup code to your user application:

```
void configure_tc(void)
{
    struct tc_config config_tc;
    tc_get_config_defaults(&config_tc);

    config_tc.counter_size = TC_COUNTER_SIZE_8BIT;
    config_tc.clock_source = GCLK_GENERATOR_1;
    config_tc.clock_prescaler = TC_CLOCK_PRESCALER_DIV1024;
    config_tc.counter_8_bit.period = 100;
    config_tc.counter_8_bit.compare_capture_channel[0] = 50;
    config_tc.counter_8_bit.compare_capture_channel[1] = 54;

    tc_init(&tc_instance, TC3, &config_tc);

    tc_enable(&tc_instance);
}

void configure_tc_callbacks(void)
{
    tc_register_callback(&tc_instance, tc_callback_to_toggle_led,
            TC_CALLBACK_OVERFLOW);
    tc_register_callback(&tc_instance, tc_callback_to_toggle_led,
            TC_CALLBACK_CC_CHANNEL0);
    tc_register_callback(&tc_instance, tc_callback_to_toggle_led,
            TC_CALLBACK_CC_CHANNEL1);

    tc_enable_callback(&tc_instance, TC_CALLBACK_OVERFLOW);
    tc_enable_callback(&tc_instance, TC_CALLBACK_CC_CHANNEL0);
    tc_enable_callback(&tc_instance, TC_CALLBACK_CC_CHANNEL1);
}
```

Add to user application initialization (typically the start of `main()`):

```
configure_tc();
configure_tc_callbacks();
```

Workflow

1. Create a module software instance structure for the TC module to store the TC driver state while it is in use.

   ```
   struct tc_module tc_instance;
   ```

Note This should never go out of scope as long as the module is in use. In most cases, this should be global.

2. Configure the TC module.

   a. Create a TC module configuration struct, which can be filled out to adjust the configuration of a physical TC peripheral.

      ```
      struct tc_config config_tc;
      ```

   b. Initialize the TC configuration struct with the module's default values.

      ```
      tc_get_config_defaults(&config_tc);
      ```

Note This should always be performed before using the configuration struct to ensure that all values are initialized to known default settings.

   c. Alter the TC settings to configure the GCLK source, prescaler, period and compare channel values.

      ```
      config_tc.counter_size = TC_COUNTER_SIZE_8BIT;
      config_tc.clock_source = GCLK_GENERATOR_1;
      config_tc.clock_prescaler = TC_CLOCK_PRESCALER_DIV1024;
      config_tc.counter_8_bit.period = 100;
      config_tc.counter_8_bit.compare_capture_channel[0] = 50;
      config_tc.counter_8_bit.compare_capture_channel[1] = 54;
      ```

   d. Configure the TC module with the desired settings.

      ```
      tc_init(&tc_instance, TC3, &config_tc);
      ```

   e. Enable the TC module to start the timer.

      ```
      tc_enable(&tc_instance);
      ```

3. Configure the TC callbacks.

   a. Register the Overflow and Compare Channel Match callback functions with the driver.

      ```
      tc_register_callback(&tc_instance, tc_callback_to_toggle_led,
              TC_CALLBACK_OVERFLOW);
      ```

```
tc_register_callback(&tc_instance, tc_callback_to_toggle_led,
        TC_CALLBACK_CC_CHANNEL0);
tc_register_callback(&tc_instance, tc_callback_to_toggle_led,
        TC_CALLBACK_CC_CHANNEL1);
```

b. Enable the Overflow and Compare Channel Match callbacks so that it will be called by the driver when appropriate.

```
tc_enable_callback(&tc_instance, TC_CALLBACK_OVERFLOW);
tc_enable_callback(&tc_instance, TC_CALLBACK_CC_CHANNEL0);
tc_enable_callback(&tc_instance, TC_CALLBACK_CC_CHANNEL1);
```

20.8.2.2 Use Case

Code

Copy-paste the following code to your user application:

```
system_interrupt_enable_global();

while (true) {
}
```

Workflow

1. Enter an infinite loop while the timer is running.

```
while (true) {
}
```

20.8.3 Quick Start Guide for TC - Callback

In this use case, the TC will be used to generate a PWM signal, with a varying duty cycle. Here the pulse width is increased each time the timer count matches the set compare value. The TC module will be set up as follows:

- GCLK generator 0 (GCLK main) clock source
- 16 bit resolution on the counter
- No prescaler
- Normal PWM wave generation
- GCLK reload action
- Don't run in standby
- No inversion of waveform output
- No capture enabled
- Count upward
- Don't perform one-shot operations
- No event input enabled
- No event action
- No event generation enabled

- Counter starts on 0

20.8.3.1 Quick Start

Prerequisites

There are no prerequisites for this use case.

Code

Add to the main application source file, before any functions:

```
#define PWM_MODULE      EXT1_PWM_MODULE

#define PWM_OUT_PIN     EXT1_PWM_0_PIN

#define PWM_OUT_MUX     EXT1_PWM_0_MUX
```

Add to the main application source file, outside of any functions:

```
struct tc_module tc_instance;
```

Copy-paste the following callback function code to your user application:

```
void tc_callback_to_change_duty_cycle(
        struct tc_module *const module_inst)
{
    static uint16_t i = 0;

    i += 128;
    tc_set_compare_value(module_inst, TC_COMPARE_CAPTURE_CHANNEL_0, i + 1);
}
```

Copy-paste the following setup code to your user application:

```
void configure_tc(void)
{
    struct tc_config config_tc;
    tc_get_config_defaults(&config_tc);

    config_tc.counter_size    = TC_COUNTER_SIZE_16BIT;
    config_tc.wave_generation = TC_WAVE_GENERATION_NORMAL_PWM;
    config_tc.counter_16_bit.compare_capture_channel[0] = 0xFFFF;

    config_tc.pwm_channel[0].enabled = true;
    config_tc.pwm_channel[0].pin_out = PWM_OUT_PIN;
    config_tc.pwm_channel[0].pin_mux = PWM_OUT_MUX;

    tc_init(&tc_instance, PWM_MODULE, &config_tc);

    tc_enable(&tc_instance);
}

void configure_tc_callbacks(void)
{
    tc_register_callback(
            &tc_instance,
            tc_callback_to_change_duty_cycle,
```

```
            TC_CALLBACK_CC_CHANNEL0);

    tc_enable_callback(&tc_instance, TC_CALLBACK_CC_CHANNEL0);
}
```

Add to user application initialization (typically the start of `main()`):

```
configure_tc();
configure_tc_callbacks();
```

Workflow

1. Create a module software instance structure for the TC module to store the TC driver state while it is in use.

   ```
   struct tc_module tc_instance;
   ```

Note This should never go out of scope as long as the module is in use. In most cases, this should be global.

2. Configure the TC module.

   a. Create a TC module configuration struct, which can be filled out to adjust the configuration of a physical TC peripheral.

      ```
      struct tc_config config_tc;
      ```

   b. Initialize the TC configuration struct with the module's default values.

      ```
      tc_get_config_defaults(&config_tc);
      ```

Note This should always be performed before using the configuration struct to ensure that all values are initialized to known default settings.

   c. Alter the TC settings to configure the counter width, wave generation mode and the compare channel 0 value.

      ```
      config_tc.counter_size    = TC_COUNTER_SIZE_16BIT;
      config_tc.wave_generation = TC_WAVE_GENERATION_NORMAL_PWM;
      config_tc.counter_16_bit.compare_capture_channel[0] = 0xFFFF;
      ```

   d. Alter the TC settings to configure the PWM output on a physical device pin.

      ```
      config_tc.pwm_channel[0].enabled = true;
      config_tc.pwm_channel[0].pin_out = PWM_OUT_PIN;
      config_tc.pwm_channel[0].pin_mux = PWM_OUT_MUX;
      ```

   e. Configure the TC module with the desired settings.

      ```
      tc_init(&tc_instance, PWM_MODULE, &config_tc);
      ```

   f. Enable the TC module to start the timer and begin PWM signal generation.

```
tc_enable(&tc_instance);
```

3. Configure the TC callbacks.

   a. Register the Compare Channel 0 Match callback functions with the driver.

```
tc_register_callback(
        &tc_instance,
        tc_callback_to_change_duty_cycle,
        TC_CALLBACK_CC_CHANNEL0);
```

   b. Enable the Compare Channel 0 Match callback so that it will be called by the driver when appropriate.

```
tc_enable_callback(&tc_instance, TC_CALLBACK_CC_CHANNEL0);
```

20.8.3.2 Use Case

Code

Copy-paste the following code to your user application:

```
system_interrupt_enable_global();

while (true) {
}
```

Workflow

1. Enter an infinite loop while the PWM wave is generated via the TC module.

```
while (true) {
}
```

20.8.4 Quick Start Guide for Using DMA with TC

The supported device list:

- SAMD21

In this use case, the TC will be used to generate a PWM signal. Here the pulse width is set to one quarter of the period. Once the counter value matches the values in the Compare/Capture Value register, a event will be tiggered for a DMA memory transfer. The TC module will be set up as follows:

- GCLK generator 0 (GCLK main) clock source
- 16 bit resolution on the counter
- No prescaler
- Normal PWM wave generation
- GCLK reload action
- Don't run in standby
- No inversion of waveform output

- No capture enabled
- Count upward
- Don't perform one-shot operations
- No event input enabled
- No event action
- No event generation enabled
- Counter starts on 0
- Capture compare channel 0 set to 0xFFFF/4

The DMA module is configured for:

- Move data from memory to memory
- Using peripheral trigger of TC6 Match/Compare 0
- Using DMA priority level 0

20.8.4.1 Quick Start

Prerequisites

There are no prerequisites for this use case.

Code

Add to the main application source file, before any functions:

```
#define PWM_MODULE      EXT1_PWM_MODULE

#define PWM_OUT_PIN     EXT1_PWM_0_PIN

#define PWM_OUT_MUX     EXT1_PWM_0_MUX
```

Add to the main application source file, outside of any functions:

```
struct tc_module tc_instance;
```

```
struct dma_resource example_resource;
```

```
#define TRANSFER_SIZE    (16)
```

```
#define TRANSFER_COUNTER (64)
```

```
static uint8_t source_memory[TRANSFER_SIZE*TRANSFER_COUNTER];
```

```
static uint8_t destination_memory[TRANSFER_SIZE*TRANSFER_COUNTER];
```

```
static volatile bool transfer_is_done = false;
```

```
COMPILER_ALIGNED(16)
DmacDescriptor example_descriptor;
```

Copy-paste the following setup code to your user application:

```
#define TRANSFER_SIZE    (16)

#define TRANSFER_COUNTER (64)

static uint8_t source_memory[TRANSFER_SIZE*TRANSFER_COUNTER];

static uint8_t destination_memory[TRANSFER_SIZE*TRANSFER_COUNTER];

static volatile bool transfer_is_done = false;

COMPILER_ALIGNED(16)
DmacDescriptor example_descriptor;

void configure_tc(void)
{
    struct tc_config config_tc;
    tc_get_config_defaults(&config_tc);

    config_tc.counter_size    = TC_COUNTER_SIZE_16BIT;
    config_tc.wave_generation = TC_WAVE_GENERATION_NORMAL_PWM;
    config_tc.counter_16_bit.compare_capture_channel[0] = (0xFFFF / 4);

    config_tc.pwm_channel[0].enabled = true;
    config_tc.pwm_channel[0].pin_out = PWM_OUT_PIN;
    config_tc.pwm_channel[0].pin_mux = PWM_OUT_MUX;

    tc_init(&tc_instance, PWM_MODULE, &config_tc);

    tc_enable(&tc_instance);
}

void transfer_done( const struct dma_resource* const resource )
{
    UNUSED(resource);

    transfer_is_done = true;
}

void configure_dma_resource(struct dma_resource *resource)
{
    struct dma_resource_config config;

    dma_get_config_defaults(&config);
    config.peripheral_trigger = TC6_DMAC_ID_MC_0;

    dma_allocate(resource, &config);
}

void setup_dma_descriptor(DmacDescriptor *descriptor)
{
    struct dma_descriptor_config descriptor_config;

    dma_descriptor_get_config_defaults(&descriptor_config);

    descriptor_config.block_transfer_count = TRANSFER_SIZE;
```

```
    descriptor_config.source_address = (uint32_t)source_memory + TRANSFER_SIZE;
    descriptor_config.destination_address = (uint32_t)destination_memory + TRANSFER_SIZE;

    dma_descriptor_create(descriptor, &descriptor_config);
}
```

Add to user application initialization (typically the start of `main()`):

```
configure_tc();
```

Workflow

Create variables

1. Create a module software instance structure for the TC module to store the TC driver state while it is in use.

```
struct tc_module tc_instance;
```

Note This should never go out of scope as long as the module is in use. In most cases, this should be global.

2. Create a module software instance structure for DMA resource to store the DMA resource state while it is in use.

```
struct dma_resource example_resource;
```

Note This should never go out of scope as long as the module is in use. In most cases, this should be global.

Configure TC

1. Create a TC module configuration struct, which can be filled out to adjust the configuration of a physical TC peripheral.

```
struct tc_config config_tc;
```

2. Initialize the TC configuration struct with the module's default values.

```
tc_get_config_defaults(&config_tc);
```

Note This should always be performed before using the configuration struct to ensure that all values are initialized to known default settings.

3. Alter the TC settings to configure the counter width, wave generation mode and the compare channel 0 value.

```
config_tc.counter_size    = TC_COUNTER_SIZE_16BIT;
config_tc.wave_generation = TC_WAVE_GENERATION_NORMAL_PWM;
config_tc.counter_16_bit.compare_capture_channel[0] = (0xFFFF / 4);
```

4. Alter the TC settings to configure the PWM output on a physical device pin.

```
config_tc.pwm_channel[0].enabled = true;
config_tc.pwm_channel[0].pin_out = PWM_OUT_PIN;
config_tc.pwm_channel[0].pin_mux = PWM_OUT_MUX;
```

5. Configure the TC module with the desired settings.

```
tc_init(&tc_instance, PWM_MODULE, &config_tc);
```

6. Enable the TC module to start the timer and begin PWM signal generation.

```
tc_enable(&tc_instance);
```

Configure DMA

1. Create a DMA resource configuration structure, which can be filled out to adjust the configuration of a single DMA transfer.

```
struct dma_resource_config config;
```

2. Initialize the DMA resource configuration struct with the module's default values.

```
dma_get_config_defaults(&config);
config.peripheral_trigger = TC6_DMAC_ID_MC_0;
```

Note This should always be performed before using the configuration struct to ensure that all values are initialized to known default settings.

3. Allocate a DMA resource with the configurations.

```
dma_allocate(resource, &config);
```

4. Create a DMA transfer descriptor configuration structure, which can be filled out to adjust the configuration of a single DMA transfer.

```
struct dma_descriptor_config descriptor_config;
```

5. Initialize the DMA transfer descriptor configuration struct with the module's default values.

```
dma_descriptor_get_config_defaults(&descriptor_config);
```

Note This should always be performed before using the configuration struct to ensure that all values are initialized to known default settings.

6. Set the specific parameters for a DMA transfer with transfer size, source address, destination address.

```
descriptor_config.block_transfer_count = TRANSFER_SIZE;
descriptor_config.source_address = (uint32_t)source_memory + TRANSFER_SIZE;
descriptor_config.destination_address = (uint32_t)destination_memory + TRANSFER_SIZE;
```

7. Create the DMA transfer descriptor.

```
dma_descriptor_create(descriptor, &descriptor_config);
```

8. Add the DMA transfer descriptor to the allocated DMA resource.

```
dma_add_descriptor(&example_resource, &example_descriptor);
```

9. Register a callback to indicate transfer status.

```
dma_register_callback(&example_resource, transfer_done,
        DMA_CALLBACK_TRANSFER_DONE);
```

10. The transfer done flag is set in the registered callback function.

```
void transfer_done( const struct dma_resource* const resource )
{
    UNUSED(resource);

    transfer_is_done = true;
}
```

Prepare data

1. Setup memory content for validate transfer.

```
for (i = 0; i < TRANSFER_SIZE*TRANSFER_COUNTER; i++) {
    source_memory[i] = i;
}
```

20.8.4.2 Use Case

Code

Copy-paste the following code to your user application:

```
for(i=0;i<TRANSFER_COUNTER;i++) {
    transfer_is_done = false;

    dma_start_transfer_job(&example_resource);

    while (!transfer_is_done) {
        /* Wait for transfer done */
    }

    example_descriptor.SRCADDR.reg += TRANSFER_SIZE;
    example_descriptor.DSTADDR.reg += TRANSFER_SIZE;
}

while(1);
```

Workflow

1. Start the loop for transfer.

```
for(i=0;i<TRANSFER_COUNTER;i++) {
```

```
    transfer_is_done = false;

    dma_start_transfer_job(&example_resource);

    while (!transfer_is_done) {
        /* Wait for transfer done */
    }

    example_descriptor.SRCADDR.reg += TRANSFER_SIZE;
    example_descriptor.DSTADDR.reg += TRANSFER_SIZE;
}
```

2. Set the transfer done flag as false.

```
transfer_is_done = false;
```

3. Start the transfer job.

```
dma_start_transfer_job(&example_resource);
```

4. Wait for transfer done.

```
while (!transfer_is_done) {
    /* Wait for transfer done */
}
```

5. Update the source and destination address for next transfer

```
example_descriptor.SRCADDR.reg += TRANSFER_SIZE;
example_descriptor.DSTADDR.reg += TRANSFER_SIZE;
```

6. enter endless loop

```
while(1);
```

21. SAM D20/D21 Watchdog Driver (WDT)

This driver for SAM D20/D21 devices provides an interface for the configuration and management of the device's Watchdog Timer module, including the enabling, disabling and kicking within the device. The following driver API modes are covered by this manual:

- Polled APIs
- Callback APIs

The following peripherals are used by this module:

- WDT (Watchdog Timer)

The outline of this documentation is as follows:

21.1 Prerequisites

There are no prerequisites for this module.

21.2 Module Overview

The Watchdog module (WDT) is designed to give an added level of safety in critical systems, to ensure a system reset is triggered in the case of a deadlock or other software malfunction that prevents normal device operation.

At a basic level, the Watchdog is a system timer with a fixed period; once enabled, it will continue to count ticks of its asynchronous clock until it is periodically reset, or the timeout period is reached. In the event of a Watchdog timeout, the module will trigger a system reset identical to a pulse of the device's reset pin, resetting all peripherals to their power-on default states and restarting the application software from the reset vector.

In many systems, there is an obvious upper bound to the amount of time each iteration of the main application loop can be expected to run, before a malfunction can be assumed (either due to a deadlock waiting on hardware or software, or due to other means). When the Watchdog is configured with a timeout period equal to this upper bound, a malfunction in the system will force a full system reset to allow for a graceful recovery.

21.2.1 Locked Mode

The Watchdog configuration can be set in the device fuses and locked in hardware, so that no software changes can be made to the Watchdog configuration. Additionally, the Watchdog can be locked on in software if it is not already locked, so that the module configuration cannot be modified until a power on reset of the device.

The locked configuration can be used to ensure that faulty software does not cause the Watchdog configuration to be changed, preserving the level of safety given by the module.

21.2.2 Window Mode

Just as there is a reasonable upper bound to the time the main program loop should take for each iteration, there is also in many applications a lower bound, i.e. a *minimum* time for which each loop iteration should run for under normal circumstances. To guard against a system failure resetting the Watchdog in a tight loop (or a failure in the system application causing the main loop to run faster than expected) a "Window" mode can be enabled to disallow resetting of the Watchdog counter before a certain period of time. If the Watchdog is not reset *after* the window opens but not *before* the Watchdog expires, the system will reset.

21.2.3 Early Warning

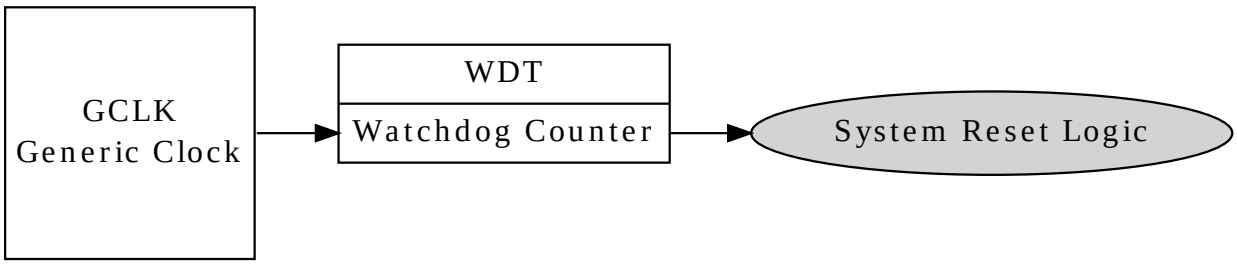
In some cases it is desirable to receive an early warning that the Watchdog is about to expire, so that some system action (such as saving any system configuration data for failure analysis purposes) can be performed before the system reset occurs. The Early Warning feature of the Watchdog module allows such a notification to be requested; after the configured early warning time (but before the expiry of the Watchdog counter) the Early Warning flag will become set, so that the user application can take an appropriate action.

Note It is important to note that the purpose of the Early Warning feature is *not* to allow the user application to reset the Watchdog; doing so will defeat the safety the module gives to the user application. Instead, this feature should be used purely to perform any tasks that need to be undertaken before the system reset occurs.

21.2.4 Physical Connection

Figure 21-1: Physical Connection on page 496 shows how this module is interconnected within the device.

Figure 21-1. Physical Connection



21.3 Special Considerations

On some devices the Watchdog configuration can be fused to be always on in a particular configuration; if this mode is enabled the Watchdog is not software configurable and can have its count reset and early warning state checked/cleared only.

21.4 Extra Information

For extra information see Extra Information for WDT Driver. This includes:

- Acronyms
- Dependencies
- Errata
- Module History

21.5 Examples

For a list of examples related to this driver, see Examples for WDT Driver.

21.6 API Overview

21.6.1 Variable and Type Definitions

21.6.1.1 Callback configuration and initialization

Type wdt_callback_t

```
typedef void(* wdt_callback_t )(void)
```

Type definition for a WDT module callback function.

21.6.2 Structure Definitions

21.6.2.1 Struct wdt_conf

Configuration structure for a Watchdog Timer instance. This structure should be initialized by the wdt_get_config_defaults() function before being modified by the user application.

Table 21-1. Members

Type	Name	Description
bool	always_on	If true, the Watchdog will be locked to the current configuration settings when the Watchdog is enabled.
enum gclk_generator	clock_source	GCLK generator used to clock the peripheral
enum wdt_period	early_warning_period	Number of Watchdog timer clock ticks until the early warning flag is set.
bool	enable	Enable/Disable the Watchdog Timer
enum wdt_period	timeout_period	Number of Watchdog timer clock ticks until the Watchdog expires.
enum wdt_period	window_period	Number of Watchdog timer clock ticks until the reset window opens.

21.6.3 Function Definitions

21.6.3.1 Configuration and initialization

Function wdt_is_syncing()

Determines if the hardware module(s) are currently synchronizing to the bus.

```
bool wdt_is_syncing(void)
```

Checks to see if the underlying hardware peripheral module(s) are currently synchronizing across multiple clock domains to the hardware bus, This function can be used to delay further operations on a module until such time that it is ready, to prevent blocking delays for synchronization in the user application.

Returns

Synchronization status of the underlying hardware module(s).

Table 21-2. Return Values

Return value	Description
true	if the module has completed synchronization
false	if the module synchronization is ongoing

Function wdt_get_config_defaults()

Initializes a Watchdog Timer configuration structure to defaults.

```
void wdt_get_config_defaults(
  struct wdt_conf *const config)
```

Initializes a given Watchdog Timer configuration structure to a set of known default values. This function should be called on all new instances of these configuration structures before being modified by the user application.

The default configuration is as follows:

- Not locked, to allow for further (re-)configuration
- Enable WDT
- Watchdog timer sourced from Generic Clock Channel 4
- A timeout period of 16384 clocks of the Watchdog module clock
- No window period, so that the Watchdog count can be reset at any time
- No early warning period to indicate the Watchdog will soon expire

Table 21-3. Parameters

Data direction	Parameter name	Description
[out]	config	Configuration structure to initialize to default values

Function wdt_set_config()

Sets up the WDT hardware module based on the configuration.

```
enum status_code wdt_set_config(
  const struct wdt_conf *const config)
```

Writes a given configuration of a WDT configuration to the hardware module, and initializes the internal device struct

Table 21-4. Parameters

Data direction	Parameter name	Description
[in]	config	Pointer to the configuration struct

Returns Status of the configuration procedure.

Table 21-5. Return Values

Return value	Description
STATUS_OK	If the module was configured correctly
STATUS_ERR_INVALID_ARG	If invalid argument(s) were supplied
STATUS_ERR_IO	If the Watchdog module is locked to be always on

Function wdt_is_locked()

Determines if the Watchdog timer is currently locked in an enabled state.

```
bool wdt_is_locked(void)
```

Determines if the Watchdog timer is currently enabled and locked, so that it cannot be disabled or otherwise reconfigured.

Returns Current Watchdog lock state.

21.6.3.2 Timeout and Early Warning Management

Function wdt_clear_early_warning()

Clears the Watchdog timer Early Warning period elapsed flag.

```
void wdt_clear_early_warning(void)
```

Clears the Watchdog timer Early Warning period elapsed flag, so that a new early warning period can be detected.

Function wdt_is_early_warning()

Determines if the Watchdog timer Early Warning period has elapsed.

```
bool wdt_is_early_warning(void)
```

Determines if the Watchdog timer Early Warning period has elapsed.

Note If no early warning period was configured, the value returned by this function is invalid.

Returns Current Watchdog Early Warning state.

Function wdt_reset_count()

Resets the count of the running Watchdog Timer that was previously enabled.

```
void wdt_reset_count(void)
```

Resets the current count of the Watchdog Timer, restarting the timeout period count elapsed. This function should be called after the window period (if one was set in the module configuration) but before the timeout period to prevent a reset of the system.

21.6.3.3 Callback configuration and initialization

Function wdt_register_callback()

Registers an asynchronous callback function with the driver.

```
enum status_code wdt_register_callback(
  const wdt_callback_t callback,
```

```
  const enum wdt_callback type)
```

Registers an asynchronous callback with the WDT driver, fired when a given criteria (such as an Early Warning) is met. Callbacks are fired once for each event.

Table 21-6. Parameters

Data direction	Parameter name	Description
[in]	callback	Pointer to the callback function to register
[in]	type	Type of callback function to register

Returns Status of the registration operation.

Table 21-7. Return Values

Return value	Description
STATUS_OK	The callback was registered successfully.
STATUS_ERR_INVALID_ARG	If an invalid callback type was supplied.

Function wdt_unregister_callback()

Unregisters an asynchronous callback function with the driver.

```
enum status_code wdt_unregister_callback(
  const enum wdt_callback type)
```

Unregisters an asynchronous callback with the WDT driver, removing it from the internal callback registration table.

Table 21-8. Parameters

Data direction	Parameter name	Description
[in]	type	Type of callback function to unregister

Returns Status of the de-registration operation.

Table 21-9. Return Values

Return value	Description
STATUS_OK	The callback was Unregistered successfully.
STATUS_ERR_INVALID_ARG	If an invalid callback type was supplied.

21.6.3.4 Callback enabling and disabling

Function wdt_enable_callback()

Enables asynchronous callback generation for a given type.

```
enum status_code wdt_enable_callback(
  const enum wdt_callback type)
```

Enables asynchronous callbacks for a given callback type. This must be called before an external interrupt channel will generate callback events.

Table 21-10. Parameters

Data direction	Parameter name	Description
[in]	type	Type of callback function to enable

Returns Status of the callback enable operation.

Table 21-11. Return Values

Return value	Description
STATUS_OK	The callback was enabled successfully.
STATUS_ERR_INVALID_ARG	If an invalid callback type was supplied.

Function wdt_disable_callback()

Disables asynchronous callback generation for a given type.

```
enum status_code wdt_disable_callback(
  const enum wdt_callback type)
```

Disables asynchronous callbacks for a given callback type.

Table 21-12. Parameters

Data direction	Parameter name	Description
[in]	type	Type of callback function to disable

Returns Status of the callback disable operation.

Table 21-13. Return Values

Return value	Description
STATUS_OK	The callback was disabled successfully.
STATUS_ERR_INVALID_ARG	If an invalid callback type was supplied.

21.6.4 Enumeration Definitions

21.6.4.1 Callback configuration and initialization

Enum wdt_callback

Enum for the possible callback types for the WDT module.

Table 21-14. Members

Enum value	Description
WDT_CALLBACK_EARLY_WARNING	Callback type for when an early warning callback from the WDT module is issued.

21.6.4.2 Enum wdt_period

Enum for the possible period settings of the Watchdog timer module, for values requiring a period as a number of Watchdog timer clock ticks.

Table 21-15. Members

Enum value	Description
WDT_PERIOD_NONE	No Watchdog period. This value can only be used when setting the Window and Early Warning periods; its use as the Watchdog Reset Period is invalid.
WDT_PERIOD_8CLK	Watchdog period of 8 clocks of the Watchdog Timer Generic Clock.
WDT_PERIOD_16CLK	Watchdog period of 16 clocks of the Watchdog Timer Generic Clock.
WDT_PERIOD_32CLK	Watchdog period of 32 clocks of the Watchdog Timer Generic Clock.
WDT_PERIOD_64CLK	Watchdog period of 64 clocks of the Watchdog Timer Generic Clock.
WDT_PERIOD_128CLK	Watchdog period of 128 clocks of the Watchdog Timer Generic Clock.
WDT_PERIOD_256CLK	Watchdog period of 256 clocks of the Watchdog Timer Generic Clock.
WDT_PERIOD_512CLK	Watchdog period of 512 clocks of the Watchdog Timer Generic Clock.
WDT_PERIOD_1024CLK	Watchdog period of 1024 clocks of the Watchdog Timer Generic Clock.
WDT_PERIOD_2048CLK	Watchdog period of 2048 clocks of the Watchdog Timer Generic Clock.
WDT_PERIOD_4096CLK	Watchdog period of 4096 clocks of the Watchdog Timer Generic Clock.
WDT_PERIOD_8192CLK	Watchdog period of 8192 clocks of the Watchdog Timer Generic Clock.
WDT_PERIOD_16384CLK	Watchdog period of 16384 clocks of the Watchdog Timer Generic Clock.

21.7 Extra Information for WDT Driver

21.7.1 Acronyms

The table below presents the acronyms used in this module:

Acronym	Description
WDT	Watchdog Timer

21.7.2 Dependencies

This driver has the following dependencies:

- System Clock Driver

21.7.3 Errata

There are no errata related to this driver.

21.7.4 Module History

An overview of the module history is presented in the table below, with details on the enhancements and fixes made to the module since its first release. The current version of this corresponds to the newest version in the table.

Changelog
Add SAMD21 support and driver updated to follow driver type convention: • wdt_init, wdt_enable, wdt_disable functions removed • wdt_set_config function added • WDT module enable state moved inside the configuration struct
Initial Release

21.8 Examples for WDT Driver

This is a list of the available Quick Start guides (QSGs) and example applications for SAM D20/D21 Watchdog Driver (WDT). QSGs are simple examples with step-by-step instructions to configure and use this driver in a selection of use cases. Note that QSGs can be compiled as a standalone application or be added to the user application.

- Quick Start Guide for WDT - Basic
- Quick Start Guide for WDT - Callback

21.8.1 Quick Start Guide for WDT - Basic

In this use case, the Watchdog module is configured for:

- System reset after 2048 clocks of the Watchdog generic clock
- Always on mode disabled
- Basic mode, with no window or early warning periods

This use case sets up the Watchdog to force a system reset after every 2048 clocks of the Watchdog's Generic Clock channel, unless the user periodically resets the Watchdog counter via a button before the timer expires. If the watchdog resets the device, a LED on the board is turned off.

21.8.1.1 Setup

Prerequisites

There are no special setup requirements for this use-case.

Code

Copy-paste the following setup code to your user application:

```
void configure_wdt(void)
{
    /* Create a new configuration structure for the Watchdog settings and fill
     * with the default module settings. */
    struct wdt_conf config_wdt;
    wdt_get_config_defaults(&config_wdt);
```

```
    /* Set the Watchdog configuration settings */
    config_wdt.always_on      = false;
    config_wdt.clock_source   = GCLK_GENERATOR_4;
    config_wdt.timeout_period = WDT_PERIOD_2048CLK;

    /* Initialize and enable the Watchdog with the user settings */
    wdt_set_config(&config_wdt);
}
```

Add to user application initialization (typically the start of `main()`):

```
configure_wdt();
```

Workflow

1. Create a Watchdog module configuration struct, which can be filled out to adjust the configuration of the Watchdog.

   ```
   struct wdt_conf config_wdt;
   ```

2. Initialize the Watchdog configuration struct with the module's default values.

   ```
   wdt_get_config_defaults(&config_wdt);
   ```

Note This should always be performed before using the configuration struct to ensure that all values are initialized to known default settings.

3. Adjust the configuration struct to set the timeout period and lock mode of the Watchdog.

   ```
   config_wdt.always_on      = false;
   config_wdt.clock_source   = GCLK_GENERATOR_4;
   config_wdt.timeout_period = WDT_PERIOD_2048CLK;
   ```

4. Setups the WDT hardware module with the requested settings.

   ```
   wdt_set_config(&config_wdt);
   ```

21.8.1.2 Quick Start Guide for WDT - Basic

Code

Copy-paste the following code to your user application:

```
enum system_reset_cause reset_cause = system_get_reset_cause();

if (reset_cause == SYSTEM_RESET_CAUSE_WDT) {
    port_pin_set_output_level(LED_0_PIN, LED_0_INACTIVE);
}
else {
    port_pin_set_output_level(LED_0_PIN, LED_0_ACTIVE);
}

while (true) {
```

```
    if (port_pin_get_input_level(BUTTON_0_PIN) == false) {
        port_pin_set_output_level(LED_0_PIN, LED_0_ACTIVE);

        wdt_reset_count();
    }
}
```

Workflow

1. Retrieve the cause of the system reset to determine if the watchdog module was the cause of the last reset.

```
enum system_reset_cause reset_cause = system_get_reset_cause();
```

2. Turn on or off the board LED based on whether the watchdog reset the device.

```
if (reset_cause == SYSTEM_RESET_CAUSE_WDT) {
    port_pin_set_output_level(LED_0_PIN, LED_0_INACTIVE);
}
else {
    port_pin_set_output_level(LED_0_PIN, LED_0_ACTIVE);
}
```

3. Enter an infinite loop to hold the main program logic.

```
while (true) {
```

4. Test to see if the board button is currently being pressed.

```
if (port_pin_get_input_level(BUTTON_0_PIN) == false) {
```

5. If the button is pressed, turn on the board LED and reset the Watchdog timer.

```
port_pin_set_output_level(LED_0_PIN, LED_0_ACTIVE);

wdt_reset_count();
```

21.8.2 Quick Start Guide for WDT - Callback

In this use case, the Watchdog module is configured for:

- System reset after 4096 clocks of the Watchdog generic clock
- Always on mode disabled
- Early warning period of 2048 clocks of the Watchdog generic clock

This use case sets up the Watchdog to force a system reset after every 4096 clocks of the Watchdog's Generic Clock channel, with an Early Warning callback being generated every 2048 clocks. Each time the Early Warning interrupt fires the board LED is turned on, and each time the device resets the board LED is turned off, giving a periodic flashing pattern.

21.8.2.1 Setup

Prerequisites

There are no special setup requirements for this use-case.

Code

Copy-paste the following setup code to your user application:

```
void watchdog_early_warning_callback(void)
{
    port_pin_set_output_level(LED_0_PIN, LED_0_ACTIVE);
}

void configure_wdt(void)
{
    /* Create a new configuration structure for the Watchdog settings and fill
     * with the default module settings. */
    struct wdt_conf config_wdt;
    wdt_get_config_defaults(&config_wdt);

    /* Set the Watchdog configuration settings */
    config_wdt.always_on            = false;
    config_wdt.clock_source         = GCLK_GENERATOR_4;
    config_wdt.timeout_period       = WDT_PERIOD_4096CLK;
    config_wdt.early_warning_period = WDT_PERIOD_2048CLK;

    /* Initialize and enable the Watchdog with the user settings */
    wdt_set_config(&config_wdt);
}

void configure_wdt_callbacks(void)
{
    wdt_register_callback(watchdog_early_warning_callback,
        WDT_CALLBACK_EARLY_WARNING);

    wdt_enable_callback(WDT_CALLBACK_EARLY_WARNING);
}
```

Add to user application initialization (typically the start of `main()`):

```
configure_wdt();
configure_wdt_callbacks();
```

Workflow

1. Configure and enable the Watchdog driver

    a. Create a Watchdog module configuration struct, which can be filled out to adjust the configuration of the Watchdog.

    ```
    struct wdt_conf config_wdt;
    ```

    b. Initialize the Watchdog configuration struct with the module's default values.

    ```
    wdt_get_config_defaults(&config_wdt);
    ```

Note This should always be performed before using the configuration struct to ensure that all values are initialized to known default settings.

    c. Adjust the configuration struct to set the timeout and early warning periods of the Watchdog.

```
config_wdt.always_on            = false;
config_wdt.clock_source         = GCLK_GENERATOR_4;
config_wdt.timeout_period       = WDT_PERIOD_4096CLK;
config_wdt.early_warning_period = WDT_PERIOD_2048CLK;
```

d. Sets up the WDT hardware module with the requested settings.

```
wdt_set_config(&config_wdt);
```

2. Register and enable the Early Warning callback handler

a. Register the user-provided Early Warning callback function with the driver, so that it will be run when an Early Warning condition occurs.

```
wdt_register_callback(watchdog_early_warning_callback,
    WDT_CALLBACK_EARLY_WARNING);
```

b. Enable the Early Warning callback so that it will generate callbacks.

```
wdt_enable_callback(WDT_CALLBACK_EARLY_WARNING);
```

21.8.2.2 Quick Start Guide for WDT - Callback

Code

Copy-paste the following code to your user application:

```
port_pin_set_output_level(LED_0_PIN, LED_0_INACTIVE);

system_interrupt_enable_global();

while (true) {
    /* Wait for callback */
}
```

Workflow

1. Turn off the board LED when the application starts.

```
port_pin_set_output_level(LED_0_PIN, LED_0_INACTIVE);
```

2. Enable global interrupts so that callbacks can be generated.

```
system_interrupt_enable_global();
```

3. Enter an infinite loop to hold the main program logic.

```
while (true) {
    /* Wait for callback */
}
```

22. SAM D21 Direct Memory Access Controller Driver (DMAC)

This driver for SAM D21 devices provides an interface for the configuration and management of the Direct Memory Access Controller(DMAC) module within the device. The DMAC can transfer data between memories and peripherals, and thus off-load these tasks from the CPU. The module supports peripheral to peripheral, peripheral to memory, memory to peripheral and memory to memory transfers.

The following peripherals are used by the DMAC Driver:

- DMAC (Direct Memory Access Controller)

The outline of this documentation is as follows:

- Prerequisites
- Module Overview
- Special Considerations
- Extra Information
- Examples
- API Overview

22.1 Prerequisites

There are no prerequisites for this module.

22.2 Module Overview

SAM D21 devices with DMAC enables high data transfer rates with minimum CPU intervention and frees up CPU time. With access to all peripherals, the DMAC can handle automatic transfer of data to/from modules. It supports static and incremental addressing for both source and destination.

The DMAC when used with Event System or peripheral triggers, provides a considerable advantage by reducing the power consumption and performing data transfer in the background. For example if the ADC is configured to generate an event, it can trigger the DMAC to transfer the data into another peripheral or into SRAM. The CPU can remain in sleep during this time to reduce power consumption.

The DMAC module has 12 channels. The DMA channel operation can be suspended at any time by software, by events from event system, or after selectable descriptor execution. The operation can be resumed by software or by events from event system. The DMAC driver for SAM D21 supports four types of transfers such as peripheral to peripheral, peripheral to memory, memory to peripheral and memory to memory.

The basic transfer unit is a beat which is defined as a single bus access. There can be multiple beats in a single block transfer and multiple block transfers in a DMA transaction. DMA transfer is based on descriptors, which holds transfer properties such as the source and destination addresses, transfer counter and other additional transfer control information. The descriptors can be static or linked. When static, a single block transfer is performed. When linked, a number of transfer descriptors can be used to enable multiple block transfers within a single DMA transaction.

The implementation of the DMA driver is based on the idea that DMA channel is a finite resource of entities with the same abilities. A DMA channel resource is able to move a defined set of data from a source address to destination address triggered by a transfer trigger. On the SAM D21 devices there are 12 DMA resources available for allocation. Each of these DMA resources can trigger interrupt callback routines and peripheral events. The other main features are

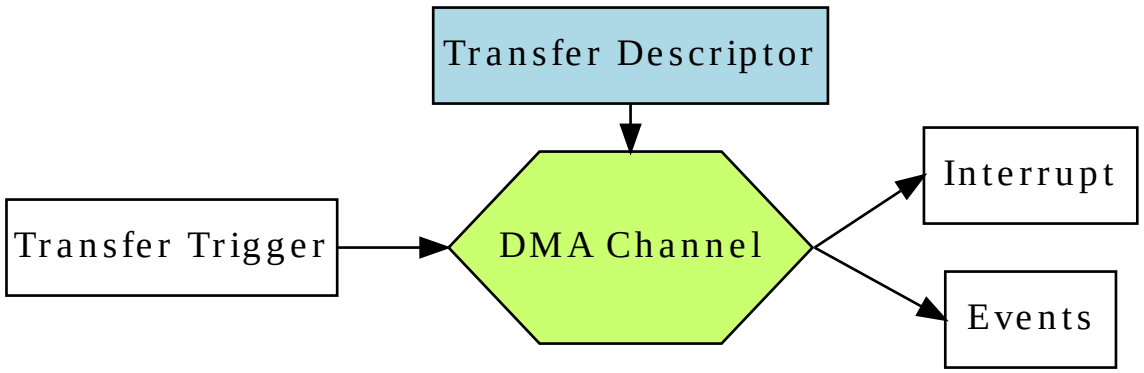
- Selectable transfer trigger source
    - Software

- Event System
- Peripheral

- Event input and output is supported for the 4 lower channels
- 4 level channel priority
- Optional interrupt generation on transfer complete, channel error or channel suspend
- Supports multi-buffer or circular buffer mode by linking multiple descriptors
- Beat size configurable as 8-bit, 16-bit or 32-bit

A simplified block diagram of the DMA Resource can be seen in Figure 22-1: Module Overview on page 509.

Figure 22-1. Module Overview



22.2.1 Terminology Used in DMAC Transfers

Name	Description
Beat	It is a single bus access by the DMAC. Configurable as 8-bit, 16-bit or 32-bit
Burst	It is a transfer of n-beats (n=1,4,8,16). For the DMAC module in SAM D21, the burst size is one beat. Arbitration takes place each time a burst transfer is completed
Block transfer	A single block transfer is a configurable number of (1 to 64k) beat transfers

22.2.2 DMA Channels

The DMAC in each device consists of several DMA channels, which along with the transfer descriptors defines the data transfer properties.

- The transfer control descriptor defines the source and destination addresses, source and destination address increment settings, the block transfer count and event output condition selection.
- Dedicated channel registers control the peripheral trigger source, trigger mode settings, event input actions and channel priority level settings.

With a successful DMA resource allocation, a dedicated DMA channel will be assigned. The channel will be occupied until the DMA resource is freed. A DMA resource handle is used to identify the specific DMA resource. When there are multiple channels with active requests, the arbiter prioritizes the channels requesting access to the bus.

22.2.3 DMA Triggers

DMA transfer can be started only when a DMA transfer request is acknowledged/granted by the arbiter. A transfer request can be triggered from software, peripheral or an event. There are dedicated source trigger selections for each DMA channel usage.

22.2.4 DMA Transfer Descriptor

The transfer descriptor resides in the SRAM and defines these channel properties.

Field Name	Field Width
Descriptor Next Address	32 Bits
Destination Address	32 Bits
Source Address	32 Bits
Block Transfer Counter	16 Bits
Block Transfer Control	16 Bits

Before starting a transfer, at least one descriptor should be configured. After a successful allocation of a DMA channel, the transfer descriptor can be added with a call to dma_add_descriptor(). If there is a transfer descriptor already allocated to the DMA resource, the descriptor will be linked to the next descriptor address.

22.2.5 DMA Interrupts/Events

Both an interrupt callback and an peripheral event can be triggered by the DMA transfer. Three types of callbacks are supported by the DMA driver: transfer complete, channel suspend and transfer error. Each of these callback types can be registered and enabled for each channel independently through the DMA driver API.

The DMAC module can also generate events on transfer complete. Event generation is enabled through the DMA channel, event channel configuration and event user multiplexing is done through the events driver.

The DMAC can generate events in the below cases:

- When a block transfer is complete
- When each beat transfer within a block transfer is complete

22.3 Special Considerations

There are no special considerations for this module.

22.4 Extra Information

For extra information see Extra Information for DMAC Driver. This includes:

- Acronyms
- Dependencies
- Errata
- Module History

22.5 Examples

For a list of examples related to this driver, see Examples for DMAC Driver.

22.6 API Overview

22.6.1 Variable and Type Definitions

22.6.1.1 Type dma_callback_t

```
typedef void(* dma_callback_t )(const struct dma_resource *const resource)
```

Type definition for a DMA resource callback function

22.6.1.2 Variable descriptor_section

```
DmacDescriptor descriptor_section
```

ExInitial description section

22.6.2 Structure Definitions

22.6.2.1 Struct dma_descriptor_config

DMA transfer descriptor configuration. When the source or destination address increment is enabled, the addresses stored into the configuration structure must correspond to the end of the transfer.

Table 22-1. Members

Type	Name	Description
enum dma_beat_size	beat_size	Beat size is configurable as 8-bit, 16-bit or 32-bit
enum dma_block_action	block_action	Action taken when a block transfer is completed
uint16_t	block_transfer_count	It is the number of beats in a block. This count value is decremented by one after each beat data transfer
bool	descriptor_valid	Descriptor valid flag used to identify whether a descriptor is valid or not
uint32_t	destination_address	Transfer destination address
bool	dst_increment_enable	Used for enabling the destination address increment
enum dma_event_output_selection	event_output_selection	This is used to generate an event on specific transfer action in a channel. Supported only in four lower channels
uint32_t	next_descriptor_address	Set to zero for static descriptors. This must have a valid memory address for linked descriptors
uint32_t	source_address	Transfer source address
bool	src_increment_enable	Used for enabling the source address increment
enum dma_step_selection	step_selection	This bit selects whether the source or destination address is using the step size settings
enum dma_address_increment_stepsize	step_size	The step size for source/ destination address increment. The next address is calculated as

Type	Name	Description
		next_addr = addr + (2^step_size * beat size)

22.6.2.2 Struct dma_events_config

Configurations for DMA events

Table 22-2. Members

Type	Name	Description
bool	event_output_enable	Enable DMA event output
enum dma_event_input_action	input_action	Event input actions

22.6.2.3 Struct dma_resource

Structure for DMA transfer resource

Table 22-3. Members

Type	Name	Description
dma_callback_t	callback[]	Array of callback functions for DMA transfer job
uint8_t	callback_enable	Bit mask for enabled callbacks
uint8_t	channel_id	Allocated DMA channel ID
DmacDescriptor *	descriptor	DMA transfer descriptor
enum status_code	job_status	Status of the last job
uint32_t	transfered_size	Transferred data size

22.6.2.4 Struct dma_resource_config

DMA configurations for transfer

Table 22-4. Members

Type	Name	Description
struct dma_events_config	event_config	DMA events configurations
uint8_t	peripheral_trigger	DMA peripheral trigger index
enum dma_priority_level	priority	DMA transfer priority
enum dma_transfer_trigger_action	trigger_action	DMA trigger action

22.6.3 Macro Definitions

22.6.3.1 Macro DMA_INVALID_CHANNEL

```
#define DMA_INVALID_CHANNEL 0xff
```

DMA invalid channel number

22.6.4 Function Definitions

22.6.4.1 Function dma_abort_job()

Abort a DMA transfer.

```
void dma_abort_job(
  struct dma_resource * resource)
```

This function will abort a DMA transfer. The DMA channel used for the DMA resource will be disabled. The block transfer count will be also calculated and written to the DMA resource structure.

Note The DMA resource will not be freed after calling this function. The function dma_free() can be used to free an allocated resource.

Table 22-5. Parameters

Data direction	Parameter name	Description
[in, out]	resource	Pointer to the DMA resource

22.6.4.2 Function dma_add_descriptor()

Add a DMA transfer descriptor to a DMA resource.

```
enum status_code dma_add_descriptor(
  struct dma_resource * resource,
  DmacDescriptor * descriptor)
```

This function will add a DMA transfer descriptor to a DMA resource. If there was a transfer descriptor already allocated to the DMA resource, the descriptor will be linked to the next descriptor address.

Table 22-6. Parameters

Data direction	Parameter name	Description
[in]	resource	Pointer to the DMA resource
[in]	descriptor	Pointer to the transfer descriptor

Table 22-7. Return Values

Return value	Description
STATUS_OK	The descriptor is added to the DMA resource
STATUS_BUSY	The DMA resource was busy and the descriptor is not added

22.6.4.3 Function dma_allocate()

Allocate a DMA with configurations.

```
enum status_code dma_allocate(
  struct dma_resource * resource,
```

```
  struct dma_resource_config * config)
```

This function will allocate a proper channel for a DMA transfer request.

Table 22-8. Parameters

Data direction	Parameter name	Description
[in, out]	dma_resource	Pointer to a DMA resource instance
[in]	transfer_config	Configurations of the DMA transfer

Returns Status of the allocation procedure.

Table 22-9. Return Values

Return value	Description
STATUS_OK	The DMA resource was allocated successfully
STATUS_ERR_NOT_FOUND	DMA resource allocation failed

22.6.4.4 Function dma_descriptor_create()

Create a DMA transfer descriptor with configurations.

```
void dma_descriptor_create(
  DmacDescriptor * descriptor,
  struct dma_descriptor_config * config)
```

This function will set the transfer configurations to the DMA transfer descriptor.

Table 22-10. Parameters

Data direction	Parameter name	Description
[in]	descriptor	Pointer to the DMA transfer descriptor
[in]	config	Pointer to the descriptor configuration structure

22.6.4.5 Function dma_descriptor_get_config_defaults()

Initializes DMA transfer configuration with predefined default values.

```
void dma_descriptor_get_config_defaults(
  struct dma_descriptor_config * config)
```

This function will initialize a given DMA descriptor configuration structure to a set of known default values. This function should be called on any new instance of the configuration structure before being modified by the user application.

The default configuration is as follows:

- Set the descriptor as valid
- Disable event output

- No block action
- Set beat size as byte
- Enable source increment
- Enable destination increment
- Step size is applied to the destination address
- Address increment is beat size multiplied by 1
- Default transfer size is set to 0
- Default source address is set to NULL
- Default destination address is set to NULL
- Default next descriptor not available

Table 22-11. Parameters

Data direction	Parameter name	Description
[out]	config	Pointer to the configuration

22.6.4.6 Function dma_disable_callback()

Disable a callback function for a dedicated DMA resource.

```
void dma_disable_callback(
  struct dma_resource * resource,
  enum dma_callback_type type)
```

Table 22-12. Parameters

Data direction	Parameter name	Description
[in]	resource	Pointer to the DMA resource
[in]	type	Callback function type

22.6.4.7 Function dma_enable_callback()

Enable a callback function for a dedicated DMA resource.

```
void dma_enable_callback(
  struct dma_resource * resource,
  enum dma_callback_type type)
```

Table 22-13. Parameters

Data direction	Parameter name	Description
[in]	resource	Pointer to the DMA resource
[in]	type	Callback function type

22.6.4.8 Function dma_free()

Free an allocated DMA resource.

```
enum status_code dma_free(
  struct dma_resource * resource)
```

This function will free an allocated DMA resource.

Table 22-14. Parameters

Data direction	Parameter name	Description
[in, out]	resource	Pointer to the DMA resource

Returns Status of the free procedure.

Table 22-15. Return Values

Return value	Description
STATUS_OK	The DMA resource was freed successfully
STATUS_BUSY	The DMA resource was busy and can't be freed
STATUS_ERR_NOT_INITIALIZED	DMA resource was not initialized

22.6.4.9 Function dma_get_config_defaults()

Initializes config with predefined default values.

```
void dma_get_config_defaults(
  struct dma_resource_config * config)
```

This function will initialize a given DMA configuration structure to a set of known default values. This function should be called on any new instance of the configuration structure before being modified by the user application.

The default configuration is as follows:

- Software trigger is used as the transfer trigger
- Priority level 0
- Only software/event trigger
- Requires a trigger for each transaction
- No event input /output

Table 22-16. Parameters

Data direction	Parameter name	Description
[out]	config	Pointer to the configuration

22.6.4.10 Function dma_get_job_status()

Get DMA resource status.

```
enum status_code dma_get_job_status(
```

```
  struct dma_resource * resource)
```

Table 22-17. Parameters

Data direction	Parameter name	Description
[in]	resource	Pointer to the DMA resource

Returns Status of the DMA resource.

22.6.4.11 Function dma_is_busy()

Check if the given DMA resource is busy.

```
bool dma_is_busy(
  struct dma_resource * resource)
```

Table 22-18. Parameters

Data direction	Parameter name	Description
[in]	resource	Pointer to the DMA resource

Returns Status which indicates whether the DMA resource is busy.

Table 22-19. Return Values

Return value	Description
true	The DMA resource has an on-going transfer
false	The DMA resource is not busy

22.6.4.12 Function dma_register_callback()

Register a callback function for a dedicated DMA resource.

```
void dma_register_callback(
  struct dma_resource * resource,
  dma_callback_t callback,
  enum dma_callback_type type)
```

There are three type of callback functions, which can be registered

- Callback for transfer complete
- Callback for transfer error
- Callback for channel suspend

Table 22-20. Parameters

Data direction	Parameter name	Description
[in]	resource	Pointer to the DMA resource

Data direction	Parameter name	Description
[in]	callback	Pointer to the callback function
[in]	type	Callback function type

22.6.4.13 Function dma_reset_descriptor()

Reset DMA descriptor.

```
void dma_reset_descriptor(
  struct dma_resource * resource)
```

This function will clear the DESCADDR register of an allocated DMA resource.

22.6.4.14 Function dma_resume_job()

Resume a suspended DMA transfer.

```
void dma_resume_job(
  struct dma_resource * resource)
```

This function try to resume a suspended transfer of a DMA resource.

Table 22-21. Parameters

Data direction	Parameter name	Description
[in]	resource	Pointer to the DMA resource

22.6.4.15 Function dma_start_transfer_job()

Start a DMA transfer.

```
enum status_code dma_start_transfer_job(
  struct dma_resource * resource)
```

This function will start a DMA transfer through an allocated DMA resource.

Table 22-22. Parameters

Data direction	Parameter name	Description
[in, out]	resource	Pointer to the DMA resource

Returns Status of the transfer start procedure

Table 22-23. Return Values

Return value	Description
STATUS_OK	The transfer was started successfully
STATUS_BUSY	The DMA resource was busy and the transfer was not started

Return value	Description
STATUS_ERR_INVALID_ARG	Transfer size is 0 and transfer was not started

22.6.4.16 Function dma_suspend_job()

Suspend a DMA transfer.

```
void dma_suspend_job(
  struct dma_resource * resource)
```

This function will request to suspend the transfer of the DMA resource. The channel is kept enabled, can receive transfer triggers (the transfer pending bit will be set), but will be removed from the arbitration scheme. The channel operation can be resumed by calling dma_resume_job().

Note This function sets the command to suspend the DMA channel associated with a DMA resource. The channel suspend interrupt flag indicates whether the transfer is truly suspended.

Table 22-24. Parameters

Data direction	Parameter name	Description
[in]	resource	Pointer to the DMA resource

22.6.4.17 Function dma_trigger_transfer()

Will set a software trigger for resource.

```
void dma_trigger_transfer(
  struct dma_resource * resource)
```

This function is used to set a software trigger on the DMA channel associated with resource. If a trigger is already pending no new trigger will be generated for the channel.

Table 22-25. Parameters

Data direction	Parameter name	Description
[in]	resource	Pointer to the DMA resource

22.6.4.18 Function dma_unregister_callback()

Unregister a callback function for a dedicated DMA resource.

```
void dma_unregister_callback(
  struct dma_resource * resource,
  enum dma_callback_type type)
```

There are three type of callback functions,

- Callback for transfer complete
- Callback for transfer error

- Callback for channel suspend

The application can unregister any of the callback functions which are already registered and are no longer needed.

Table 22-26. Parameters

Data direction	Parameter name	Description
[in]	resource	Pointer to the DMA resource
[in]	type	Callback function type

22.6.4.19 Function dma_update_descriptor()

Update DMA descriptor.

```
void dma_update_descriptor(
  struct dma_resource * resource,
  DmacDescriptor * descriptor)
```

This function can update the descriptor of an allocated DMA resource.

22.6.5 Enumeration Definitions

22.6.5.1 Enum dma_address_increment_stepsize

Address increment step size. These bits select the address increment step size. The setting apply to source or destination address, depending on STEPSEL setting.

Table 22-27. Members

Enum value	Description
DMA_ADDRESS_INCREMENT_STEP_SIZE_1	The address is incremented by (beat size * 1)
DMA_ADDRESS_INCREMENT_STEP_SIZE_2	The address is incremented by (beat size * 2)
DMA_ADDRESS_INCREMENT_STEP_SIZE_4	The address is incremented by (beat size * 4)
DMA_ADDRESS_INCREMENT_STEP_SIZE_8	The address is incremented by (beat size * 8)
DMA_ADDRESS_INCREMENT_STEP_SIZE_16	The address is incremented by (beat size * 16)
DMA_ADDRESS_INCREMENT_STEP_SIZE_32	The address is incremented by (beat size * 32)
DMA_ADDRESS_INCREMENT_STEP_SIZE_64	The address is incremented by (beat size * 64)
DMA_ADDRESS_INCREMENT_STEP_SIZE_128	The address is incremented by (beat size * 128)

22.6.5.2 Enum dma_beat_size

The basic transfer unit in DMAC is a beat, which is defined as a single bus access. Its size is configurable and applies to both read and write

Table 22-28. Members

Enum value	Description
DMA_BEAT_SIZE_BYTE	8-bit access
DMA_BEAT_SIZE_HWORD	16-bit access
DMA_BEAT_SIZE_WORD	32-bit access

22.6.5.3 Enum dma_block_action

Block action definitions.

Table 22-29. Members

Enum value	Description
DMA_BLOCK_ACTION_NOACT	No action
DMA_BLOCK_ACTION_INT	Channel in normal operation and sets transfer complete interrupt flag after block transfer
DMA_BLOCK_ACTION_SUSPEND	Trigger channel suspend after block transfer and sets channel suspend interrupt flag once the channel is suspended
DMA_BLOCK_ACTION_BOTH	Sets transfer complete interrupt flag after a block transfer and trigger channel suspend. The channel suspend interrupt flag will be set once the channel is suspended

22.6.5.4 Enum dma_callback_type

Callback types for DMA callback driver.

Table 22-30. Members

Enum value	Description
DMA_CALLBACK_TRANSFER_DONE	Callback for transfer complete
DMA_CALLBACK_TRANSFER_ERROR	Callback for any of transfer errors. A transfer error is flagged if a bus error is detected during an AHB access or when the DMAC fetches an invalid descriptor
DMA_CALLBACK_CHANNEL_SUSPEND	Callback for channel suspend
DMA_CALLBACK_N	Number of available callbacks

22.6.5.5 Enum dma_event_input_action

DMA input actions.

Table 22-31. Members

Enum value	Description
DMA_EVENT_INPUT_NOACT	No action
DMA_EVENT_INPUT_TRIG	Normal transfer and periodic transfer trigger
DMA_EVENT_INPUT_CTRIG	Conditional transfer trigger
DMA_EVENT_INPUT_CBLOCK	Conditional block transfer
DMA_EVENT_INPUT_SUSPEND	Channel suspend operation
DMA_EVENT_INPUT_RESUME	Channel resume operation
DMA_EVENT_INPUT_SSKIP	Skip next block suspend action

22.6.5.6 Enum dma_event_output_selection

Event output selection.

Table 22-32. Members

Enum value	Description
DMA_EVENT_OUTPUT_DISABLE	Event generation disable
DMA_EVENT_OUTPUT_BLOCK	Event strobe when block transfer complete
DMA_EVENT_OUTPUT_RESERVED	Event output reserved
DMA_EVENT_OUTPUT_BEAT	Event strobe when beat transfer complete

22.6.5.7 Enum dma_priority_level

DMA priority level

Table 22-33. Members

Enum value	Description
DMA_PRIORITY_LEVEL_0	Priority level 0
DMA_PRIORITY_LEVEL_1	Priority level 1
DMA_PRIORITY_LEVEL_2	Priority level 2
DMA_PRIORITY_LEVEL_3	Priority level 3

22.6.5.8 Enum dma_step_selection

DMA step selection. This bit determines whether the step size setting is applied to source or destination address

Table 22-34. Members

Enum value	Description
DMA_STEPSEL_DST	Step size settings apply to the destination address
DMA_STEPSEL_SRC	Step size settings apply to the source address

22.6.5.9 Enum dma_transfer_trigger_action

DMA trigger action type.

Table 22-35. Members

Enum value	Description
DMA_TRIGGER_ACTON_BLOCK	Perform a block transfer when triggered
DMA_TRIGGER_ACTON_BEAT	Perform a beat transfer when triggered
DMA_TRIGGER_ACTON_TRANSACTION	Perform a transaction when triggered

22.7 Extra Information for DMAC Driver

22.7.1 Acronyms

Below is a table listing the acronyms used in this module, along with their intended meanings.

Acronym	Description
DMA	Direct Memory Access
DMAC	Direct Memory Access Controller
CPU	Central Processing Unit

22.7.2 Dependencies

This driver has the following dependencies:

- System Clock Driver

22.7.3 Errata

There are no errata related to this driver.

22.7.4 Module History

An overview of the module history is presented in the table below, with details on the enhancements and fixes made to the module since its first release. The current version of this corresponds to the newest version in the table.

Changelog
Initial Release

22.8 Examples for DMAC Driver

This is a list of the available Quick Start Guides (QSGs) and example applications for SAM D21 Direct Memory Access Controller Driver (DMAC). QSGs are simple examples with step-by-step instructions to configure and use this driver in a selection of use cases. Note that QSGs can be compiled as a standalone application or be added to the user application.

- Quick Start Guide for Memory to Memory

Note More DMA usage examples are available in peripheral QSGs. A quick start guide for TC/TCC shows the usage of DMA event trigger; SERCOM SPI/USART/I2C has example for DMA transfer from peripheral to memory or from memory to peripheral; ADC/DAC shows peripheral to peripheral transfer.

22.8.1 Quick Start Guide for Memory to Memory

data transfer using DMAC

The supported device list:

- SAMD21

In this use case, the DMAC is configured for:

- Moving data from memory to memory
- Using software trigger
- Using DMA priority level 0
- Transaction as DMA trigger action
- No action on input events

- Output event not enabled

22.8.1.1 Setup

Prerequisites

There are no special setup requirements for this use-case.

Code

Copy-paste the following setup code to your user application:

```
#define DATA_LENGTH (1024)

static uint8_t source_memory[DATA_LENGTH];

static uint8_t destination_memory[DATA_LENGTH];

static volatile bool transfer_is_done = false;

COMPILER_ALIGNED(16)
DmacDescriptor example_descriptor;

static void transfer_done( const struct dma_resource* const resource )
{
    transfer_is_done = true;
}

static void configure_dma_resource(struct dma_resource *resource)
{
    struct dma_resource_config config;

    dma_get_config_defaults(&config);

    dma_allocate(resource, &config);
}

static void setup_transfer_descriptor(DmacDescriptor *descriptor )
{
    struct dma_descriptor_config descriptor_config;

    dma_descriptor_get_config_defaults(&descriptor_config);

    descriptor_config.block_transfer_count = sizeof(source_memory);
    descriptor_config.source_address = (uint32_t)source_memory +
        sizeof(source_memory);
    descriptor_config.destination_address = (uint32_t)destination_memory +
        sizeof(source_memory);

    dma_descriptor_create(descriptor, &descriptor_config);
}
```

Add the below section to user application initialization (typically the start of `main()`):

```
configure_dma_resource(&example_resource);

setup_transfer_descriptor(&example_descriptor);

dma_add_descriptor(&example_resource, &example_descriptor);
```

```
dma_register_callback(&example_resource, transfer_done,
        DMA_CALLBACK_TRANSFER_DONE);

dma_enable_callback(&example_resource, DMA_CALLBACK_TRANSFER_DONE);

for (uint32_t i = 0; i < DATA_LENGTH; i++) {
    source_memory[i] = i;
}
```

Workflow

1. Create a DMA resource configuration structure, which can be filled out to adjust the configuration of a single DMA transfer.

```
struct dma_resource_config config;
```

2. Initialize the DMA resource configuration struct with the module's default values.

```
dma_get_config_defaults(&config);
```

Note This should always be performed before using the configuration struct to ensure that all values are initialized to known default settings.

3. Allocate a DMA resource with the configurations.

```
dma_allocate(resource, &config);
```

4. Declare a DMA transfer descriptor configuration structure, which can be filled out to adjust the configuration of a single DMA transfer.

```
struct dma_descriptor_config descriptor_config;
```

5. Initialize the DMA transfer descriptor configuration struct with the module's default values.

```
dma_descriptor_get_config_defaults(&descriptor_config);
```

Note This should always be performed before using the configuration struct to ensure that all values are initialized to known default settings.

6. Set the specific parameters for a DMA transfer with transfer size, source address, destination address. In this example, we have enabled the source and destination address increment. The source and destination addresses to be stored into descriptor_config must correspond to the end of the transfer.

```
descriptor_config.block_transfer_count = sizeof(source_memory);
descriptor_config.source_address = (uint32_t)source_memory +
    sizeof(source_memory);
descriptor_config.destination_address = (uint32_t)destination_memory +
    sizeof(source_memory);
```

7. Create the DMA transfer descriptor.

```
dma_descriptor_create(descriptor, &descriptor_config);
```

8. Add the DMA transfer descriptor to the allocated DMA resource.

```
dma_add_descriptor(&example_resource, &example_descriptor);
```

9. Register a callback to indicate transfer status.

```
dma_register_callback(&example_resource, transfer_done,
        DMA_CALLBACK_TRANSFER_DONE);
```

10. Set the transfer done flag in the registered callback function.

```
static void transfer_done( const struct dma_resource* const resource )
{
    transfer_is_done = true;
}
```

11. Enable the registered callbacks.

```
dma_enable_callback(&example_resource, DMA_CALLBACK_TRANSFER_DONE);
```

22.8.1.2 Use Case

Code

Add the following code at the start of `main()`

```
struct dma_resource example_resource;
```

Copy the following code to your user application:

```
dma_start_transfer_job(&example_resource);

dma_trigger_transfer(&example_resource);

while (!transfer_is_done) {
    /* Wait for transfer done */
}

while (true) {
    /* Nothing to do */
}
```

Workflow

1. Start the DMA transfer job with the allocated DMA resource and transfer descriptor.

```
dma_start_transfer_job(&example_resource);
```

2. Set the software trigger for the DMA channel. This can be done before or after the DMA job is started. Note that all transfers needs a trigger to start.

```
dma_trigger_transfer(&example_resource);
```

3. Waiting for the setting of the transfer done flag.

```
while (!transfer_is_done) {
    /* Wait for transfer done */
}
```

23. SAM D21 Inter-IC Sound Controller Driver (I2S)

This driver for SAM D21 devices provides an interface for the configuration and management of the device's Inter-IC Sound Controller functionality.

The following driver API modes are covered by this manual:

- Polled APIs
- Callback APIs

The following peripherals are used by this module:

- I2S (Inter-IC Sound Controller)

The outline of this documentation is as follows:

23.1 Prerequisites

There are no prerequisites for this module.

23.2 Module Overview

The I2S provides bidirectional, synchronous, digital audio link with external audio devices through these signal pins:

- Serial Data (SDm)
- Frame Sync (FSn)
- Serial Clock (SCKn)
- Master Clock (MCKn)

The I2S consists of 2 Clock Units and 2 Serializers, which can be separately configured and enabled, to provide varies functionalities as follow:

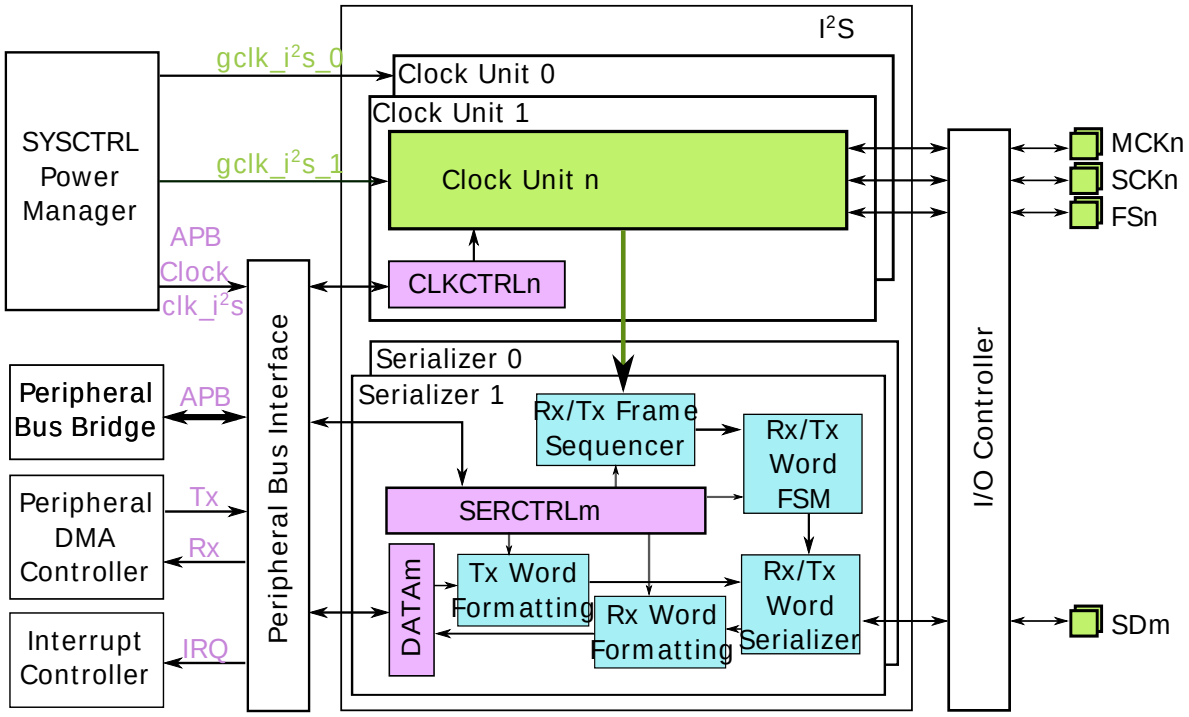
- Communicate to Audio CODECs as Master or Slave, or provides clock and frame sync signals as Controller
- Communicate to DAC or ADC through dedicated I2S serial interface
- Communicate to multi-slot or multiple stereo DACs or ADCs, via Time Division Multiplexed (TDM) format
- Reading mono or stereo MEMS microphones, using the Pulse Density Modulation (PDM) interface

The I2S supports compact stereo data word, where left channel data bits are in lower half and right channel data bits are in upper half. It reduces the number of data words for stereo audio data and the DMA bandwidth.

In master mode, the frame is configured by number of slots and slot size, and allows range covering 16fs to 1024fs MCK, to provide oversampling clock to an external audio CODEC or digital signal processor (DSP).

A block diagram of the I2S can be seen in Figure 23-1: I2S Block Diagram on page 529.

Figure 23-1. I2S Block Diagram



This driver for I2S module provides an interface to

- initialize and control I2S module
- configure and control the I2S Clock Unit and Serializer
- transmit/receive data through I2S Serializer

23.2.1 Clocks

To use I2S module, the I2S bus interface clock (clk_i2s) must be enabled via Power Manager.

For each I2S Clock Unit, a generic clock (gclk_i2s_n) is connnected. When I2S works in master mode the generic clock is used. It should be prepared before clock unit is used. In master mode the input generic clock will be used as MCK for SCKn and FSn generation, in addition, the MCK could be devided and output to I2S MCKn pin, as oversampling clock to external audio device.

The I2S Serializer uses clock and control signal from Clock Unit to handle transfer. Select different clock unit with different configurations allows the I2S to work as master or slave, to work on non-related clocks.

When using the driver with ASF, enabling the register interface is normally done by the `init` function. The gclk source for the asynchronous domain is normally configured and set through the _configuration struct_ / _init_ function. If gclk source != 0 is used, this source has to be configured and enabled through invoking the system_gclk driver function when needed, or modifying conf_clock.h to enable it at the beginning.

23.2.2 Audio Frame Generation

Audio sample data for all channels are sent in frames, one frame can consist 1 - 8 slots where each slot can be configured to a size 8-bit, 16-bit, 24-bit or 32-bit. The audio frame synch clock is generated by the I2S Clock unit in the master/controller mode. The frame rate (or frame sync frequency) is calculated as follow:

FS = SCK / number_of_slots / number_of_bits_in_slot

The serial clock (SCK) source is either an external source (slave mode) or generated by the I2S clock unit (controller or master mode) using the MCK as source.

SCK = MCK / sck_div

Note SCK generation division value is MCKDIV in register.

MCK is either an external source or generated using the gclk input from a generic clock generator.

23.2.3 Master, Controller and Slave modes

The i2s module has three modes: master, controller and slave.

23.2.3.1 Master

In master mode the module will control the data flow on the i2s bus and can be responsible for clock generation. The Serializers are enabled and will transmit/receive data. On a bus with only master and slave the SCK and FS clock signal will be outputted on the SCK and FS pin on the master module. MCK can optionally be outputted on the MCK pin, if there is a controller module on the bus the SCK, FS and optionally the MCK clock is sourced from the same pins. Serial data will be trancieved on the SD pin in both scenarios.

23.2.3.2 Controller

In controller mode the module will generate the clock signals, but the Serializers are disabled and no data will be transmitted/received by the module in this mode. The clock signals is outputted on the SCK, FS and optionally the MCK pin.

23.2.3.3 Slave

In slave mode the module will use the SCK and FS clock source from the master or the controller which is received on the SCK and FS pin. The MCK can optionally be sourced externally on the MCK pin. The Serializers are enabled and will tranceive data on the SD pin. All data flow is controlled by the master.

23.2.3.4 Switch modes

The mode switching between master, controller and slave modes are actually done by modifying the source mode of I2S pins. The source mode of I2S pins are selected by writing corresponding bits in CLKCTRLn. Since source mode switching changes the direction of pin, the mode must be changed when the I2S Clock Unit is stopped.

23.2.4 Data Stream Reception/Transmission

The I2S module support several data stream formats:

- I2S format
- Time Division Multiplexed (TDM) format
- Pulse Density Modulation (PDM) format (reception only)

Basically the I2S module can send several words within each frame, it's more like TDM format. With adjust to the number of data words in a frame, the FS width, the FS to data bits delay, etc., the module is able to handle I2S compliant data stream.

Also the Serializer can receive PDM format data stream, which allows the I2S module receive 1 PDM data on each SCK edge.

23.2.4.1 I2S Stream Reception/Transmission

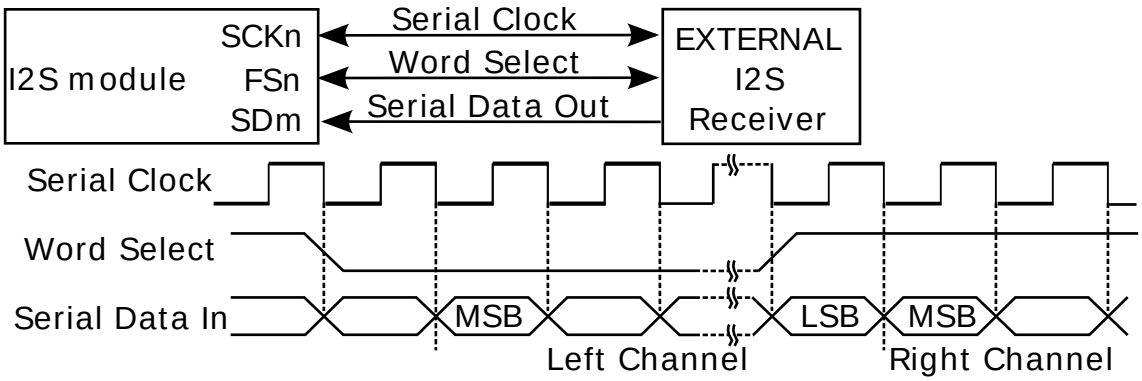
For 2-channel I2S compliant data stream format the i2s module uses the FS line as word select (WS) signal and will send left channel data word on low WS level and right channel data word on high WS level as specified in the I2S standard. The supported word sizes are 8-, 16-, 18-, 20-, 24- and 32- bit.

Thus for I2S stream, the following settings should be applied to the module:

- Data starting delay after FS transition : one SCK period
- FS width : half of frame
- Data bits adjust in word : left-adjusted
- Bit transmitting order : MSB first

Following is an example for I2S application connections and waveforms. See Figure 23-2: I2S Example Diagram on page 531.

Figure 23-2. I2S Example Diagram



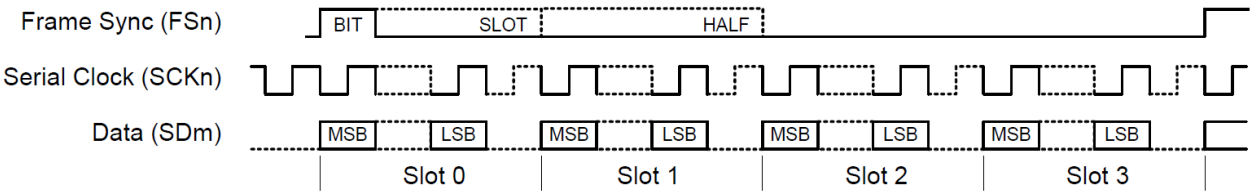
23.2.4.2 TDM Stream Reception/Transmission

In TDM format, the module sends several data words in each frame. For this data stream format most of the configurations could be adjusted:

- Main Frame related settings are as follow:
  - Frame Sync (FS) options:
    - the active edge of the FS (or if FS is inverted before use)
    - the width of the FS
  - the delay between FS to first data bit
- Data alignment in slot
- The number of slots and slot size can be adjusted, it has been mentioned in Audio Frame Generation
- The data word size is controlled by Serializer, it can be chosen among 8, 16, 18, 20, 24 and 32 bits.

The general TDM waveform generation is as follow:

Figure 23-3. TDM Waveform generation

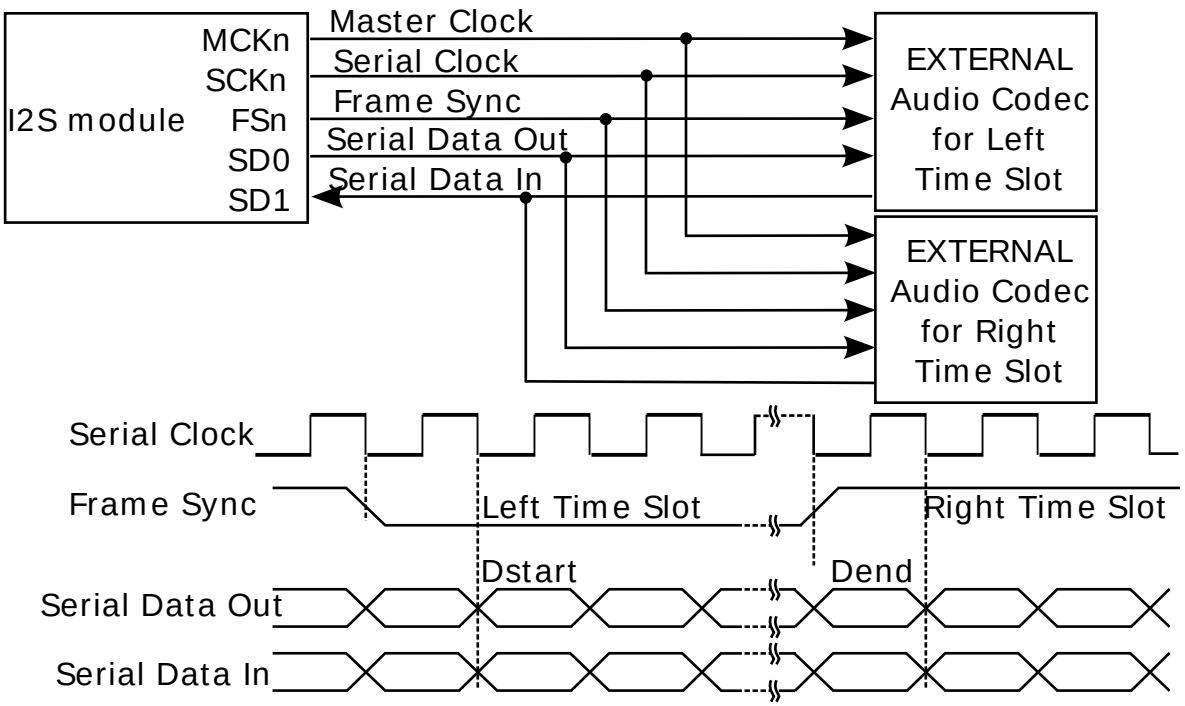


Some other settings could also be found to set up clock, data formatting and pin mux. refer to Clock Unit Configurations and Serializer Configurations for more details.

Following is examples for different application use cases.

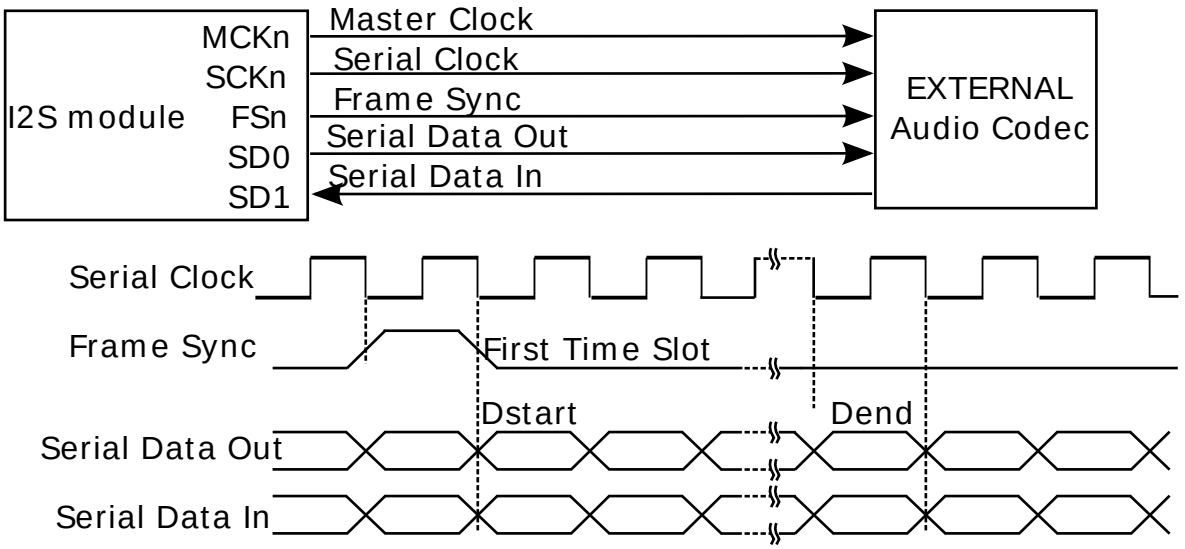
See Figure 23-4: Codec Example Diagram on page 532 for the Time Slot Application connection and waveform example.

Figure 23-4. Codec Example Diagram



See Figure 23-5: Time Slot Example Diagram on page 532 for the Codec Application connection and waveform example.

Figure 23-5. Time Slot Example Diagram

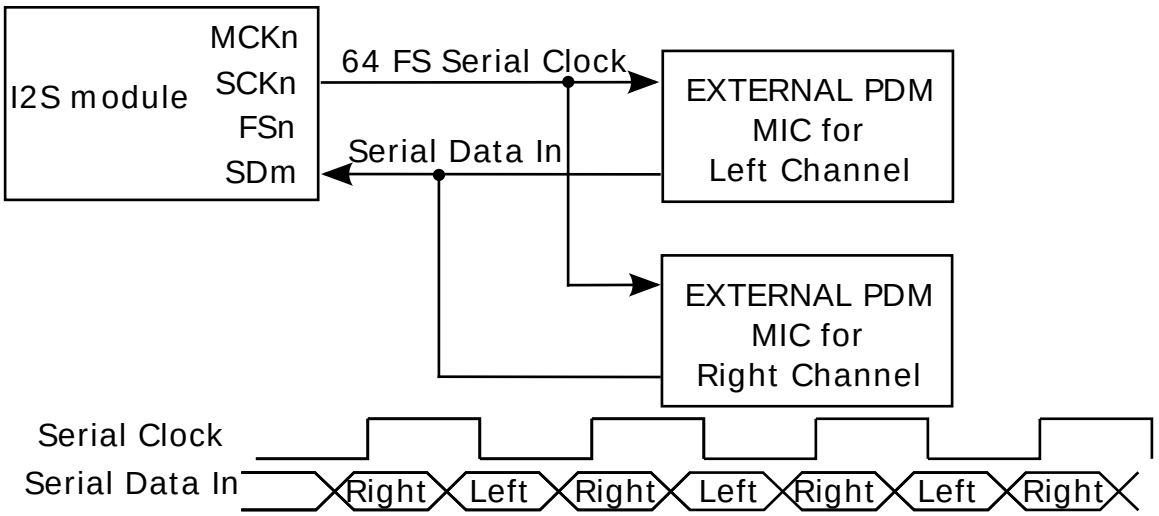


23.2.4.3 PDM Reception

The I2S Serializer integrates PDM reception feature, to use this feature, simply select PDM2 mode in Serializer configuration. In PDM2 mode, it assumes two microphones are input for stereo stream. The left microphone bits will be stored in lower half and right microphone bits in upper half of the data word, like in compact stereo format.

See Figure 23-6: Time PDM2 Example Diagram on page 533 for an example of PDM Microphones Application with both left and right channel microphone connected.

Figure 23-6. Time PDM2 Example Diagram



23.2.4.4 MONO and Compact Data

The I2S Serializer can accept some pre-defined data format and generates the data stream in specified way.

When transmitting data, the Serializer can work in MONO mode: assum input is single channel mono data on left channel and copy it to right channel automatically.

Also the I2S Serializer can support compact stereo data word. The data word size of the Serializer can be set to 16-bit compact on page 553 or 8-bit compact on page 553, with these option I2S Serializer will compact left channel data and right channel data together, the left channel data will take lower bytes and right channel data take higher bytes.

23.2.5 Loop-back Mode

The I2S can be configured to loop back the Transmitter to Receiver. In this mode Serializer's input will be connected to another Serializer's output internally.

23.2.6 Sleep Modes

The I2S will continue to operate in any sleep mode, where the selected source clocks are running.

23.3 Special Considerations

There is no special considerations for I2S module.

23.4 Extra Information

For extra information see Extra Information for I2S Driver. This includes:

- Acronyms
- Dependencies
- Errata
- Module History

23.5 Examples

For a list of examples related to this driver, see Examples for I2S Driver.

23.6 API Overview

23.6.1 Variable and Type Definitions

23.6.1.1 Type i2s_serializer_callback_t

```
typedef void(* i2s_serializer_callback_t )(struct i2s_module *const module)
```

Type of the callback functions

23.6.2 Structure Definitions

23.6.2.1 Struct i2s_clock_config

Configure for I2S clock (SCK)

Table 23-1. Members

Type	Name	Description
enum gclk_generator	gclk_src	Clock source selection
uint8_t	mck_out_div	Divide generic clock to master clock output (1~32, 0,1 means no div)
bool	mck_out_enable	Generate MCK clock output
bool	mck_out_invert	Invert master clock output
enum i2s_master_clock_source	mck_src	Master clock source selection: generated or input from pin
uint8_t	sck_div	Divide generic clock to serial clock (1~32, 0,1 means no div)
bool	sck_out_invert	Invert serial clock output
enum i2s_serial_clock_source	sck_src	Serial clock source selection: generated or input from pin

23.6.2.2 Struct i2s_clock_unit_config

Configure for I2S clock unit

Table 23-2. Members

Type	Name	Description
struct i2s_clock_config	clock	Configure clock generation
struct i2s_frame_config	frame	Configure frame generation
struct i2s_pin_config	fs_pin	Configure frame sync pin
struct i2s_pin_config	mck_pin	Configure master clock pin
struct i2s_pin_config	sck_pin	Configure serial clock pin

23.6.2.3 Struct i2s_frame_config

Configure fir I2S frame

Table 23-3. Members

Type	Name	Description
enum i2s_data_delay	data_delay	Data delay from Frame Sync (FS) to first data bit
struct i2s_frame_sync_config	frame_sync	Frame sync (FS)
uint8_t	number_slots	Number of slots in a frame (1~8, 0,1 means minimum 1)
enum i2s_slot_size	slot_size	Size of each slot in frame

23.6.2.4 Struct i2s_frame_sync_config

Configure fir I2S frame sync (FS)

Table 23-4. Members

Type	Name	Description
bool	invert_out	Invert Frame Sync (FS) signal before output
bool	invert_use	Invert Frame Sync (FS) signal before use
enum i2s_frame_sync_source	source	Frame Sync (FS) generated or input from pin
enum i2s_frame_sync_width	width	Frame Sync (FS) width

23.6.2.5 Struct i2s_module

Table 23-5. Members

Type	Name	Description
I2s *	hw	Module HW register access base
struct i2s_serializer_module	serializer[]	Module Serializer used

23.6.2.6 Struct i2s_pin_config

Configure for I2S pin

Table 23-6. Members

Type	Name	Description
bool	enable	Enable this pin for I2S module
uint8_t	gpio	GPIO index to access the pin
uint8_t	mux	Pin function MUX

23.6.2.7 Struct i2s_serializer_config

Configure for I2S Serializer

Table 23-7. Members

Type	Name	Description
enum i2s_bit_padding	bit_padding	Data Formatting Bit Extension

Type	Name	Description
enum i2s_clock_unit	clock_unit	Clock unit selection
bool	data_adjust_left_in_slot	Data Slot Formatting Adjust, set to true to adjust words in slot to left
bool	data_adjust_left_in_word	Data Word Formatting Adjust, set to true to adjust bits in word to left
enum i2s_data_padding	data_padding	Data padding when under-run
struct i2s_pin_config	data_pin	Configure Serializer data pin
enum i2s_data_size	data_size	Data Word Size
bool	disable_data_slot[]	Disable data slot
enum i2s_dma_usage	dma_usage	DMA usage
enum i2s_line_default_state	line_default_state	Line default state where slot is disabled
bool	loop_back	Set to true to loop-back output to input pin for test
enum i2s_serializer_mode	mode	Serializer Mode
bool	mono_mode	Set to true to assumes mono input and duplicate it (left channel) to right channel
bool	transfer_lsb_first	Set to true to transfer LSB first, false to transfer MSB first

23.6.2.8 Struct i2s_serializer_module

Table 23-8. Members

Type	Name	Description
i2s_serializer_callback_t	callback[]	Callbacks list for Serializer
enum i2s_data_size	data_size	Serializer data word size
uint8_t	enabled_callback_mask	Callback mask for enabled callbacks
void *	job_buffer	Job buffer
enum status_code	job_status	Status of the ongoing or last transfer job
enum i2s_serializer_mode	mode	Serializer mode
uint8_t	registered_callback_mask	Callback mask for registered callbacks
uint32_t	requested_words	Requested data words to read/ write
uint32_t	transferred_words	Transferred data words for read/ write

23.6.3 Macro Definitions

23.6.3.1 Module status flags

I2S status flags, returned by i2s_get_status() and cleared by i2s_clear_status().

Macro I2S_STATUS_TRANSMIT_UNDERRUN

```
#define I2S_STATUS_TRANSMIT_UNDERRUN(x) \
  (1u << ((x)+0))
```

Module Serializer x (0~1) Transmit Underrun

Macro I2S_STATUS_TRANSMIT_READY

```
#define I2S_STATUS_TRANSMIT_READY(x) \
  (1u << ((x)+2))
```

Module Serializer x (0~1) is ready to accept new data to be transmitted

Macro I2S_STATUS_RECEIVE_OVERRUN

```
#define I2S_STATUS_RECEIVE_OVERRUN(x) \
  (1u << ((x)+4))
```

Module Serializer x (0~1) Receive Overrun

Macro I2S_STATUS_RECEIVE_READY

```
#define I2S_STATUS_RECEIVE_READY(x) \
  (1u << ((x)+6))
```

Module Serializer x (0~1) has received a new data

Macro I2S_STATUS_SYNC_BUSY

```
#define I2S_STATUS_SYNC_BUSY (1u << 8)
```

Module is busy on synchronization

23.6.4 Function Definitions

23.6.4.1 Driver Initialization

Function i2s_init()

Initializes a hardware I2S module instance.

```
enum status_code i2s_init(
  struct i2s_module *const module_inst,
  I2s * hw)
```

Enables the clock and initialize the I2S module.

Table 23-9. Parameters

Data direction	Parameter name	Description
[in, out]	module_inst	Pointer to the software module instance struct
[in]	hw	Pointer to the TCC hardware module

Returns Status of the initialization procedure.

Table 23-10. Return Values

Return value	Description
STATUS_OK	The module was initialized successfully
STATUS_BUSY	Hardware module was busy when the initialization procedure was attempted
STATUS_ERR_DENIED	Hardware module was already enabled

23.6.4.2 Enable/Disable/Reset

Function i2s_enable()

Enable the I2S module.

```
void i2s_enable(
  const struct i2s_module *const module_inst)
```

Enables a I2S module that has been previously initialized.

Table 23-11. Parameters

Data direction	Parameter name	Description
[in]	module_inst	Pointer to the software module instance struct

Function i2s_disable()

Disables the I2S module.

```
void i2s_disable(
  const struct i2s_module *const module_inst)
```

Disables a I2S module.

Table 23-12. Parameters

Data direction	Parameter name	Description
[in]	module_inst	Pointer to the software module instance struct

Function i2s_reset()

Resets the I2S module.

```
void i2s_reset(
  const struct i2s_module *const module_inst)
```

Resets the I2S module, restoring all hardware module registers to their default values and disabling the module. The I2S module will not be accessible while the reset is being performed.

Table 23-13. Parameters

Data direction	Parameter name	Description
[in]	module_inst	Pointer to the software module instance struct

23.6.4.3 Clock Unit Initialization and Configuration

Function i2s_clock_unit_get_config_defaults()

Initializes config with predefined default values for I2S clock unit.

```
void i2s_clock_unit_get_config_defaults(
  struct i2s_clock_unit_config *const config)
```

This function will initialize a given I2S Clock Unit configuration structure to a set of known default values. This function should be called on any new instance of the configuration structures before being modified by the user application.

The default configuration is as follow:

- The clock unit does not generate output clocks (MCK, SCK and FS)
- The pins (MCK, SCK and FS) and Mux configurations are not set

Table 23-14. Parameters

Data direction	Parameter name	Description
[out]	config	Pointer to a I2S module clock unit configuration struct to set

Function i2s_clock_unit_set_config()

Configure specified I2S clock unit.

```
enum status_code i2s_clock_unit_set_config(
  struct i2s_module *const module_inst,
  const enum i2s_clock_unit clock_unit,
  const struct i2s_clock_unit_config * config)
```

Enables the clock and initialize the clock unit, based on the given configurations.

Table 23-15. Parameters

Data direction	Parameter name	Description
[in, out]	module_inst	Pointer to the software module instance struct

Data direction	Parameter name	Description
[in]	clock_unit	I2S clock unit to initialize and configure
[in]	config	Pointer to the I2S clock unit configuration options struct

Returns Status of the configuration procedure.

Table 23-16. Return Values

Return value	Description
STATUS_OK	The module was initialized successfully
STATUS_BUSY	Hardware module was busy when the configuration procedure was attempted
STATUS_ERR_DENIED	Hardware module was already enabled
STATUS_ERR_INVALID_ARG	Invalid divider value or MCK direction setting conflict

23.6.4.4 Clock Unit Enable/Disable

Function i2s_clock_unit_enable()

Enable the Specified Clock Unit of I2S module.

```
void i2s_clock_unit_enable(
  const struct i2s_module *const module_inst,
  const enum i2s_clock_unit clock_unit)
```

Enables a Clock Unit in I2S module that has been previously initialized.

Table 23-17. Parameters

Data direction	Parameter name	Description
[in]	module_inst	Pointer to the software module instance struct
[in]	clock_unit	I2S Clock Unit to enable

Function i2s_clock_unit_disable()

Disable the Specified Clock Unit of I2S module.

```
void i2s_clock_unit_disable(
  const struct i2s_module *const module_inst,
  const enum i2s_clock_unit clock_unit)
```

Disables a Clock Unit in I2S module that has been previously initialized.

Table 23-18. Parameters

Data direction	Parameter name	Description
[in]	module_inst	Pointer to the software module instance struct

Data direction	Parameter name	Description
[in]	clock_unit	I2S Clock Unit to disable

23.6.4.5 Serializer Initialization and Configuration

Function i2s_serializer_get_config_defaults()

Initializes config with predefined default values for I2S Serializer.

```
void i2s_serializer_get_config_defaults(
  struct i2s_serializer_config *const config)
```

This function will initialize a given I2S Clock Unit configuration structure to a set of known default values. This function should be called on any new instance of the configuration structures before being modified by the user application.

The default configuration is as follow:

- Output data does not internally loopback to input line
- Does not extend mono data (left channel) to right channel
- None of the data slot is disabled
- MSB of I2S data is transferred first
- In data word data is adjusted right
- In slot data word is adjusted left
- The data size is 16-bit width
- I2S will padd 0 to not defined bits
- I2S will padd 0 to not defined words
- I2S will use single DMA channel for all data channels
- I2S will use clock unit 0 to serve as clock
- The default data line state is 0, when there is no data
- I2S will transmit data to output line
- The data pin and Mux configuration are not set

Table 23-19. Parameters

Data direction	Parameter name	Description
[out]	config	Pointer to a I2S module Serializer configuration struct to set

Function i2s_serializer_set_config()

Configure specified I2S serializer.

```
enum status_code i2s_serializer_set_config(
  struct i2s_module *const module_inst,
  const enum i2s_serializer serializer,
```

```
  const struct i2s_serializer_config * config)
```

Enables the clock and initialize the serializer, based on the given configurations.

Table 23-20. Parameters

Data direction	Parameter name	Description
[in, out]	module_inst	Pointer to the software module instance struct
[in]	serializer	I2S serializer to initialize and configure
[in]	config	Pointer to the I2S serializer configuration options struct

Returns Status of the configuration procedure.

Table 23-21. Return Values

Return value	Description
STATUS_OK	The module was initialized successfully
STATUS_BUSY	Hardware module was busy when the configuration procedure was attempted
STATUS_ERR_DENIED	Hardware module was already enabled

23.6.4.6 Serializer Enable/Disable

Function i2s_serializer_enable()

Enable the Specified Serializer of I2S module.

```
void i2s_serializer_enable(
  const struct i2s_module *const module_inst,
  const enum i2s_serializer serializer)
```

Enables a Serializer in I2S module that has been previously initialized.

Table 23-22. Parameters

Data direction	Parameter name	Description
[in]	module_inst	Pointer to the software module instance struct
[in]	serializer	I2S Serializer to enable

Function i2s_serializer_disable()

Disable the Specified Serializer of I2S module.

```
void i2s_serializer_disable(
  const struct i2s_module *const module_inst,
  const enum i2s_serializer serializer)
```

Disables a Serializer in I2S module that has been previously initialized.

Table 23-23. Parameters

Data direction	Parameter name	Description
[in]	module_inst	Pointer to the software module instance struct
[in]	serializer	I2S Serializer to disable

23.6.4.7 Status Management

Function i2s_get_status()

Retrieves the current module status.

```
uint32_t i2s_get_status(
  const struct i2s_module *const module_inst)
```

Retrieves the status of the module, giving overall state information.

Table 23-24. Parameters

Data direction	Parameter name	Description
[in]	module_inst	Pointer to the I2S software instance struct

Returns Bitmask of I2S_STATUS_* flags

Table 23-25. Return Values

Return value	Description
I2S_STATUS_SYNC_BUSY	Module is busy synchronization
I2S_STATUS_TRANSMIT_UNDERRUN(x)	Serializer x (0~1) is underrun
I2S_STATUS_TRANSMIT_READY(x)	Serializer x (0~1) is ready to transmit new data word
I2S_STATUS_RECEIVE_OVERRUN(x)	Serializer x (0~1) is overrun
I2S_STATUS_RECEIVE_READY(x)	Serializer x (0~1) has data ready to read

Function i2s_clear_status()

Clears a module status flags.

```
void i2s_clear_status(
  const struct i2s_module *const module_inst,
  uint32_t status)
```

Clears the given status flags of the module.

Table 23-26. Parameters

Data direction	Parameter name	Description
[in]	module_inst	Pointer to the I2S software instance struct
[in]	status	Bitmask of I2S_STATUS_* flags to clear

Function i2s_enable_status_interrupt()

Enable interrupts on status set.

```
enum status_code i2s_enable_status_interrupt(
  struct i2s_module *const module_inst,
  uint32_t status)
```

Enable the given status interrupt request from the I2S module.

Table 23-27. Parameters

Data direction	Parameter name	Description
[in]	module_inst	Pointer to the I2S software instance struct
[in]	status	Status interrupts to enable

Returns Status of enable procedure

Table 23-28. Return Values

Return value	Description
STATUS_OK	Interrupt is enabled successfully
STATUS_ERR_INVALID_ARG	Status with no interrupt is passed

Function i2s_disable_status_interrupt()

Disable interrupts on status set.

```
void i2s_disable_status_interrupt(
  struct i2s_module *const module_inst,
  uint32_t status)
```

Disable the given status interrupt request from the I2S module.

Table 23-29. Parameters

Data direction	Parameter name	Description
[in]	module_inst	Pointer to the I2S software instance struct
[in]	status	Status interrupts to disable

23.6.4.8 Data read/write

Function i2s_serializer_write_wait()

Write a data word to the specified Serializer of I2S module.

```
void i2s_serializer_write_wait(
  const struct i2s_module *const module_inst,
  enum i2s_serializer serializer,
```

```
  uint32_t data)
```

Table 23-30. Parameters

Data direction	Parameter name	Description
[in]	module_inst	Pointer to the software module instance struct
[in]	serializer	The Serializer to write to
[in]	data	The data to write

Function i2s_serializer_read_wait()

Read a data word from the specified Serializer of I2S module.

```
uint32_t i2s_serializer_read_wait(
  const struct i2s_module *const module_inst,
  enum i2s_serializer serializer)
```

Table 23-31. Parameters

Data direction	Parameter name	Description
[in]	module_inst	Pointer to the software module instance struct
[in]	serializer	The Serializer to read

Function i2s_serializer_write_buffer_wait()

Write buffer to the specified Serializer of I2S module.

```
enum status_code i2s_serializer_write_buffer_wait(
  const struct i2s_module *const module_inst,
  enum i2s_serializer serializer,
  void * buffer,
  uint32_t size)
```

Table 23-32. Parameters

Data direction	Parameter name	Description
[in]	module_inst	Pointer to the software module instance struct
[in]	serializer	The Serializer to write to
[in]	buffer	The data buffer to write
[in]	size	Number of data words to write

Returns

Status of the initialization procedure.

Table 23-33. Return Values

Return value	Description
STATUS_OK	The data was sent successfully
STATUS_INVALID_ARG	An invalid buffer pointer was supplied

Table 23-34. Parameters

Data direction	Parameter name	Description
[in]	module_inst	Pointer to the software module instance struct
[in]	serializer	The serializer to write to
[in]	buffer	The data buffer to write
[in]	size	Number of data words to write

Returns Status of the initialization procedure.

Table 23-35. Return Values

Return value	Description
STATUS_OK	The data was sent successfully
STATUS_ERR_DENIED	The module or serializer is disabled
STATUS_ERR_INVALID_ARG	An invalid buffer pointer was supplied

Function i2s_serializer_read_buffer_wait()

Read from the specified Serializer of I2S module to a buffer.

```
enum status_code i2s_serializer_read_buffer_wait(
  const struct i2s_module *const module_inst,
  enum i2s_serializer serializer,
  void * buffer,
  uint32_t size)
```

Table 23-36. Parameters

Data direction	Parameter name	Description
[in]	module_inst	Pointer to the software module instance struct
[in]	serializer	The Serializer to write to
[in]	buffer	The buffer to fill read data
[in]	size	Number of data words to read

Returns Status of the initialization procedure.

Table 23-37. Return Values

Return value	Description
STATUS_OK	The data was sent successfully
STATUS_INVALID_ARG	An invalid buffer pointer was supplied

Table 23-38. Parameters

Data direction	Parameter name	Description
[in]	module_inst	Pointer to the software module instance struct

Data direction	Parameter name	Description
[in]	serializer	The serializer to write to
[in]	buffer	The buffer to fill read data (NULL to discard)
[in]	size	Number of data words to read

Returns Status of the initialization procedure.

Table 23-39. Return Values

Return value	Description
STATUS_OK	The data was sent successfully
STATUS_ERR_DENIED	The module or serializer is disabled
STATUS_ERR_INVALID_ARG	An invalid buffer pointer was supplied

23.6.4.9 Callback Management

Function i2s_serializer_register_callback()

Registers a callback for serializer.

```
void i2s_serializer_register_callback(
  struct i2s_module *const module_inst,
  const enum i2s_serializer serializer,
  const i2s_serializer_callback_t callback_func,
  const enum i2s_serializer_callback callback_type)
```

Registers a callback function which is implemented by the user.

Note The callback must be enabled by for the interrupt handler to call it when the condition for the callback is met.

Table 23-40. Parameters

Data direction	Parameter name	Description
[in]	module	Pointer to ADC software instance struct
[in]	serializer	The serializer that generates callback
[in]	callback_func	Pointer to callback function
[in]	callback_type	Callback type given by an enum

Function i2s_serializer_unregister_callback()

Unregisters a callback for serializer.

```
void i2s_serializer_unregister_callback(
  struct i2s_module *const module_inst,
  const enum i2s_serializer serializer,
```

```
  const enum i2s_serializer_callback callback_type)
```

Unregisters a callback function which is implemented by the user.

Table 23-41. Parameters

Data direction	Parameter name	Description
[in]	module	Pointer to ADC software instance struct
[in]	serializer	The serializer that generates callback
[in]	callback_type	Callback type given by an enum

Function i2s_serializer_enable_callback()

Enables callback for serializer.

```
void i2s_serializer_enable_callback(
  struct i2s_module *const module_inst,
  const enum i2s_serializer serializer,
  const enum i2s_serializer_callback callback_type)
```

Enables the callback function registered by i2s_serializer_register_callback. The callback function will be called from the interrupt handler when the conditions for the callback type are met.

Table 23-42. Parameters

Data direction	Parameter name	Description
[in]	module	Pointer to ADC software instance struct
[in]	serializer	The serializer that generates callback
[in]	callback_type	Callback type given by an enum

Function i2s_serializer_disable_callback()

Disables callback for Serializer.

```
void i2s_serializer_disable_callback(
  struct i2s_module *const module_inst,
  const enum i2s_serializer serializer,
  const enum i2s_serializer_callback callback_type)
```

Disables the callback function registered by the i2s_serializer_register_callback.

Table 23-43. Parameters

Data direction	Parameter name	Description
[in]	module	Pointer to ADC software instance struct
[in]	serializer	The serializer that generates callback
[in]	callback_type	Callback type given by an enum

23.6.4.10 Job Management

Function i2s_serializer_write_buffer_job()

Write buffer to the specified Serializer of I2S module.

```
enum status_code i2s_serializer_write_buffer_job(
  struct i2s_module *const module_inst,
  const enum i2s_serializer serializer,
  const void * buffer,
  const uint32_t size)
```

Table 23-44. Parameters

Data direction	Parameter name	Description
[in]	module_inst	Pointer to the software module instance struct
[in]	serializer	The serializer to write to
[in]	buffer	The data buffer to write
[in]	size	Number of data words to write

Returns

Status of the initialization procedure.

Table 23-45. Return Values

Return value	Description
STATUS_OK	The data was sent successfully
STATUS_ERR_DENIED	The serializer is not in transmit mode
STATUS_ERR_INVALID_ARG	An invalid buffer pointer was supplied

Function i2s_serializer_read_buffer_job()

Read from the specified Serializer of I2S module to a buffer.

```
enum status_code i2s_serializer_read_buffer_job(
  struct i2s_module *const module_inst,
  const enum i2s_serializer serializer,
  void * buffer,
  const uint32_t size)
```

Table 23-46. Parameters

Data direction	Parameter name	Description
[in]	module_inst	Pointer to the software module instance struct
[in]	serializer	The serializer to write to
[out]	buffer	The buffer to fill read data
[in]	size	Number of data words to read

Returns Status of the initialization procedure.

Table 23-47. Return Values

Return value	Description
STATUS_OK	The data was sent successfully
STATUS_ERR_DENIED	The serializer is not in receive mode
STATUS_ERR_INVALID_ARG	An invalid buffer pointer was supplied

Function i2s_serializer_abort_job()

Aborts an ongoing job running on serializer.

```
void i2s_serializer_abort_job(
  struct i2s_module *const module_inst,
  const enum i2s_serializer serializer,
  const enum i2s_job_type job_type)
```

Aborts an ongoing job.

Table 23-48. Parameters

Data direction	Parameter name	Description
[in]	module_inst	Pointer to the software module instance struct
[in]	serializer	The serializer which runs the job
[in]	job_type	Type of job to abort

Function i2s_serializer_get_job_status()

Gets the status of a job running on serializer.

```
enum status_code i2s_serializer_get_job_status(
  const struct i2s_module *const module_inst,
  const enum i2s_serializer serializer,
  const enum i2s_job_type job_type)
```

Gets the status of an ongoing or the last job.

Table 23-49. Parameters

Data direction	Parameter name	Description
[in]	module_inst	Pointer to the software module instance struct
[in]	serializer	The serializer which runs the job
[in]	job_type	Type of job to abort

Returns Status of the job

23.6.4.11 Function i2s_is_syncing()

Determines if the hardware module(s) are currently synchronizing to the bus.

```
bool i2s_is_syncing(
  const struct i2s_module *const module_inst)
```

Checks to see if the underlying hardware peripheral module(s) are currently synchronizing across multiple clock domains to the hardware bus, This function can be used to delay further operations on a module until such time that it is ready, to prevent blocking delays for synchronization in the user application.

Table 23-50. Parameters

Data direction	Parameter name	Description
[in]	module_inst	Pointer to the software module instance struct

Returns

Synchronization status of the underlying hardware module(s).

Table 23-51. Return Values

Return value	Description
true	if the module has completed synchronization
false	if the module synchronization is ongoing

23.6.5 Enumeration Definitions

23.6.5.1 Enum i2s_bit_order

I2S data bit order

Table 23-52. Members

Enum value	Description
I2S_BIT_ORDER_MSB_FIRST	Transfer Data Most Significant Bit first (Default for I2S protocol)
I2S_BIT_ORDER_LSB_FIRST	Transfer Data Least Significant Bit first

23.6.5.2 Enum i2s_bit_padding

I2S data bit padding

Table 23-53. Members

Enum value	Description
I2S_BIT_PADDING_0	Padding with 0
I2S_BIT_PADDING_1	Padding with 1
I2S_BIT_PADDING_MSB	Padding with MSBit
I2S_BIT_PADDING_LSB	Padding with LSBit

23.6.5.3 Enum i2s_clock_unit

I2S clock unit selection

Table 23-54. Members

Enum value	Description
I2S_CLOCK_UNIT_0	Clock Unit channel 0
I2S_CLOCK_UNIT_1	Clock Unit channel 1
I2S_CLOCK_UNIT_N	Number of Clock Unit channels

23.6.5.4 Enum i2s_data_adjust

I2S data word adjust

Table 23-55. Members

Enum value	Description
I2S_DATA_ADJUST_RIGHT	Data is right adjusted in word
I2S_DATA_ADJUST_LEFT	Data is left adjusted in word

23.6.5.5 Enum i2s_data_delay

Data delay from Frame Sync (FS)

Table 23-56. Members

Enum value	Description
I2S_DATA_DELAY_0	Left Justified (no delay)
I2S_DATA_DELAY_1	I2S data delay (1-bit delay)
I2S_DATA_DELAY_LEFT_JUSTIFIED	Left Justified (no delay)
I2S_DATA_DELAY_I2S	I2S data delay (1-bit delay)

23.6.5.6 Enum i2s_data_format

I2S data format, to extend mono data to 2 channels

Table 23-57. Members

Enum value	Description
I2S_DATA_FORMAT_STEREO	Normal mode, keep data to its right channel
I2S_DATA_FORMAT_MONO	Assume input is mono data for left channel, the data is duplicated to right channel

23.6.5.7 Enum i2s_data_padding

I2S data padding

Table 23-58. Members

Enum value	Description
I2S_DATA_PADDING_0	Padding 0 in case of under-run
I2S_DATA_PADDING_SAME_AS_LAST	Padding last data in case of under-run
I2S_DATA_PADDING_LAST	Padding last data in case of under-run (abbr. `I2S_DATA_PADDING_SAME_AS_LAST`)

Enum value	Description
I2S_DATA_PADDING_SAME	Padding last data in case of under-run (abbr. I2S_DATA_PADDING_SAME_AS_LAST)

23.6.5.8 Enum i2s_data_size

I2S data word size

Table 23-59. Members

Enum value	Description
I2S_DATA_SIZE_32BIT	32-bit
I2S_DATA_SIZE_24BIT	24-bit
I2S_DATA_SIZE_20BIT	20-bit
I2S_DATA_SIZE_18BIT	18-bit
I2S_DATA_SIZE_16BIT	16-bit
I2S_DATA_SIZE_16BIT_COMPACT	16-bit compact stereo
I2S_DATA_SIZE_8BIT	8-bit
I2S_DATA_SIZE_8BIT_COMPACT	8-bit compact stereo

23.6.5.9 Enum i2s_dma_usage

DMA channels usage for I2S

Table 23-60. Members

Enum value	Description
I2S_DMA_USE_SINGLE_CHANNEL_FOR_ALL	Single DMA channel for all I2S channels
I2S_DMA_USE_ONE_CHANNEL_PER_DATA_CHANNEL	One DMA channel per data channel

23.6.5.10 Enum i2s_frame_sync_source

Frame Sync (FS) source

Table 23-61. Members

Enum value	Description
I2S_FRAME_SYNC_SOURCE_SCKDIV	Frame Sync (FS) is divided from I2S Serial Clock
I2S_FRAME_SYNC_SOURCE_FSPIN	Frame Sync (FS) is input from FS input pin

23.6.5.11 Enum i2s_frame_sync_width

Frame Sync (FS) output pulse width

Table 23-62. Members

Enum value	Description
I2S_FRAME_SYNC_WIDTH_SLOT	Frame Sync (FS) Pulse is 1 Slot width
I2S_FRAME_SYNC_WIDTH_HALF_FRAME	Frame Sync (FS) Pulse is half a Frame width
I2S_FRAME_SYNC_WIDTH_BIT	Frame Sync (FS) Pulse is 1 Bit width

Enum value	Description
I2S_FRAME_SYNC_WIDTH_BURST	1-bit wide Frame Sync (FS) per Data sample, only used when Data transfer is requested

23.6.5.12 Enum i2s_job_type

Enum for the possible types of I2S asynchronous jobs that may be issued to the driver.

Table 23-63. Members

Enum value	Description
I2S_JOB_WRITE_BUFFER	Asynchronous I2S write from a user provided buffer
I2S_JOB_READ_BUFFER	Asynchronous I2S read into a user provided buffer

23.6.5.13 Enum i2s_line_default_state

I2S line default value when slot disabled

Table 23-64. Members

Enum value	Description
I2S_LINE_DEFAULT_0	Output default value is 0
I2S_LINE_DEFAULT_1	Output default value is 1
I2S_LINE_DEFAULT_HIGH_IMPEDANCE	Output default value is high impedance
I2S_LINE_DEFAULT_HIZ	Output default value is high impedance (abbr. `I2S_LINE_DEFAULT_HIGH_IMPEDANCE`)

23.6.5.14 Enum i2s_master_clock_source

Master Clock (MCK) source selection

Table 23-65. Members

Enum value	Description
I2S_MASTER_CLOCK_SOURCE_GCLK	Master Clock (MCK) is from general clock
I2S_MASTER_CLOCK_SOURCE_MCKPIN	Master Clock (MCK) is from MCK input pin

23.6.5.15 Enum i2s_serial_clock_source

Serial Clock (SCK) source selection

Table 23-66. Members

Enum value	Description
I2S_SERIAL_CLOCK_SOURCE_MCKDIV	Serial Clock (SCK) is divided from Master Clock
I2S_SERIAL_CLOCK_SOURCE_SCKPIN	Serial Clock (SCK) is input from SCK input pin

23.6.5.16 Enum i2s_serializer

I2S Serializer selection

Table 23-67. Members

Enum value	Description
I2S_SERIALIZER_0	Serializer channel 0
I2S_SERIALIZER_1	Serializer channel 1
I2S_SERIALIZER_N	Number of Serializer channels

23.6.5.17 Enum i2s_serializer_callback

Table 23-68. Members

Enum value	Description
I2S_SERIALIZER_CALLBACK_BUFFER_DONE	Callback for buffer read/write finished
I2S_SERIALIZER_CALLBACK_OVER_UNDER_RUN	Callback for Serializer overrun/underrun

23.6.5.18 Enum i2s_serializer_mode

I2S Serializer mode

Table 23-69. Members

Enum value	Description
I2S_SERIALIZER_RECEIVE	Serializer is used to receive data
I2S_SERIALIZER_TRANSMIT	Serializer is used to transmit data
I2S_SERIALIZER_PDM2	Serializer is used to receive PDM data on each clock edge

23.6.5.19 Enum i2s_slot_adjust

I2S data slot adjust

Table 23-70. Members

Enum value	Description
I2S_SLOT_ADJUST_RIGHT	Data is right adjusted in slot
I2S_SLOT_ADJUST_LEFT	Data is left adjusted in slot

23.6.5.20 Enum i2s_slot_size

Time Slot Size in number of I2S serial clocks (bits)

Table 23-71. Members

Enum value	Description
I2S_SLOT_SIZE_8_BIT	8-bit slot
I2S_SLOT_SIZE_16_BIT	16-bit slot
I2S_SLOT_SIZE_24_BIT	24-bit slot
I2S_SLOT_SIZE_32_BIT	32-bit slot

23.7 Extra Information for I2S Driver

23.7.1 Acronyms

Below is a table listing the acronyms used in this module, along with their intended meanings.

Acronym	Description
I2S, IIS	Inter-IC Sound Controller
MCK	Master Clock
SCK	Serial Clock
FS	Frame Sync
SD	Serial Data
ADC	Analog-to-Digital Converter
DAC	Digital-to-Analog Converter
TDM	Time Division Multiplexed
PDM	Pulse Density Modulation
LSB	Least Significant Bit
MSB	Most Significant Bit
DSP	Digital Signal Processor

23.7.2 Dependencies

This driver has the following dependencies:

- System Pin Multiplexer Driver

23.7.3 Errata

There are no errata related to this driver.

23.7.4 Module History

An overview of the module history is presented in the table below, with details on the enhancements and fixes made to the module since its first release. The current version of this corresponds to the newest version in the table.

Changelog
Initial Release

23.8 Examples for I2S Driver

This is a list of the available Quick Start guides (QSGs) and example applications for SAM D21 Inter-IC Sound Controller Driver (I2S). QSGs are simple examples with step-by-step instructions to configure and use this driver in a selection of use cases. Note that QSGs can be compiled as a standalone application or be added to the user application.

- Quick Start Guide for I2S - Basic
- Quick Start Guide for I2S - Callback
- Quick Start Guide for I2S - DMA

23.8.1 Quick Start Guide for I2S - Basic

In this use case, the I2S will be used to generate Master Clock (MCK), Serial Clock (SCK), Frame Sync (FS) and Serial Data (SD) signals.

Here MCK is set to the half of processor clock. SCK is set to a quarter of the frequency of processor. FS generates half-half square wave for left and right audio channel data. The output serial data of channels toggle from two values to generate square wave, if codec or DAC is connected.

The I2S module will be set up as follows:

- GCLK generator 0 (GCLK main) clock source
- MCK, SCK and FS clocks outputs are enabled
- MCK output divider set to 2
- SCK generation divider set to 4
- Each frame will contain 2 32-bit slots
- Data will be left adjusted and start transmit without delay

23.8.1.1 Quick Start

Prerequisites

There are no prerequisites for this use case.

Code

Add to the main application source file, before any functions:

```
#define CONF_I2S_MODULE      I2S
#define CONF_I2S_MCK_PIN     PIN_PA09G_I2S_MCK0
#define CONF_I2S_MCK_MUX     MUX_PA09G_I2S_MCK0
#define CONF_I2S_SCK_PIN     PIN_PA10G_I2S_SCK0
#define CONF_I2S_SCK_MUX     MUX_PA10G_I2S_SCK0
#define CONF_I2S_FS_PIN      PIN_PA11G_I2S_FS0
#define CONF_I2S_FS_MUX      MUX_PA11G_I2S_FS0
#define CONF_I2S_SD_PIN      PIN_PA07G_I2S_SD0
#define CONF_I2S_SD_MUX      MUX_PA07G_I2S_SD0
```

Add to the main application source file, outside of any functions:

```
struct i2s_module i2s_instance;
```

Copy-paste the following setup code to your user application:

```
static void _configure_i2s(void)
{
    i2s_init(&i2s_instance, CONF_I2S_MODULE);

    struct i2s_clock_unit_config config_clock_unit;
    i2s_clock_unit_get_config_defaults(&config_clock_unit);
```

```
    config_clock_unit.clock.gclk_src = GCLK_GENERATOR_0;

    config_clock_unit.clock.mck_src = I2S_MASTER_CLOCK_SOURCE_GCLK;
    config_clock_unit.clock.mck_out_enable = true;
    config_clock_unit.clock.mck_out_div = 2;

    config_clock_unit.clock.sck_src = I2S_SERIAL_CLOCK_SOURCE_MCKDIV;
    config_clock_unit.clock.sck_div = 4;

    config_clock_unit.frame.number_slots = 2;
    config_clock_unit.frame.slot_size = I2S_SLOT_SIZE_32_BIT;
    config_clock_unit.frame.data_delay = I2S_DATA_DELAY_0;

    config_clock_unit.frame.frame_sync.source = I2S_FRAME_SYNC_SOURCE_SCKDIV;
    config_clock_unit.frame.frame_sync.width = I2S_FRAME_SYNC_WIDTH_HALF_FRAME;

    config_clock_unit.mck_pin.enable = true;
    config_clock_unit.mck_pin.gpio = CONF_I2S_MCK_PIN;
    config_clock_unit.mck_pin.mux = CONF_I2S_MCK_MUX;

    config_clock_unit.sck_pin.enable = true;
    config_clock_unit.sck_pin.gpio = CONF_I2S_SCK_PIN;
    config_clock_unit.sck_pin.mux = CONF_I2S_SCK_MUX;

    config_clock_unit.fs_pin.enable = true;
    config_clock_unit.fs_pin.gpio = CONF_I2S_FS_PIN;
    config_clock_unit.fs_pin.mux = CONF_I2S_FS_MUX;

    i2s_clock_unit_set_config(&i2s_instance, I2S_CLOCK_UNIT_0,
            &config_clock_unit);

    struct i2s_serializer_config config_serializer;
    i2s_serializer_get_config_defaults(&config_serializer);

    config_serializer.clock_unit = I2S_CLOCK_UNIT_0;
    config_serializer.mode = I2S_SERIALIZER_TRANSMIT;
    config_serializer.data_size = I2S_DATA_SIZE_16BIT;

    config_serializer.data_pin.enable = true;
    config_serializer.data_pin.gpio = CONF_I2S_SD_PIN;
    config_serializer.data_pin.mux = CONF_I2S_SD_MUX;

    i2s_serializer_set_config(&i2s_instance, I2S_SERIALIZER_0,
            &config_serializer);

    i2s_enable(&i2s_instance);
    i2s_clock_unit_enable(&i2s_instance, I2S_CLOCK_UNIT_0);
    i2s_serializer_enable(&i2s_instance, I2S_SERIALIZER_0);
}
```

Add to user application initialization (typically the start of `main()`):

```
_configure_i2s();
```

Workflow

1. Create a module software instance structure for the I2S module to store the I2S driver state while it is in use.

   ```
   struct i2s_module i2s_instance;
   ```

Note This should never go out of scope as long as the module is in use. In most cases, this should be global.

2. Configure the I2S module.

   a. Initialize the I2S module.

```
i2s_init(&i2s_instance, CONF_I2S_MODULE);
```

   b. Initialize the I2S Clock Unit.

      i. Create a I2S Clock Unit configuration struct, which can be filled out to adjust the configuration of a physical I2S Clock Unit.

```
struct i2s_clock_unit_config config_clock_unit;
```

      ii. Initialize the I2S Clock Unit configuration struct with the module's default values.

```
i2s_clock_unit_get_config_defaults(&config_clock_unit);
```

Note This should always be performed before using the configuration struct to ensure that all values are initialized to known default settings.

      iii. Alter the I2S Clock Unit settings to configure the general clock source, MCK, SCK and FS generation.

```
config_clock_unit.clock.gclk_src = GCLK_GENERATOR_0;

config_clock_unit.clock.mck_src = I2S_MASTER_CLOCK_SOURCE_GCLK;
config_clock_unit.clock.mck_out_enable = true;
config_clock_unit.clock.mck_out_div = 2;

config_clock_unit.clock.sck_src = I2S_SERIAL_CLOCK_SOURCE_MCKDIV;
config_clock_unit.clock.sck_div = 4;

config_clock_unit.frame.number_slots = 2;
config_clock_unit.frame.slot_size = I2S_SLOT_SIZE_32_BIT;
config_clock_unit.frame.data_delay = I2S_DATA_DELAY_0;

config_clock_unit.frame.frame_sync.source = I2S_FRAME_SYNC_SOURCE_SCKDIV;
config_clock_unit.frame.frame_sync.width = I2S_FRAME_SYNC_WIDTH_HALF_FRAME;
```

      iv. Alter the I2S Clock Unit settings to configure the MCK, SCK and FS output on physical device pins.

```
config_clock_unit.mck_pin.enable = true;
config_clock_unit.mck_pin.gpio = CONF_I2S_MCK_PIN;
config_clock_unit.mck_pin.mux = CONF_I2S_MCK_MUX;

config_clock_unit.sck_pin.enable = true;
config_clock_unit.sck_pin.gpio = CONF_I2S_SCK_PIN;
config_clock_unit.sck_pin.mux = CONF_I2S_SCK_MUX;

config_clock_unit.fs_pin.enable = true;
config_clock_unit.fs_pin.gpio = CONF_I2S_FS_PIN;
```

```
config_clock_unit.fs_pin.mux = CONF_I2S_FS_MUX;
```

v. Configure the I2S Clock Unit with the desired settings.

```
i2s_clock_unit_set_config(&i2s_instance, I2S_CLOCK_UNIT_0,
        &config_clock_unit);
```

c. Initialize the I2S Serializer.

i. Create a I2S Serializer configuration struct, which can be filled out to adjust the configuration of a physical I2S Serializer.

```
struct i2s_serializer_config config_serializer;
```

ii. Initialize the I2S Serializer configuration struct with the module's default values.

```
i2s_serializer_get_config_defaults(&config_serializer);
```

Note

This should always be performed before using the configuration struct to ensure that all values are initialized to known default settings.

iii. Alter the I2S Serializer settings to configure the serial data generation.

```
config_serializer.clock_unit = I2S_CLOCK_UNIT_0;
config_serializer.mode = I2S_SERIALIZER_TRANSMIT;
config_serializer.data_size = I2S_DATA_SIZE_16BIT;
```

iv. Alter the I2S Serializer settings to configure the SD on a physical device pin.

```
config_serializer.data_pin.enable = true;
config_serializer.data_pin.gpio = CONF_I2S_SD_PIN;
config_serializer.data_pin.mux = CONF_I2S_SD_MUX;
```

v. Configure the I2S Serializer with the desired settings.

```
i2s_serializer_set_config(&i2s_instance, I2S_SERIALIZER_0,
        &config_serializer);
```

d. Enable the I2S module, the Clock Unit and Serializer to start the clocks and ready to transmit data.

```
i2s_enable(&i2s_instance);
i2s_clock_unit_enable(&i2s_instance, I2S_CLOCK_UNIT_0);
i2s_serializer_enable(&i2s_instance, I2S_SERIALIZER_0);
```

23.8.1.2 Use Case

Code

Copy-paste the following code to your user application:

```
while (true) {
    /* Infinite loop */
```

```
    i2s_serializer_write_wait(&i2s_instance, I2S_SERIALIZER_0, 0xF87F);
    i2s_serializer_write_wait(&i2s_instance, I2S_SERIALIZER_0, 0x901F);
    i2s_serializer_write_wait(&i2s_instance, I2S_SERIALIZER_0, 0);
    i2s_serializer_write_wait(&i2s_instance, I2S_SERIALIZER_0, 0);
}
```

Workflow

1. Enter an infinite loop to output data sequence via the I2S Serializer.

```
while (true) {
    /* Infinite loop */
    i2s_serializer_write_wait(&i2s_instance, I2S_SERIALIZER_0, 0xF87F);
    i2s_serializer_write_wait(&i2s_instance, I2S_SERIALIZER_0, 0x901F);
    i2s_serializer_write_wait(&i2s_instance, I2S_SERIALIZER_0, 0);
    i2s_serializer_write_wait(&i2s_instance, I2S_SERIALIZER_0, 0);
}
```

23.8.2 Quick Start Guide for I2S - Callback

In this use case, the I2S will be used to generate Master Clock (MCK), Serial Clock (SCK), Frame Sync (FS) and Serial Data (SD) signals.

Here MCK is set to the half of processor clock. SCK is set to a quarter of the frequency of processor. FS generates half-half square wave for left and right audio channel data. The output serial data of channels toggle from two values to generate square wave, if codec or DAC is connected.

The I2S module will be set up as follows:

- GCLK generator 0 (GCLK main) clock source
- MCK, SCK and FS clocks outputs are enabled
- MCK output divider set to 2
- SCK generation divider set to 4
- Each frame will contain 2 32-bit slots
- Data will be left adjusted and start transmit without delay

23.8.2.1 Quick Start

Prerequisites

There are no prerequisites for this use case.

Code

Add to the main application source file, before any functions:

```
#define CONF_I2S_MODULE      I2S

#define CONF_I2S_MCK_PIN     PIN_PA09G_I2S_MCK0

#define CONF_I2S_MCK_MUX     MUX_PA09G_I2S_MCK0

#define CONF_I2S_SCK_PIN     PIN_PA10G_I2S_SCK0
```

```
#define CONF_I2S_SCK_MUX     MUX_PA10G_I2S_SCK0

#define CONF_I2S_FS_PIN      PIN_PA11G_I2S_FS0

#define CONF_I2S_FS_MUX      MUX_PA11G_I2S_FS0

#define CONF_I2S_SD_PIN      PIN_PA07G_I2S_SD0

#define CONF_I2S_SD_MUX      MUX_PA07G_I2S_SD0
```

Add to the main application source file, outside of any functions:

```
struct i2s_module i2s_instance;
```

Copy-paste the following data buffer code to your user application:

```
uint16_t data_buffer[4] = {0xF87F, 0x901F, 0, 0};
```

Copy-paste the following callback function code to your user application:

```
static void _i2s_callback_to_send_buffer(
        struct i2s_module *const module_inst)
{
    i2s_serializer_write_buffer_job(module_inst,
            I2S_SERIALIZER_0, data_buffer, 4);
}
```

Copy-paste the following setup code to your user application:

```
static void _configure_i2s(void)
{
    i2s_init(&i2s_instance, CONF_I2S_MODULE);

    struct i2s_clock_unit_config config_clock_unit;
    i2s_clock_unit_get_config_defaults(&config_clock_unit);

    config_clock_unit.clock.gclk_src = GCLK_GENERATOR_0;

    config_clock_unit.clock.mck_src = I2S_MASTER_CLOCK_SOURCE_GCLK;
    config_clock_unit.clock.mck_out_enable = true;
    config_clock_unit.clock.mck_out_div = 2;

    config_clock_unit.clock.sck_src = I2S_SERIAL_CLOCK_SOURCE_MCKDIV;
    config_clock_unit.clock.sck_div = 4;

    config_clock_unit.frame.number_slots = 2;
    config_clock_unit.frame.slot_size = I2S_SLOT_SIZE_32_BIT;
    config_clock_unit.frame.data_delay = I2S_DATA_DELAY_0;

    config_clock_unit.frame.frame_sync.source = I2S_FRAME_SYNC_SOURCE_SCKDIV;
    config_clock_unit.frame.frame_sync.width = I2S_FRAME_SYNC_WIDTH_HALF_FRAME;

    config_clock_unit.mck_pin.enable = true;
    config_clock_unit.mck_pin.gpio = CONF_I2S_MCK_PIN;
    config_clock_unit.mck_pin.mux = CONF_I2S_MCK_MUX;

    config_clock_unit.sck_pin.enable = true;
```

```
    config_clock_unit.sck_pin.gpio = CONF_I2S_SCK_PIN;
    config_clock_unit.sck_pin.mux = CONF_I2S_SCK_MUX;

    config_clock_unit.fs_pin.enable = true;
    config_clock_unit.fs_pin.gpio = CONF_I2S_FS_PIN;
    config_clock_unit.fs_pin.mux = CONF_I2S_FS_MUX;

    i2s_clock_unit_set_config(&i2s_instance, I2S_CLOCK_UNIT_0,
            &config_clock_unit);

    struct i2s_serializer_config config_serializer;
    i2s_serializer_get_config_defaults(&config_serializer);

    config_serializer.clock_unit = I2S_CLOCK_UNIT_0;
    config_serializer.mode = I2S_SERIALIZER_TRANSMIT;
    config_serializer.data_size = I2S_DATA_SIZE_16BIT;

    config_serializer.data_pin.enable = true;
    config_serializer.data_pin.gpio = CONF_I2S_SD_PIN;
    config_serializer.data_pin.mux = CONF_I2S_SD_MUX;

    i2s_serializer_set_config(&i2s_instance, I2S_SERIALIZER_0,
            &config_serializer);

    i2s_enable(&i2s_instance);
    i2s_clock_unit_enable(&i2s_instance, I2S_CLOCK_UNIT_0);
    i2s_serializer_enable(&i2s_instance, I2S_SERIALIZER_0);
}

static void _configure_i2s_callbacks(void)
{
    i2s_serializer_register_callback(
            &i2s_instance,
            I2S_SERIALIZER_0,
            _i2s_callback_to_send_buffer,
            I2S_SERIALIZER_CALLBACK_BUFFER_DONE);

    i2s_serializer_enable_callback(&i2s_instance,
            I2S_SERIALIZER_0,
            I2S_SERIALIZER_CALLBACK_BUFFER_DONE);
}
```

Add to user application initialization (typically the start of `main()`):

```
_configure_i2s();
_configure_i2s_callbacks();
```

Add to user application start transmitting job (typically in `main()`, after initialization):

```
i2s_serializer_write_buffer_job(&i2s_instance,
        I2S_SERIALIZER_0, data_buffer, 4);
```

Workflow

1. Create a module software instance structure for the I2S module to store the I2S driver state while it is in use.

```
struct i2s_module i2s_instance;
```

Note This should never go out of scope as long as the module is in use. In most cases, this should be global.

2. Configure the I2S module.

   a. Initialize the I2S module.

```
i2s_init(&i2s_instance, CONF_I2S_MODULE);
```

   b. Initialize the I2S Clock Unit.

      i. Create a I2S module configuration struct, which can be filled out to adjust the configuration of a physical I2S Clock Unit.

```
struct i2s_clock_unit_config config_clock_unit;
```

      ii. Initialize the I2S Clock Unit configuration struct with the module's default values.

```
i2s_clock_unit_get_config_defaults(&config_clock_unit);
```

Note This should always be performed before using the configuration struct to ensure that all values are initialized to known default settings.

      iii. Alter the I2S Clock Unit settings to configure the general clock source, MCK, SCK and FS generation.

```
config_clock_unit.clock.gclk_src = GCLK_GENERATOR_0;

config_clock_unit.clock.mck_src = I2S_MASTER_CLOCK_SOURCE_GCLK;
config_clock_unit.clock.mck_out_enable = true;
config_clock_unit.clock.mck_out_div = 2;

config_clock_unit.clock.sck_src = I2S_SERIAL_CLOCK_SOURCE_MCKDIV;
config_clock_unit.clock.sck_div = 4;

config_clock_unit.frame.number_slots = 2;
config_clock_unit.frame.slot_size = I2S_SLOT_SIZE_32_BIT;
config_clock_unit.frame.data_delay = I2S_DATA_DELAY_0;

config_clock_unit.frame.frame_sync.source = I2S_FRAME_SYNC_SOURCE_SCKDIV;
config_clock_unit.frame.frame_sync.width = I2S_FRAME_SYNC_WIDTH_HALF_FRAME;
```

      iv. Alter the I2S Clock Unit settings to configure the MCK, SCK and FS output on physical device pins.

```
config_clock_unit.mck_pin.enable = true;
config_clock_unit.mck_pin.gpio = CONF_I2S_MCK_PIN;
config_clock_unit.mck_pin.mux = CONF_I2S_MCK_MUX;

config_clock_unit.sck_pin.enable = true;
config_clock_unit.sck_pin.gpio = CONF_I2S_SCK_PIN;
config_clock_unit.sck_pin.mux = CONF_I2S_SCK_MUX;

config_clock_unit.fs_pin.enable = true;
config_clock_unit.fs_pin.gpio = CONF_I2S_FS_PIN;
```

```
config_clock_unit.fs_pin.mux = CONF_I2S_FS_MUX;
```

v. Configure the I2S Clock Unit with the desired settings.

```
i2s_clock_unit_set_config(&i2s_instance, I2S_CLOCK_UNIT_0,
        &config_clock_unit);
```

c. Initialize the I2S Serializer.

i. Create a I2S Serializer configuration struct, which can be filled out to adjust the configuration of a physical I2S Serializer.

```
struct i2s_serializer_config config_serializer;
```

ii. Initialize the I2S Serializer configuration struct with the module's default values.

```
i2s_serializer_get_config_defaults(&config_serializer);
```

Note This should always be performed before using the configuration struct to ensure that all values are initialized to known default settings.

iii. Alter the I2S Serializer settings to configure the serial data generation.

```
config_serializer.clock_unit = I2S_CLOCK_UNIT_0;
config_serializer.mode = I2S_SERIALIZER_TRANSMIT;
config_serializer.data_size = I2S_DATA_SIZE_16BIT;
```

iv. Alter the I2S Serializer settings to configure the SD on a physical device pin.

```
config_serializer.data_pin.enable = true;
config_serializer.data_pin.gpio = CONF_I2S_SD_PIN;
config_serializer.data_pin.mux = CONF_I2S_SD_MUX;
```

v. Configure the I2S Serializer with the desired settings.

```
i2s_serializer_set_config(&i2s_instance, I2S_SERIALIZER_0,
        &config_serializer);
```

d. Enable the I2S module, the Clock Unit and Serializer to start the clocks and ready to transmit data.

```
i2s_enable(&i2s_instance);
i2s_clock_unit_enable(&i2s_instance, I2S_CLOCK_UNIT_0);
i2s_serializer_enable(&i2s_instance, I2S_SERIALIZER_0);
```

3. Configure the I2S callbacks.

a. Register the Serializer 0 tx ready callback function with the driver.

```
i2s_serializer_register_callback(
        &i2s_instance,
        I2S_SERIALIZER_0,
        _i2s_callback_to_send_buffer,
```

```
        I2S_SERIALIZER_CALLBACK_BUFFER_DONE);
```

b. Enable the Serializer 0 tx ready callback so that it will be called by the driver when appropriate.

```
i2s_serializer_enable_callback(&i2s_instance,
        I2S_SERIALIZER_0,
        I2S_SERIALIZER_CALLBACK_BUFFER_DONE);
```

4. Start a transmitting job.

```
i2s_serializer_write_buffer_job(&i2s_instance,
        I2S_SERIALIZER_0, data_buffer, 4);
```

23.8.2.2 Use Case

Code

Copy-paste the following code to your user application:

```
system_interrupt_enable_global();

i2s_serializer_write_buffer_job(&i2s_instance,
        I2S_SERIALIZER_0, data_buffer, 4);

while (true) {
}
```

Workflow

1. Enter an infinite loop while the output is generated via the I2S module.

```
while (true) {
}
```

23.8.3 Quick Start Guide for I2S - DMA

In this use case, the I2S will be used to generate Master Clock (MCK), Serial Clock (SCK), Frame Sync (FS) and Serial Data (SD) signals.

Here MCK is set to the half of processor clock. SCK is set to a quarter of the frequency of processor. FS generates half-half square wave for left and right audio channel data. The output serial data of channels toggle from two values to generate square wave, if codec or DAC is connected.

The output SD is also fed back to another I2S channel by internal loop back, and transfer to values buffer by DMA.

The I2S module will be setup as follows:

- GCLK generator 0 (GCLK main) clock source
- MCK, SCK and FS clocks outputs are enabled
- MCK output divider set to 2
- SCK generation divider set to 4
- Each frame will contain 2 32-bit slots
- Data will be left adjusted and start transmit without delay

23.8.3.1 Quick Start

Prerequisites

There are no prerequisites for this use case.

Code

Add to the main application source file, before any functions:

```
#define CONF_I2S_MODULE      I2S

#define CONF_I2S_MCK_PIN     PIN_PA09G_I2S_MCK0

#define CONF_I2S_MCK_MUX     MUX_PA09G_I2S_MCK0

#define CONF_I2S_SCK_PIN     PIN_PA10G_I2S_SCK0

#define CONF_I2S_SCK_MUX     MUX_PA10G_I2S_SCK0

#define CONF_I2S_FS_PIN      PIN_PA11G_I2S_FS0

#define CONF_I2S_FS_MUX      MUX_PA11G_I2S_FS0

#define CONF_I2S_SD_PIN      PIN_PA07G_I2S_SD0

#define CONF_I2S_SD_MUX      MUX_PA07G_I2S_SD0
```

```
#define CONF_RX_TRIGGER 0x2A
```

```
#define CONF_TX_TRIGGER 0x2B
```

Add to the main application source file, outside of any functions:

```
struct i2s_module i2s_instance;
```

```
uint16_t rx_values[4] = {0xEEEE, 0xEEEE, 0xEEEE, 0xEEEE};
struct dma_resource rx_dma_resource;
COMPILER_ALIGNED(16) DmacDescriptor rx_dma_descriptor;
```

```
uint16_t tx_values[4] = {0xF87F, 0x901F, 0, 0};
struct dma_resource tx_dma_resource;
COMPILER_ALIGNED(16) DmacDescriptor tx_dma_descriptor;
```

Copy-paste the following setup code to your user application:

```
static void _config_dma_for_rx(void)
{
    struct dma_resource_config config;

    dma_get_config_defaults(&config);

    config.trigger_action = DMA_TRIGGER_ACTON_BEAT;
    config.peripheral_trigger = CONF_RX_TRIGGER;

    dma_allocate(&rx_dma_resource, &config);
```

```
    struct dma_descriptor_config descriptor_config;

    dma_descriptor_get_config_defaults(&descriptor_config);

    descriptor_config.block_transfer_count = 4;
    descriptor_config.beat_size = DMA_BEAT_SIZE_HWORD;
    descriptor_config.step_selection = DMA_STEPSEL_SRC;
    descriptor_config.src_increment_enable = false;
    descriptor_config.destination_address =
            (uint32_t)rx_values + sizeof(rx_values);
    descriptor_config.source_address = (uint32_t)&CONF_I2S_MODULE->DATA[1];

    dma_descriptor_create(&rx_dma_descriptor, &descriptor_config);

    rx_dma_descriptor.DESCADDR.reg = (uint32_t)&rx_dma_descriptor;

    dma_add_descriptor(&rx_dma_resource, &rx_dma_descriptor);
    dma_start_transfer_job(&rx_dma_resource);
}
```

```
static void _config_dma_for_tx(void)
{
    struct dma_resource_config config;
    dma_get_config_defaults(&config);
    config.trigger_action = DMA_TRIGGER_ACTON_BEAT;
    config.peripheral_trigger = CONF_TX_TRIGGER;
    dma_allocate(&tx_dma_resource, &config);

    struct dma_descriptor_config descriptor_config;

    dma_descriptor_get_config_defaults(&descriptor_config);

    descriptor_config.block_transfer_count = 4;
    descriptor_config.beat_size = DMA_BEAT_SIZE_HWORD;
    descriptor_config.dst_increment_enable = false;
    descriptor_config.source_address =
            (uint32_t)tx_values + sizeof(tx_values);
    descriptor_config.destination_address = (uint32_t)&CONF_I2S_MODULE->DATA[0];

    dma_descriptor_create(&tx_dma_descriptor, &descriptor_config);

    tx_dma_descriptor.DESCADDR.reg = (uint32_t)&tx_dma_descriptor;

    dma_add_descriptor(&tx_dma_resource, &tx_dma_descriptor);
    dma_start_transfer_job(&tx_dma_resource);
}
```

```
static void _configure_i2s(void)
{
    i2s_init(&i2s_instance, CONF_I2S_MODULE);

    struct i2s_clock_unit_config config_clock_unit;
    i2s_clock_unit_get_config_defaults(&config_clock_unit);

    config_clock_unit.clock.gclk_src = GCLK_GENERATOR_0;

    config_clock_unit.clock.mck_src = I2S_MASTER_CLOCK_SOURCE_GCLK;
    config_clock_unit.clock.mck_out_enable = true;
```

```
    config_clock_unit.clock.mck_out_div = 2;

    config_clock_unit.clock.sck_src = I2S_SERIAL_CLOCK_SOURCE_MCKDIV;
    config_clock_unit.clock.sck_div = 4;

    config_clock_unit.frame.number_slots = 2;
    config_clock_unit.frame.slot_size = I2S_SLOT_SIZE_32_BIT;
    config_clock_unit.frame.data_delay = I2S_DATA_DELAY_0;

    config_clock_unit.frame.frame_sync.source = I2S_FRAME_SYNC_SOURCE_SCKDIV;
    config_clock_unit.frame.frame_sync.width = I2S_FRAME_SYNC_WIDTH_HALF_FRAME;

    config_clock_unit.mck_pin.enable = true;
    config_clock_unit.mck_pin.gpio = CONF_I2S_MCK_PIN;
    config_clock_unit.mck_pin.mux = CONF_I2S_MCK_MUX;

    config_clock_unit.sck_pin.enable = true;
    config_clock_unit.sck_pin.gpio = CONF_I2S_SCK_PIN;
    config_clock_unit.sck_pin.mux = CONF_I2S_SCK_MUX;

    config_clock_unit.fs_pin.enable = true;
    config_clock_unit.fs_pin.gpio = CONF_I2S_FS_PIN;
    config_clock_unit.fs_pin.mux = CONF_I2S_FS_MUX;

    i2s_clock_unit_set_config(&i2s_instance, I2S_CLOCK_UNIT_0,
            &config_clock_unit);

    struct i2s_serializer_config config_serializer;
    i2s_serializer_get_config_defaults(&config_serializer);

    config_serializer.clock_unit = I2S_CLOCK_UNIT_0;
    config_serializer.mode = I2S_SERIALIZER_TRANSMIT;
    config_serializer.data_size = I2S_DATA_SIZE_16BIT;

    config_serializer.data_pin.enable = true;
    config_serializer.data_pin.gpio = CONF_I2S_SD_PIN;
    config_serializer.data_pin.mux = CONF_I2S_SD_MUX;

    i2s_serializer_set_config(&i2s_instance, I2S_SERIALIZER_0,
            &config_serializer);

    config_serializer.loop_back = true;
    config_serializer.mode = I2S_SERIALIZER_RECEIVE;
    config_serializer.data_size = I2S_DATA_SIZE_16BIT;

    config_serializer.data_pin.enable = false;

    i2s_serializer_set_config(&i2s_instance, I2S_SERIALIZER_1,
            &config_serializer);

    i2s_enable(&i2s_instance);
    i2s_clock_unit_enable(&i2s_instance, I2S_CLOCK_UNIT_0);
    i2s_serializer_enable(&i2s_instance, I2S_SERIALIZER_1);
    i2s_serializer_enable(&i2s_instance, I2S_SERIALIZER_0);
}
```

Add to user application initialization (typically the start of `main()`):

```
_config_dma_for_rx();
_config_dma_for_tx();
```

```
_configure_i2s();
```

Workflow

Configure the DMAC module to obtain received value from I2S Serializer 1.

1. Allocate and configure the DMA resource
   a. Create a DMA resource instance.

```
struct dma_resource rx_dma_resource;
```

Note This should never go out of scope as long as the resource is in use. In most cases, this should be global.

   b. Create a DMA resource configuration struct.

```
struct dma_resource_config config;
```

   c. Initialize the DMA resource configuration struct with default values.

```
dma_get_config_defaults(&config);
```

Note This should always be performed before using the configuration struct to ensure that all values are initialized to known default settings.

   d. Adjust the DMA resource configurations.

```
config.trigger_action = DMA_TRIGGER_ACTON_BEAT;
config.peripheral_trigger = CONF_RX_TRIGGER;
```

   e. Allocate a DMA resource with the configurations.

```
dma_allocate(&rx_dma_resource, &config);
```

2. Prepare DMA transfer descriptor
   a. Create a DMA transfer descriptor.

```
COMPILER_ALIGNED(16) DmacDescriptor rx_dma_descriptor;
```

Note When multiple descriptors are linked. The linked item should never go out of scope before it's loaded (to DMA Write-Back memory section). In most cases, if more than one descriptors are used, they should be global except the very first one.

   b. Create a DMA transfer descriptor configuration struct, which can be filled out to adjust the configuration of a single DMA transfer.

```
struct dma_descriptor_config descriptor_config;
```

c. Initialize the DMA transfer descriptor configuration struct with default values.

```
dma_descriptor_get_config_defaults(&descriptor_config);
```

Note

This should always be performed before using the configuration struct to ensure that all values are initialized to known default settings.

d. Adjust the DMA transfer descriptor configurations.

```
descriptor_config.block_transfer_count = 4;
descriptor_config.beat_size = DMA_BEAT_SIZE_HWORD;
descriptor_config.step_selection = DMA_STEPSEL_SRC;
descriptor_config.src_increment_enable = false;
descriptor_config.destination_address =
        (uint32_t)rx_values + sizeof(rx_values);
descriptor_config.source_address = (uint32_t)&CONF_I2S_MODULE->DATA[1];
```

e. Create the DMA transfer descriptor with configuration.

```
dma_descriptor_create(&rx_dma_descriptor, &descriptor_config);
```

f. Adjust the DMA transfer descriptor if multiple DMA transfer will be performed.

```
rx_dma_descriptor.DESCADDR.reg = (uint32_t)&rx_dma_descriptor;
```

3. Start DMA transfer job with prepared descriptor

a. Add the DMA transfer descriptor to the allocated DMA resource.

```
dma_add_descriptor(&rx_dma_resource, &rx_dma_descriptor);
```

b. Start the DMA transfer job with the allocated DMA resource and transfer descriptor.

```
dma_start_transfer_job(&rx_dma_resource);
```

Configure the DMAC module to transmit data through I2S serializer 0.

The flow is similar to last DMA configure step for receive.

1. Allocate and configure the DMA resource

```
struct dma_resource tx_dma_resource;
```

```
struct dma_resource_config config;
dma_get_config_defaults(&config);
config.trigger_action = DMA_TRIGGER_ACTON_BEAT;
config.peripheral_trigger = CONF_TX_TRIGGER;
dma_allocate(&tx_dma_resource, &config);
```

2. Prepare DMA transfer descriptor

```
COMPILER_ALIGNED(16) DmacDescriptor tx_dma_descriptor;
```

```
struct dma_descriptor_config descriptor_config;

dma_descriptor_get_config_defaults(&descriptor_config);

descriptor_config.block_transfer_count = 4;
descriptor_config.beat_size = DMA_BEAT_SIZE_HWORD;
descriptor_config.dst_increment_enable = false;
descriptor_config.source_address =
        (uint32_t)tx_values + sizeof(tx_values);
descriptor_config.destination_address = (uint32_t)&CONF_I2S_MODULE->DATA[0];

dma_descriptor_create(&tx_dma_descriptor, &descriptor_config);

tx_dma_descriptor.DESCADDR.reg = (uint32_t)&tx_dma_descriptor;
```

3. Start DMA transfer job with prepared descriptor

```
dma_add_descriptor(&tx_dma_resource, &tx_dma_descriptor);
dma_start_transfer_job(&tx_dma_resource);
```

Configure the I2S

1. Create I2S module software instance structure for the I2S module to store the I2S driver state while it is in use.

```
struct i2s_module i2s_instance;
```

Note This should never go out of scope as long as the module is in use. In most cases, this should be global.

2. Configure the I2S module.
   a. Initialize the I2S module.

```
i2s_init(&i2s_instance, CONF_I2S_MODULE);
```

   b. Initialize the I2S Clock Unit.
      i. Create a I2S module configuration struct, which can be filled out to adjust the configuration of a physical I2S Clock Unit.

```
struct i2s_clock_unit_config config_clock_unit;
```

      ii. Initialize the I2S Clock Unit configuration struct with the module's default values.

```
i2s_clock_unit_get_config_defaults(&config_clock_unit);
```

Note This should always be performed before using the configuration struct to ensure that all values are initialized to known default settings.

iii. Alter the I2S Clock Unit settings to configure the general clock source, MCK, SCK and FS generation.

```
config_clock_unit.clock.gclk_src = GCLK_GENERATOR_0;

config_clock_unit.clock.mck_src = I2S_MASTER_CLOCK_SOURCE_GCLK;
config_clock_unit.clock.mck_out_enable = true;
config_clock_unit.clock.mck_out_div = 2;

config_clock_unit.clock.sck_src = I2S_SERIAL_CLOCK_SOURCE_MCKDIV;
config_clock_unit.clock.sck_div = 4;

config_clock_unit.frame.number_slots = 2;
config_clock_unit.frame.slot_size = I2S_SLOT_SIZE_32_BIT;
config_clock_unit.frame.data_delay = I2S_DATA_DELAY_0;

config_clock_unit.frame.frame_sync.source = I2S_FRAME_SYNC_SOURCE_SCKDIV;
config_clock_unit.frame.frame_sync.width = I2S_FRAME_SYNC_WIDTH_HALF_FRAME;
```

iv. Alter the I2S Clock Unit settings to configure the MCK, SCK and FS output on physical device pins.

```
config_clock_unit.mck_pin.enable = true;
config_clock_unit.mck_pin.gpio = CONF_I2S_MCK_PIN;
config_clock_unit.mck_pin.mux = CONF_I2S_MCK_MUX;

config_clock_unit.sck_pin.enable = true;
config_clock_unit.sck_pin.gpio = CONF_I2S_SCK_PIN;
config_clock_unit.sck_pin.mux = CONF_I2S_SCK_MUX;

config_clock_unit.fs_pin.enable = true;
config_clock_unit.fs_pin.gpio = CONF_I2S_FS_PIN;
config_clock_unit.fs_pin.mux = CONF_I2S_FS_MUX;
```

v. Configure the I2S Clock Unit with the desired settings.

```
i2s_clock_unit_set_config(&i2s_instance, I2S_CLOCK_UNIT_0,
        &config_clock_unit);
```

c. Initialize the I2S Serializers.

i. Create a I2S Serializer configuration struct, which can be filled out to adjust the configuration of a physical I2S Serializer.

```
struct i2s_serializer_config config_serializer;
```

ii. Initialize the I2S Serializer configuration struct with the module's default values.

```
i2s_serializer_get_config_defaults(&config_serializer);
```

Note This should always be performed before using the configuration struct to ensure that all values are initialized to known default settings.

iii. Alter the I2S Serializer settings to configure the SD transmit generation.

```
config_serializer.clock_unit = I2S_CLOCK_UNIT_0;
config_serializer.mode = I2S_SERIALIZER_TRANSMIT;
config_serializer.data_size = I2S_DATA_SIZE_16BIT;
```

iv. Alter the I2S Serializer settings to configure the SD transmit on a physical device pin.

```
config_serializer.data_pin.enable = true;
config_serializer.data_pin.gpio = CONF_I2S_SD_PIN;
config_serializer.data_pin.mux = CONF_I2S_SD_MUX;
```

v. Configure the I2S Serializer 0 with the desired transmit settings.

```
i2s_serializer_set_config(&i2s_instance, I2S_SERIALIZER_0,
        &config_serializer);
```

vi. Alter the I2S Serializer settings to configure the SD receive.

```
config_serializer.loop_back = true;
config_serializer.mode = I2S_SERIALIZER_RECEIVE;
config_serializer.data_size = I2S_DATA_SIZE_16BIT;
```

vii. Alter the I2S Serializer settings to configure the SD receive on a physical device pin (here it's disabled since we use internal loopback).

```
config_serializer.data_pin.enable = false;
```

viii. Configure the I2S Serializer 1 with the desired transmit settings.

```
i2s_serializer_set_config(&i2s_instance, I2S_SERIALIZER_1,
        &config_serializer);
```

d. Enable the I2S module, the Clock Unit and Serializer to start the clocks and ready to transmit data.

```
i2s_enable(&i2s_instance);
i2s_clock_unit_enable(&i2s_instance, I2S_CLOCK_UNIT_0);
i2s_serializer_enable(&i2s_instance, I2S_SERIALIZER_1);
i2s_serializer_enable(&i2s_instance, I2S_SERIALIZER_0);
```

23.8.3.2 Use Case

Code

Copy-paste the following code to your user application:

```
while (true) {
    /* Infinite loop */
}
```

Workflow

1. Enter an infinite loop while the signals are generated via the I2S module.

```
while (true) {
    /* Infinite loop */
}
```

24. SAM D21 Timer Counter for Control Applications Driver (TCC)

This driver for SAM D21 devices provides an interface for the configuration and management of the TCC module within the device, for waveform generation and timing operations. It also provides extended options for control applications.

The following driver API modes are covered by this manual:

- Polled APIs
- Callback APIs

The following peripherals are used by this module:

- TCC (Timer/Counter for Control Applications)

The outline of this documentation is as follows:

- Prerequisites
- Module Overview
- Special Considerations
- Extra Information
- Examples
- API Overview

24.1 Prerequisites

There are no prerequisites for this module.

24.2 Module Overview

The Timer/Counter for Control Applications (TCC) module provides a set of timing and counting related functionality, such as the generation of periodic waveforms, the capturing of a periodic waveform's frequency/duty cycle, software timekeeping for periodic operations, waveform extension control, fault detection etc.

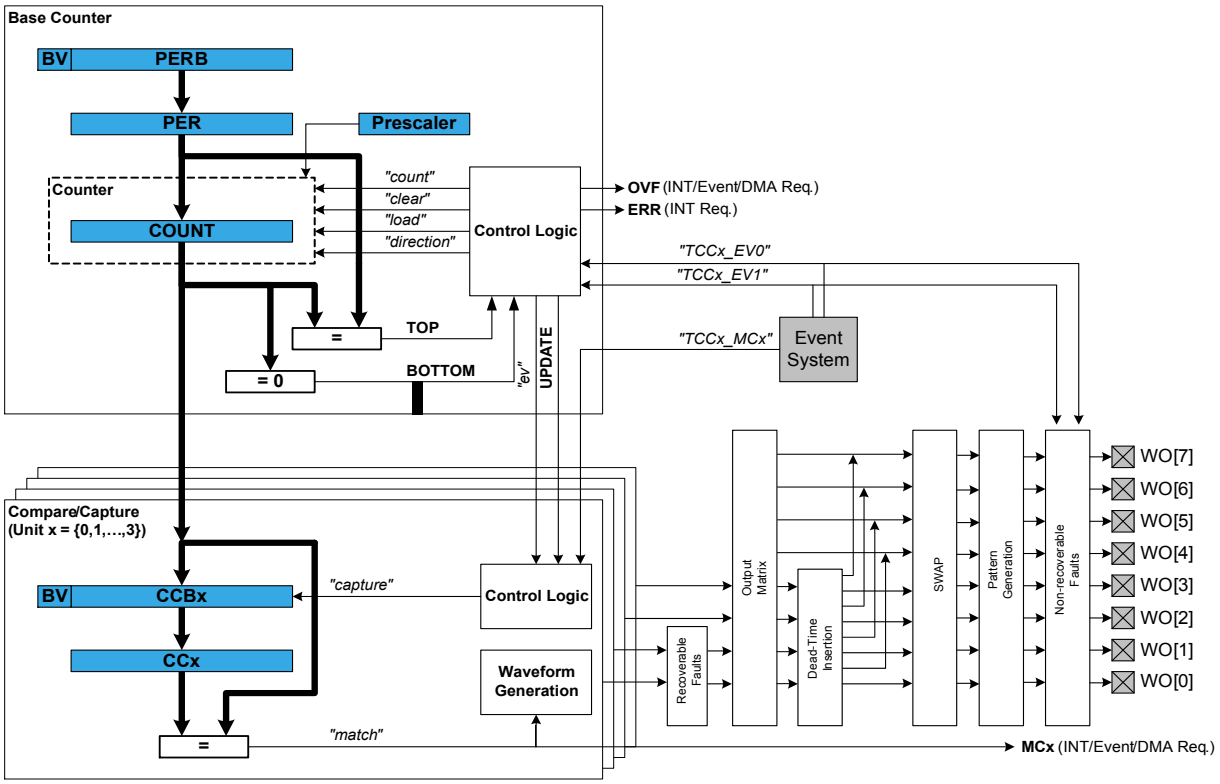
The counter size of the TCC modules can be 16- or 24-bit depending on the TCC instance. Please refer SAM D21 TCC Feature List for details on TCC instances.

The TCC module for the SAM D21 includes the following functions:

- Generation of PWM signals
- Generation of timestamps for events
- General time counting
- Waveform period capture
- Waveform frequency capture
- Additional control for generated waveform outputs
- Fault protection for waveform generation

Figure 24-1: Overview of the TCC module on page 577 shows the overview of the TCC module.

Figure 24-1. Overview of the TCC module



24.2.1 Functional Description

The TCC module consists of following sections:

- Base Counter
- Compare/Capture channels, with waveform generation
- Waveform extension control and fault detection
- Interface to the event system, DMAC and the interrupt system

The base counter can be configured to either count a prescaled generic clock or events from the event system. (TCEx, with event action configured to counting). The counter value can be used by compare/capture channels which can be set up either in compare mode or capture mode.

In capture mode, the counter value is stored when a configurable event occurs. This mode can be used to generate timestamps used in event capture, or it can be used for the measurement of a periodic input signal's frequency/duty cycle.

In compare mode, the counter value is compared against one or more of the configured channels' compare values. When the counter value coincides with a compare value an action can be taken automatically by the module, such as generating an output event or toggling a pin when used for frequency or PWM signal generation.

Note

The connection of events between modules requires the use of the SAM Event System Driver (EVENTS) to route output event of one module to the the input event of another. For more information on event routing, refer to the event driver documentation.

In compare mode, when output signal is generated, extended waveform controls are available, to arrange the compare outputs into specific formats. The Output matrix can change the channel output routing, Pattern generation unit can overwrite the output signal line to specific state. The Fault protection feature of the TCC supports recoverable and non-recoverable faults.

24.2.2 Base Timer/Counter

24.2.2.1 Timer/Counter Size

Each TCC has a counter size of either 16- or 24-bits. The size of the counter determines the maximum value it can count to before an overflow occurs. Table 24-1: Timer counter sizes and their maximum count values on page 578 shows the maximum values for each of the possible counter sizes.

Table 24-1. Timer counter sizes and their maximum count values

Counter Size	Max (Hexadecimal)	Max (Decimal)
16-bit	0xFFFF	65,535
24-bit	0xFFFFFF	16,777,215

The period/top value of the counter can be set, to define counting period. This will allow the counter to overflow when the counter value reaches the period/top value.

24.2.2.2 Timer/Counter Clock and Prescaler

TCC is clocked asynchronously to the system clock by a GCLK (Generic Clock) channel. The GCLK channel can be connected to any of the GCLK generators. The GCLK generators are configured to use one of the available clock sources in the system such as internal oscillator, external crystals etc. - see the Generic Clock driver for more information.

Each TCC module in the SAM D21 has its own individual clock prescaler, which can be used to divide the input clock frequency used by the counter. This prescaler only scales the clock used to provide clock pulses for the counter to count, and does not affect the digital register interface portion of the module, thus the timer registers will synchronized to the raw GCLK frequency input to the module.

As a result of this, when selecting a GCLK frequency and timer prescaler value the user application should consider both the timer resolution required and the synchronization frequency, to avoid lengthy synchronization times of the module if a very slow GCLK frequency is fed into the TCC module. It is preferable to use a higher module GCLK frequency as the input to the timer and prescale this down as much as possible to obtain a suitable counter frequency in latency-sensitive applications.

24.2.2.3 Timer/Counter Control Inputs (Events)

The TCC can take several actions on the occurrence of an input event. The event actions are listed in Table 24-2: TCC module event actions on page 578.

Table 24-2. TCC module event actions

Event Action	Description	Applied Event
TCC_EVENT_ACTION_OFF	No action on the event input	All
TCC_EVENT_ACTION_RETRIGGEF	Re-trigger Counter on event	All
TCC_EVENT_ACTION_NON_RECO	Generate Non-Recoverable Fault on event	All
TCC_EVENT_ACTION_START	Counter start on event	EV0
TCC_EVENT_ACTION_DIR_CONTF	Counter direction control	EV0
TCC_EVENT_ACTION_DECREMEN	Counter decrement on event	EV0
TCC_EVENT_ACTION_PERIOD_PU	Capture pulse period and pulse width	EV0
TCC_EVENT_ACTION_PULSE_WID	Capture pulse width and pulse period	EV0
TCC_EVENT_ACTION_STOP	Counter stop on event	EV1
TCC_EVENT_ACTION_COUNT_EV	Counter count on event	EV1
TCC_EVENT_ACTION_INCREMEN	Counter increment on event	EV1

Event Action	Description	Applied Event
TCC_EVENT_ACTION_COUNT_DU	Counter count during active state of asynchronous event	EV1

24.2.2.4 Timer/Counter Reloading

The TCC also has a configurable reload action, used when a re-trigger event occurs. Examples of a re-trigger event could be the counter reaching the max value when counting up, or when an event from the event system makes the counter to re-trigger. The reload action determines if the prescaler should be reset, and on which clock. The counter will always be reloaded with the value it is set to start counting. The user can choose between three different reload actions, described in Table 24-3: TCC module reload actions on page 579.

Table 24-3. TCC module reload actions

Reload Action	Description
TCC_RELOAD_ACTION_GCLK	Reload TCC counter value on next GCLK cycle. Leave prescaler as-is.
TCC_RELOAD_ACTION_PRESC	Reloads TCC counter value on next prescaler clock. Leave prescaler as-is.
TCC_RELOAD_ACTION_RESYNC	Reload TCC counter value on next GCLK cycle. Clear prescaler to zero.

The reload action to use will depend on the specific application being implemented. One example is when an external trigger for a reload occurs; if the TCC uses the prescaler, the counter in the prescaler should not have a value between zero and the division factor. The counter in the TCC module and the counter in the prescaler should both start at zero. If the counter is set to re-trigger when it reaches the max value, this is not the right option to use. In such a case it would be better if the prescaler is left unaltered when the re-trigger happens, letting the counter reset on the next GCLK cycle.

24.2.2.5 One-shot Mode

The TCC module can be configured in one-shot mode. When configured in this manner, starting the timer will cause it to count until the next overflow or underflow condition before automatically halting, waiting to be manually triggered by the user application software or an event from the event system.

24.2.3 Capture Operations

In capture operations, any event from the event system or a pin change can trigger a capture of the counter value. This captured counter value can be used as timestamps for the events, or it can be used in frequency and pulse width capture.

24.2.3.1 Capture Operations - Event

Event capture is a simple use of the capture functionality, designed to create timestamps for specific events. When the input event appears, the current counter value is copied into the corresponding compare/capture register, which can then be read by the user application.

Note that when performing any capture operation, there is a risk that the counter reaches its top value (MAX) when counting up, or the bottom value (zero) when counting down, before the capture event occurs. This can distort the result, making event timestamps to appear shorter than they really are. In this case, the user application should check for timer overflow when reading a capture result in order to detect this situation and perform an appropriate adjustment.

Before checking for a new capture, TCC_STATUS_COUNT_OVERFLOW should be checked. The response to an overflow error is left to the user application, however it may be necessary to clear both the overflow flag and the capture flag upon each capture reading.

24.2.3.2 Capture Operations - Pulse Width

Pulse Width Capture mode makes it possible to measure the pulse width and period of PWM signals. This mode uses two capture channels of the counter. There are two modes for pulse width capture; Pulse Width Period (PWP) and Period Pulse Width (PPW). In PWP mode, capture channel 0 is used for storing the pulse width and capture channel 1 stores the observed period. While in PPW mode, the roles of the two capture channels are reversed.

As in the above example it is necessary to poll on interrupt flags to see if a new capture has happened and check that a capture overflow error has not occurred.

Refer to Timer/Counter Control Inputs (Events) to set up the input event to perform pulse width capture.

24.2.4 Compare Match Operation

In compare match operation, Compare/Capture registers are compared with the counter value. When the timer's count value matches the value of a compare channel, a user defined action can be taken.

24.2.4.1 Basic Timer

A Basic Timer is a simple application where compare match operation is used to determine when a specific period has elapsed. In Basic Timer operations, one or more values in the module's Compare/Capture registers are used to specify the time (in terms of the number of prescaled GCLK cycles, or input events) at which an action should be taken by the microcontroller. This can be an Interrupt Service Routine (ISR), event generation via the event system, or a software flag that is polled from the user application.

24.2.4.2 Waveform Generation

Waveform generation enables the TCC module to generate square waves, or if combined with an external passive low-pass filter, analog waveforms.

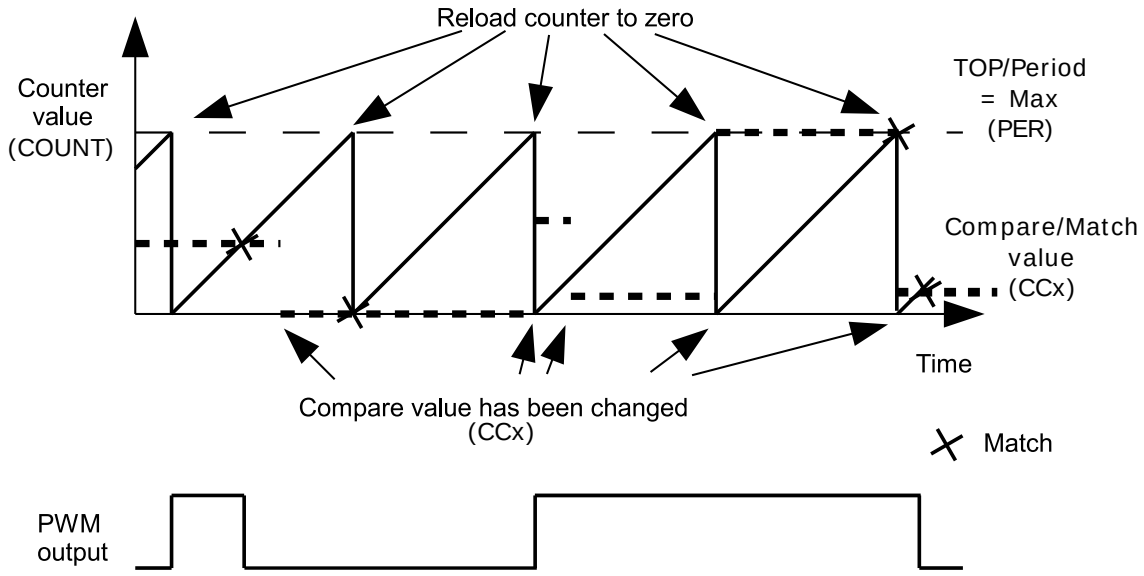
24.2.4.3 Waveform Generation - PWM

Pulse width modulation is a form of waveform generation and a signalling technique that can be useful in many applications. When PWM mode is used, a digital pulse train with a configurable frequency and duty cycle can be generated by the TCC module and output to a GPIO pin of the device.

Often PWM is used to communicate a control or information parameter to an external circuit or component. Differing impedances of the source generator and sink receiver circuits is less of an issue when using PWM compared to using an analog voltage value, as noise will not generally affect the signal's integrity to a meaningful extent.

Figure 24-2: Example of PWM in Single-Slope mode, and different counter operations on page 580 illustrates operations and different states of the counter and its output when using the timer in Normal PWM mode(Single Slope). As can be seen, the TOP/PERIOD value is unchanged and is set to MAX. The compare match value is changed at several points to illustrate the resulting waveform output changes. The PWM output is set to normal (i.e. non-inverted) output mode.

Figure 24-2. Example of PWM in Single-Slope mode, and different counter operations



Several PWM modes are supported by the TCC module, refer to datasheet for the details on PWM waveform generation.

24.2.4.4 Waveform Generation - Frequency

Normal Frequency Generation is in many ways identical to PWM generation. However, only in Frequency Generation, a toggle occurs on the output when a match on a compare channels occurs.

When the Match Frequency Generation is used, the timer value is reset on match condition, resulting in a variable frequency square wave with a fixed 50% duty cycle.

24.2.5 Waveform Extended Controls

24.2.5.1 Pattern Generation

Pattern insertion allows the TCC module to change the actual pin output level without modifying the compare/match settings. As follow:

Table 24-4. TCC module Output Pattern Generation

Pattern	Description
TCC_OUTPUT_PATTERN_DISABLE	Pattern disabled, generate output as is
TCC_OUTPUT_PATTERN_0	Generate pattern 0 on output (keep the output LOW)
TCC_OUTPUT_PATTERN_1	Generate pattern 1 on output (keep the output HIGH)

24.2.5.2 Recoverable Faults

The recoverable faults can trigger one or several of following fault actions:

1. *Halt* action: The recoverable faults can halt the TCC timer/counter, so that the final output wave is kept at a defined state. When the fault state is removed it's possible to recover the counter and waveform generation. The halt action is defined as follow:

   Table 24-5. TCC module Recoverable Fault Halt Actions

Action	Description
TCC_FAULT_HALT_ACTION_DISABLE	Halt action is disabled
TCC_FAULT_HALT_ACTION_HW_HALT	The timer/counter is halted as long as the corresponding fault is present
TCC_FAULT_HALT_ACTION_SW_HALT	The timer/counter is halted until the corresponding fault is removed and fault state cleared by software
TCC_FAULT_HALT_ACTION_NON_RECOVERABLE	Force all the TCC output pins to a pre-defined level, as what Non-Recoverable Fault do

2. *Restart* action: When enabled, the recoverable faults can restart the TCC timer/counter.

3. *Keep* action: When enabled, the recoverable faults can keep the corresponding channel output to zero when the fault condition is present.

4. *Capture* action: When the recoverable fault occurs, the capture action can time stamps the corresponding fault. The following capture mode is supported:

   Table 24-6. TCC module Recoverable Fault Capture Actions

Action	Description
TCC_FAULT_CAPTURE_DISABLE	Capture action is disabled
TCC_FAULT_CAPTURE_EACH	Equivalent to standard capture operation, on each fault occurrence the time stamp is captured
TCC_FAULT_CAPTURE_MINIMUM	Get the minimum time stamped value in all time stamps

Action	Description
TCC_FAULT_CAPTURE_MAXIMUM	Get the maximum time stamped value in all time stamps
TCC_FAULT_CAPTURE_SMALLER	Time stamp the fault input if the value is smaller than last one
TCC_FAULT_CAPTURE_BIGGER	Time stamp the fault input if the value is bigger than last one
TCC_FAULT_CAPTURE_CHANGE	Time stamp the fault input if the time stamps changes its increment direction

In TCC module, only the first two compare channels (CC0 and CC1) can work with recoverable fault inputs. The corresponding event inputs (TCCx MC0 and TCCx MC1) are then used as fault inputs respectively. The faults are called Fault A and Fault B.

The recoverable fault can be filtered or effected by corresponding channel output. On fault condition there are many other settings that can be chosen. Please refer to data sheet for more details about the recoverable fault operations.

24.2.5.3 Non-Recoverable Faults

The non-recoverable faults force all the TCC output pins to a pre-defined level (can be forced to 0 or 1). The input control signal of non-recoverable fault is from timer/counter event (TCCx EV0 and TCCx EV1). To enable non-recoverable fault, corresponding TCEx event action must be set to non-recoverable fault action (TCC_EVENT_ACTION_NON_RECOVERABLE_FAULT on page 610). Refer to Timer/Counter Control Inputs (Events) to see the available event input action.

24.2.6 Double and Circular Buffering

The pattern, period and the compare channels registers are double buffered. For these options there are effective registers (PATT, PER and CCx) and buffer registers (PATTB, PERB and CCx). When writing to the buffer registers, the values are buffered and will be committed to effective registers on UPDATE condition.

Usually the buffered value is cleared after it's committed, but there is also option to circular the register buffers. The period (PER) and four lowest compare channels register (CCx, x is 0 ~ 3) support this function. When circular buffer is used, on UPDATE the previous period or compare values are copied back into the corresponding period buffer and compare buffers. This way, the register value and its buffer register value is actually switched on UPDATE condition, and will be switched back on next UPDATE condition.

For input capture, the buffer register (CCBx) and the corresponding capture channel register (CCx) act like a FIFO. When regular register (CCx) is empty or read, any content in the buffer register is passed to regular one.

In TCC module driver, when the double buffering write is enabled, any write through tcc_set_top_value(), tcc_set_compare_value() and tcc_set_pattern() will be done to the corresponding buffer register. Then the value in the buffer register will be transferred to the regular register on the next UPDATE condition or by a force UPDATE using tcc_force_double_buffer_update().

24.2.7 Sleep Mode

TCC modules can be configured to operate in any sleep mode, with its "run in standby" function enabled. It can wakeup the device using interrupts or perform internal actions with the help of the Event System.

24.3 Special Considerations

24.3.1 Module Features

The features of TCC, such as timer/counter size, number of compare capture channels, number of outputs, are dependent on the TCC module instance being used.

24.3.1.1 SAM D21 TCC Feature List

For SAM D21, the TCC features are as follow:

Table 24-7. TCC module features for SAM D21

TCC#	Match/ Capture Channels	Wave outputs	Counter Size (bits)	Fault	Dithering	Output Matrix	Dead-Time Insertion	SWAP	Pattern
0	4	8	24	Y	Y	Y	Y	Y	Y
1	2	4	24	Y	Y				Y
2	2	2	16	Y					

24.3.2 Channels VS. Pin outs

As the TCC module may have more waveform output pins than the number of compare/capture channels, the free pins (with number higher than number of channels) will reuse the waveform generated by channels subsequently. E.g., if the number of channels is 4 and number of wave output pins is 8, channel 0 output will be available on out pin 0 and 4, channel 1 output on wave out pin 1 and 5, and so on.

24.4 Extra Information

For extra information see Extra Information for TCC Driver. This includes:

- Acronyms
- Dependencies
- Errata
- Module History

24.5 Examples

For a list of examples related to this driver, see Examples for TCC Driver.

24.6 API Overview

24.6.1 Variable and Type Definitions

24.6.1.1 Type tcc_callback_t

```
typedef void(* tcc_callback_t )(struct tcc_module *const module)
```

Type definition for the TCC callback function

24.6.2 Structure Definitions

24.6.2.1 Struct tcc_capture_config

Structure used when configuring TCC channels in capture mode

Table 24-8. Members

Type	Name	Description
enum tcc_channel_function	channel_function[]	Channel functions selection (capture/match)

24.6.2.2 Struct tcc_config

Configuration struct for a TCC instance. This structure should be initialized by the tcc_get_config_defaults function before being modified by the user application.

Table 24-9. Members

Type	Name	Description
union tcc_config.@412	@412	TCC match/capture configurations.
struct tcc_counter_config	counter	Structure for configuring TCC base timer/counter
bool	double_buffering_enabled	Set to true to enable double buffering write. When enabled any write through tcc_set_top_value(), tcc_set_compare_value() and tcc_set_pattern() will direct to the buffer register as buffered value, and the buffered value will be committed to effective register on UPDATE condition, if update is not locked.[1]
struct tcc_pins_config	pins	Structure for configuring TCC output pins
bool	run_in_standby	When true the module is enabled during standby
struct tcc_wave_extension_config	wave_ext	Structure for configuring TCC waveform extension

Notes: [1]The init values in tcc_config for tcc_init are always filled to effective registers, no matter double buffering enabled or not.

24.6.2.3 Union tcc_config.__unnamed__

TCC match/capture configurations.

Table 24-10. Members

Type	Name	Description
struct tcc_capture_config	capture	Helps to configure a TCC channel in capture mode
struct tcc_match_wave_config	compare	For configuring a TCC channel in compare mode
struct tcc_match_wave_config	wave	Serves the same purpose as compare. Used as an alias for compare, when a TCC channel is configured for wave generation

24.6.2.4 Struct tcc_counter_config

Structure for configuring a TCC as a counter

Table 24-11. Members

Type	Name	Description
enum tcc_clock_prescaler	clock_prescaler	Specifies the prescaler value for GCLK_TCC.
enum gclk_generator	clock_source	GCLK generator used to clock the peripheral.

Type	Name	Description
uint32_t	count	Value to initialize the count register
enum tcc_count_direction	direction	Specifies the direction for the TCC to count.
bool	oneshot	When true, counter will be stopped on the next hardware or software re-trigger event or overflow/ underflow
uint32_t	period	Period/top and period/top buffer values for counter
enum tcc_reload_action	reload_action	Specifies the reload or reset time of the counter and prescaler resynchronization on a re-trigger event for the TCC.

24.6.2.5 Struct tcc_events

Event flags for the tcc_enable_events() and tcc_disable_events().

Table 24-12. Members

Type	Name	Description
bool	generate_event_on_channel[]	Generate an output event on a channel capture/match. Specify which channels will generate events
bool	generate_event_on_counter_event	Generate an output event on counter boundary. See tcc_event_output_action
bool	generate_event_on_counter_overflo	Generate an output event on counter overflow/underflow.
bool	generate_event_on_counter_retrigge	Generate an output event on counter retrigger
struct tcc_input_event_config	input_config[]	Input events configuration
bool	on_event_perform_channel_action[]	Perform the configured event action when an incoming channel event is signalled
bool	on_input_event_perform_action[]	Perform the configured event action when an incoming event is signalled.
struct tcc_output_event_config	output_config	Output event configuration

24.6.2.6 Struct tcc_input_event_config

For configuring an input event

Table 24-13. Members

Type	Name	Description
enum tcc_event_action	action	Event action on incoming event.
bool	invert	Invert incoming event input line.

Type	Name	Description
bool	modify_action	Modify event action

24.6.2.7 Struct tcc_match_wave_config

The structure which helps to configure a TCC channel for compare operation and wave generation

Table 24-14. Members

Type	Name	Description
enum tcc_channel_function	channel_function[]	Channel functions selection (capture/match)
uint32_t	match[]	Value to be used for compare match on each channel.
enum tcc_wave_generation	wave_generation	Specifies which waveform generation mode to use.
enum tcc_wave_polarity	wave_polarity[]	Specifies polarity for match output waveform generation.
enum tcc_ramp	wave_ramp	Specifies Ramp mode for waveform generation.

24.6.2.8 Struct tcc_module

TCC software instance structure, used to retain software state information of an associated hardware module instance.

Note The fields of this structure should not be altered by the user application; they are reserved only for module-internal use.

Table 24-15. Members

Type	Name	Description
tcc_callback_t	callback[]	Array of callbacks
bool	double_buffering_enabled	Set to true to write to buffered registers
uint32_t	enable_callback_mask	Bit mask for callbacks enabled
Tcc *	hw	Hardware module pointer of the associated Timer/Counter peripheral.
uint32_t	register_callback_mask	Bit mask for callbacks registered

24.6.2.9 Struct tcc_non_recoverable_fault_config

Table 24-16. Members

Type	Name	Description
uint8_t	filter_value	Fault filter value applied on TCEx event input line (0x0 ~ 0xF). Must

Type	Name	Description
		be 0 when TCEx event is used as synchronous event.
enum tcc_fault_state_output	output	Output

24.6.2.10 Struct tcc_output_event_config

Structure used for configuring an output event

Table 24-17. Members

Type	Name	Description
enum tcc_event_generation_selection	generation_selection	It decides which part of the counter cycle the counter event output is generated
bool	modify_generation_selection	A switch to allow enable/disable of events, without modifying the event output configuration.

24.6.2.11 Struct tcc_pins_config

Structure which is used when taking wave output from TCC

Table 24-18. Members

Type	Name	Description
bool	enable_wave_out_pin[]	When true, PWM output pin for the given channel is enabled.
uint32_t	wave_out_pin[]	Specifies pin output for each channel.
uint32_t	wave_out_pin_mux[]	Specifies MUX setting for each output channel pin.

24.6.2.12 Struct tcc_recoverable_fault_config

Table 24-19. Members

Type	Name	Description
enum tcc_fault_blanking	blanking	Fault Blanking Start Point for recoverable Fault
uint8_t	blanking_cycles	Fault blanking value (0 ~ 255), disable input source for several TCC clocks after the detection of the waveform edge.
enum tcc_fault_capture_action	capture_action	Capture action for recoverable Fault
enum tcc_fault_capture_channel	capture_channel	Channel triggered by recoverable Fault
uint8_t	filter_value	Fault filter value applied on MCEx event input line (0x0 ~ 0xF). Must be 0 when MCEx event is used as synchronous event. Apply to both

Type	Name	Description
		recoverable and non-recoverable fault.
enum tcc_fault_halt_action	halt_action	Halt action for recoverable Fault
bool	keep	Set to true to enable keep action (keep until end of TCC cycle)
bool	qualification	Set to true to enable input qualification (disable input when output is inactive)
bool	restart	Set to true to enable restart action
enum tcc_fault_source	source	Specifies if the event input generates recoverable Fault. The event system channel connected to MCEx event input must be configured as asynchronous.

24.6.2.13 Struct tcc_wave_extension_config

This structure is used to specify the waveform extension features for TCC

Table 24-20. Members

Type	Name	Description
bool	invert[]	Invert waveform final outputs lines.
struct tcc_non_recoverable_fault_config	non_recoverable_fault[]	Configuration for non-recoverable faults.
struct tcc_recoverable_fault_config	recoverable_fault[]	Configuration for recoverable faults.

24.6.3 Macro Definitions

24.6.3.1 Module status flags

TCC status flags, returned by tcc_get_status() and cleared by tcc_clear_status().

Macro TCC_STATUS_CHANNEL_MATCH_CAPTURE

```
#define TCC_STATUS_CHANNEL_MATCH_CAPTURE(ch) \
  (1UL << (ch))
```

Timer channel ch (0 ~ 3) has matched against its compare value, or has captured a new value

Macro TCC_STATUS_CHANNEL_OUTPUT

```
#define TCC_STATUS_CHANNEL_OUTPUT(ch) \
  (1UL << ((ch)+8))
```

Timer channel ch (0 ~ 3) match/compare output state.

Macro TCC_STATUS_NON_RECOVERABLE_FAULT_OCCUR

```
#define TCC_STATUS_NON_RECOVERABLE_FAULT_OCCUR(x) \
  (1UL << ((x)+16))
```

A Non-Recoverable Fault x (0 ~ 1) has occurred

Macro TCC_STATUS_RECOVERABLE_FAULT_OCCUR

```
#define TCC_STATUS_RECOVERABLE_FAULT_OCCUR(n) \
  (1UL << ((n)+18))
```

A Recoverable Fault n (0 ~ 1 representing A ~ B) has occured

Macro TCC_STATUS_NON_RECOVERABLE_FAULT_PRESENT

```
#define TCC_STATUS_NON_RECOVERABLE_FAULT_PRESENT(x) \
  (1UL << ((x)+20))
```

The Non-Recoverable Fault x (0 ~ 1) input is present

Macro TCC_STATUS_RECOVERABLE_FAULT_PRESENT

```
#define TCC_STATUS_RECOVERABLE_FAULT_PRESENT(n) \
  (1UL << ((n)+22))
```

A Recoverable Fault n (0 ~ 1 representing A ~ B) is present

Macro TCC_STATUS_SYNC_READY

```
#define TCC_STATUS_SYNC_READY (1UL << 23)
```

Timer registers synchronization has completed, and the synchronized count value may be read.

Macro TCC_STATUS_CAPTURE_OVERFLOW

```
#define TCC_STATUS_CAPTURE_OVERFLOW (1UL << 24)
```

A new value was captured before the previous value was read, resulting in lost data.

Macro TCC_STATUS_COUNTER_EVENT

```
#define TCC_STATUS_COUNTER_EVENT (1UL << 25)
```

A counter event occurred

Macro TCC_STATUS_COUNTER_RETRIGGERED

```
#define TCC_STATUS_COUNTER_RETRIGGERED (1UL << 26)
```

A counter retrigger occurred

Macro TCC_STATUS_COUNT_OVERFLOW

```
#define TCC_STATUS_COUNT_OVERFLOW (1UL << 27)
```

The timer count value has overflowed from its maximum value to its minimum when counting upward, or from its minimum value to its maximum when counting downward.

Macro TCC_STATUS_RAMP_CYCLE_INDEX

```
#define TCC_STATUS_RAMP_CYCLE_INDEX (1UL << 28)
```

Ramp period cycle index. In ramp operation, each two period cycles are marked as cycle A and B, the index 0 represents cycle A and 1 represents cycle B.

Macro TCC_STATUS_STOPPED

```
#define TCC_STATUS_STOPPED (1UL << 29)
```

The counter has been stopped (due to disable, stop command or one-shot)

24.6.3.2 Macro _TCC_CHANNEL_ENUM_LIST

```
#define _TCC_CHANNEL_ENUM_LIST(type) \
  MREPEAT(TCC_NUM_CHANNELS, _TCC_ENUM, type##_CHANNEL)
```

24.6.3.3 Macro _TCC_ENUM

```
#define _TCC_ENUM(n, type) \
  TCC_##type##_##n,
```

24.6.3.4 Macro _TCC_WO_ENUM_LIST

```
#define _TCC_WO_ENUM_LIST(type) \
```

```
  MREPEAT(TCC_NUM_WAVE_OUTPUTS, _TCC_ENUM, type)
```

24.6.3.5 Macro TCC_NUM_CHANNELS

```
#define TCC_NUM_CHANNELS 4
```

Max number of channels supported by the driver (Channel index from 0 to TCC_NUM_CHANNELS - 1).

24.6.3.6 Macro TCC_NUM_FAULTS

```
#define TCC_NUM_FAULTS 2
```

Max number of (recoverable) faults supported by the driver.

24.6.3.7 Macro TCC_NUM_WAVE_OUTPUTS

```
#define TCC_NUM_WAVE_OUTPUTS 8
```

Max number of wave outputs lines supported by the driver (Output line index from 0 to TCC_NUM_WAVE_OUTPUTS - 1).

24.6.4 Function Definitions

24.6.4.1 Driver Initialization and Configuration

Function tcc_is_syncing()

Determines if the hardware module is currently synchronizing to the bus.

```
bool tcc_is_syncing(
  const struct tcc_module *const module_inst)
```

Checks to see if the underlying hardware peripheral module is currently synchronizing across multiple clock domains to the hardware bus. This function can be used to delay further operations on a module until such time that it is ready, to prevent blocking delays for synchronization in the user application.

Table 24-21. Parameters

Data direction	Parameter name	Description
[in]	module_inst	Pointer to the software module instance struct

Returns Synchronization status of the underlying hardware module.

Table 24-22. Return Values

Return value	Description
true	If the module has completed synchronization

Return value	Description
false	If the module synchronization is ongoing

Function tcc_get_config_defaults()

Initializes config with predefined default values.

```
void tcc_get_config_defaults(
  struct tcc_config *const config,
  Tcc *const hw)
```

This function will initialize a given TCC configuration structure to a set of known default values. This function should be called on any new instance of the configuration structures before being modified by the user application.

The default configuration is as follows:

- Don't run in standby
- When setting top,compare or pattern by API, do double buffering write
- The base timer/counter configurations:
  - GCLK generator 0 clock source
  - No prescaler
  - GCLK reload action
  - Count upward
  - Don't perform one-shot operations
  - Counter starts on 0
  - Period/top value set to maximum
- The match/capture configurations:
  - All Capture compare channel value set to 0
  - No capture enabled (all channels use compare function)
  - Normal frequency wave generation
  - Waveform generation polarity set to 0
  - Don't perform ramp on waveform
- The waveform extension configurations:
  - No recoverable fault is enabled, fault actions are disabled, filter is set to 0
  - No non-recoverable fault state output is enabled and filter is 0
  - No inversion of waveform output
- No channel output enabled
- No PWM pin output enabled

- Pin and Mux configuration not set

Table 24-23. Parameters

Data direction	Parameter name	Description
[out]	config	Pointer to a TCC module configuration structure to set
[in]	hw	Pointer to the TCC hardware module

Function tcc_init()

Initializes a hardware TCC module instance.

```
enum status_code tcc_init(
  struct tcc_module *const module_inst,
  Tcc *const hw,
  const struct tcc_config *const config)
```

Enables the clock and initializes the given TCC module, based on the given configuration values

Table 24-24. Parameters

Data direction	Parameter name	Description
[in, out]	module_inst	Pointer to the software module instance struct
[in]	hw	Pointer to the TCC hardware module
[in]	config	Pointer to the TCC configuration options struct

Returns Status of the initialization procedure.

Table 24-25. Return Values

Return value	Description
STATUS_OK	The module was initialized successfully
STATUS_BUSY	Hardware module was busy when the initialization procedure was attempted
STATUS_INVALID_ARG	An invalid configuration option or argument was supplied
STATUS_ERR_DENIED	Hardware module was already enabled

24.6.4.2 Event Management

Function tcc_enable_events()

Enables the TCC module event input or output.

```
enum status_code tcc_enable_events(
  struct tcc_module *const module_inst,
```

```
  struct tcc_events *const events)
```

Enables one or more input or output events to or from the TCC module. See tcc_events for a list of events this module supports.

Note Events cannot be altered while the module is enabled.

Table 24-26. Parameters

Data direction	Parameter name	Description
[in]	module_inst	Pointer to the software module instance struct
[in]	events	Struct containing flags of events to enable or configure

Returns Status of the events setup procedure.

Table 24-27. Return Values

Return value	Description
STATUS_OK	The module was initialized successfully
STATUS_INVALID_ARG	An invalid configuration option or argument was supplied

Function tcc_disable_events()

Disables the event input or output of a TCC instance.

```
void tcc_disable_events(
  struct tcc_module *const module_inst,
  struct tcc_events *const events)
```

Disables one or more input or output events for the given TCC module. See tcc_events for a list of events this module supports.

Note Events cannot be altered while the module is enabled.

Table 24-28. Parameters

Data direction	Parameter name	Description
[in]	module_inst	Pointer to the software module instance struct
[in]	events	Struct containing flags of events to disable

24.6.4.3 Enable/Disable/Reset

Function tcc_enable()

Enable the TCC module.

```
void tcc_enable(
  const struct tcc_module *const module_inst)
```

Enables a TCC module that has been previously initialized. The counter will start when the counter is enabled.

Note When the counter is configured to re-trigger on an event, the counter will not start until the next incoming event appears. Then it restarts on any following event.

Table 24-29. Parameters

Data direction	Parameter name	Description
[in]	module_inst	Pointer to the software module instance struct

Function tcc_disable()

Disables the TCC module.

```
void tcc_disable(
  const struct tcc_module *const module_inst)
```

Disables a TCC module and stops the counter.

Table 24-30. Parameters

Data direction	Parameter name	Description
[in]	module_inst	Pointer to the software module instance struct

Function tcc_reset()

Resets the TCC module.

```
void tcc_reset(
  const struct tcc_module *const module_inst)
```

Resets the TCC module, restoring all hardware module registers to their default values and disabling the module. The TCC module will not be accessible while the reset is being performed.

Note When resetting a 32-bit counter only the master TCC module's instance structure should be passed to the function.

Table 24-31. Parameters

Data direction	Parameter name	Description
[in]	module_inst	Pointer to the software module instance struct

24.6.4.4 Set/Toggle Count Direction

Function tcc_set_count_direction()

Sets the TCC module count direction.

```
void tcc_set_count_direction(
  const struct tcc_module *const module_inst,
  enum tcc_count_direction dir)
```

Sets the count direction of an initialized TCC module. The specified TCC module can remain running or stopped.

Table 24-32. Parameters

Data direction	Parameter name	Description
[in]	module_inst	Pointer to the software module instance struct
[in]	dir	New timer count direction to set

Function tcc_toggle_count_direction()

Toggles the TCC module count direction.

```
void tcc_toggle_count_direction(
  const struct tcc_module *const module_inst)
```

Toggles the count direction of an initialized TCC module. The specified TCC module can remain running or stopped.

Table 24-33. Parameters

Data direction	Parameter name	Description
[in]	module_inst	Pointer to the software module instance struct

24.6.4.5 Get/Set Count Value

Function tcc_get_count_value()

Get count value of the given TCC module.

```
uint32_t tcc_get_count_value(
  const struct tcc_module *const module_inst)
```

Retrieves the current count value of a TCC module. The specified TCC module can remain running or stopped.

Table 24-34. Parameters

Data direction	Parameter name	Description
[in]	module_inst	Pointer to the software module instance struct

Returns Count value of the specified TCC module.

Function tcc_set_count_value()

Sets count value for the given TCC module.

```
enum status_code tcc_set_count_value(
  const struct tcc_module *const module_inst,
  const uint32_t count)
```

Sets the timer count value of an initialized TCC module. The specified TCC module can remain running or stopped.

Table 24-35. Parameters

Data direction	Parameter name	Description
[in]	module_inst	Pointer to the software module instance struct
[in]	count	New timer count value to set

Returns Status which indicates whether the new value is set.

Table 24-36. Return Values

Return value	Description
STATUS_OK	The timer count was updated successfully
STATUS_ERR_INVALID_ARG	An invalid timer counter size was specified

24.6.4.6 Stop/Restart Counter

Function tcc_stop_counter()

Stops the counter.

```
void tcc_stop_counter(
  const struct tcc_module *const module_inst)
```

This function will stop the counter. When the counter is stopped the value in the count register is set to 0 if the counter was counting up, or max or the top value if the counter was counting down.

Table 24-37. Parameters

Data direction	Parameter name	Description
[in]	module_inst	Pointer to the software module instance struct

Function tcc_restart_counter()

Starts the counter from beginning.

```
void tcc_restart_counter(
  const struct tcc_module *const module_inst)
```

Restarts an initialized TCC module's counter.

Table 24-38. Parameters

Data direction	Parameter name	Description
[in]	module_inst	Pointer to the software module instance struct

24.6.4.7 Get/Set Compare/Capture Register

Function tcc_get_capture_value()

Gets the TCC module capture value.

```
uint32_t tcc_get_capture_value(
  const struct tcc_module *const module_inst,
  const enum tcc_match_capture_channel channel_index)
```

Retrieves the capture value in the indicated TCC module capture channel.

Table 24-39. Parameters

Data direction	Parameter name	Description
[in]	module_inst	Pointer to the software module instance struct
[in]	channel_index	Index of the Compare Capture channel to read

Returns Capture value stored in the specified timer channel.

Function tcc_set_compare_value()

Sets a TCC module compare value.

```
enum status_code tcc_set_compare_value(
  const struct tcc_module *const module_inst,
  const enum tcc_match_capture_channel channel_index,
  const uint32_t compare)
```

Writes a compare value to the given TCC module compare/capture channel.

If double buffering is enabled it always write to the buffer register. The value will then be updated immediately by calling tcc_force_double_buffer_update(), or be updated when the lock update bit is cleared and the UPDATE condition happen.

Table 24-40. Parameters

Data direction	Parameter name	Description
[in]	module_inst	Pointer to the software module instance struct

Data direction	Parameter name	Description
[in]	channel_index	Index of the compare channel to write to
[in]	compare	New compare value to set

Returns Status of the compare update procedure.

Table 24-41. Return Values

Return value	Description
STATUS_OK	The compare value was updated successfully
STATUS_ERR_INVALID_ARG	An invalid channel index was supplied or compare value exceed resolution

24.6.4.8 Set Top Value

Function tcc_set_top_value()

Set the timer TOP/PERIOD value.

```
enum status_code tcc_set_top_value(
  const struct tcc_module *const module_inst,
  const uint32_t top_value)
```

This function writes the given value to the PER/PERB register.

If double buffering is enabled it always write to the buffer register (PERB). The value will then be updated immediately by calling tcc_force_double_buffer_update(), or be updated when the lock update bit is cleared and the UPDATE condition happen.

When using MFRQ, the top value is defined by the CC0 register value and the PER value is ignored, so tcc_set_compare_value(module,channel_0,value) must be used instead of this function to change the actual top value in that case. For all other waveforms operation the top value is defined by PER register value.

Table 24-42. Parameters

Data direction	Parameter name	Description
[in]	module_inst	Pointer to the software module instance struct
[in]	top_value	New value to be loaded into the PER/PERB register

Returns Status of the TOP set procedure.

Table 24-43. Return Values

Return value	Description
STATUS_OK	The timer TOP value was updated successfully
STATUS_ERR_INVALID_ARG	An invalid channel index was supplied or top/period value exceed resolution

24.6.4.9 Set Output Pattern

Function tcc_set_pattern()

Sets the TCC module waveform output pattern.

```
enum status_code tcc_set_pattern(
  const struct tcc_module *const module_inst,
  const uint32_t line_index,
  const enum tcc_output_pattern pattern)
```

Force waveform output line to generate specific pattern (0, 1 or as is).

If double buffering is enabled it always write to the buffer register. The value will then be updated immediately by calling tcc_force_double_buffer_update(), or be updated when the lock update bit is cleared and the UPDATE condition happen.

Table 24-44. Parameters

Data direction	Parameter name	Description
[in]	module_inst	Pointer to the software module instance struct
[in]	line_index	Output line index
[in]	pattern	Output pattern to use (tcc_output_pattern)

Returns Status of the pattern set procedure.

Table 24-45. Return Values

Return value	Description
STATUS_OK	The PATT register is updated successfully
STATUS_ERR_INVALID_ARG	An invalid line index was supplied

24.6.4.10 Set Ramp Index

Function tcc_set_ramp_index()

Sets the TCC module ramp index on next cycle.

```
void tcc_set_ramp_index(
  const struct tcc_module *const module_inst,
  const enum tcc_ramp_index ramp_index)
```

In RAMP2 and RAMP2A operation, we can force either cycle A or cycle B at the output, on the next clock cycle When ramp index command is disabled, cycle A and cycle B will appear at the output, on alternate clock cycles See tcc_ramp.

Table 24-46. Parameters

Data direction	Parameter name	Description
[in]	module_inst	Pointer to the software module instance struct

Data direction	Parameter name	Description
[in]	ramp_index	Ramp index (tcc_ramp_index) of the next cycle

24.6.4.11 Status Management

Function tcc_is_running()

Checks if the timer/counter is running.

```
bool tcc_is_running(
  struct tcc_module *const module_inst)
```

Table 24-47. Parameters

Data direction	Parameter name	Description
[in]	module_inst	Pointer to the TCC software instance struct

Returns Status which indicates whether the module is running.

Table 24-48. Return Values

Return value	Description
true	The timer/counter is running.
false	The timer/counter is stopped.

Function tcc_get_status()

Retrieves the current module status.

```
uint32_t tcc_get_status(
  struct tcc_module *const module_inst)
```

Retrieves the status of the module, giving overall state information.

Table 24-49. Parameters

Data direction	Parameter name	Description
[in]	module_inst	Pointer to the TCC software instance struct

Returns Bitmask of TCC_STATUS_* flags

Table 24-50. Return Values

Return value	Description
TCC_STATUS_CHANNEL_MATCH_CAPTURE(n)	Channel n match/capture has occured
TCC_STATUS_CHANNEL_OUTPUT(n)	Channel n match/capture output state

Return value	Description
TCC_STATUS_NON_RECOVERABLE_FAULT_OCCUR	Non-recoverable fault x has occured
TCC_STATUS_RECOVERABLE_FAULT_OCCUR(n)	Recoverable fault n has occured
TCC_STATUS_NON_RECOVERABLE_FAULT_PRESE	Non-recoverable fault x input present
TCC_STATUS_RECOVERABLE_FAULT_PRESENT(n)	Recoverable fault n input present
TCC_STATUS_SYNC_READY	None of register is syncing
TCC_STATUS_CAPTURE_OVERFLOW	Timer capture data has overflowed
TCC_STATUS_COUNTER_EVENT	Timer counter event has occurred
TCC_STATUS_COUNT_OVERFLOW	Timer count value has overflowed
TCC_STATUS_COUNTER_RETRIGGERED	Timer counter has been retriggered
TCC_STATUS_STOP	Timer counter has been stopped
TCC_STATUS_RAMP_CYCLE_INDEX	Wave ramp index for cycle

Function tcc_clear_status()

Clears a module status flag.

```
void tcc_clear_status(
  struct tcc_module *const module_inst,
  const uint32_t status_flags)
```

Clears the given status flag of the module.

Table 24-51. Parameters

Data direction	Parameter name	Description
[in]	module_inst	Pointer to the TCC software instance struct
[in]	status_flags	Bitmask of TCC_STATUS_* flags to clear

24.6.4.12 Double Buffering Management

Function tcc_enable_double_buffering()

Enable TCC double buffering write.

```
void tcc_enable_double_buffering(
  struct tcc_module *const module_inst)
```

When double buffering write is enabled, following function will write values to buffered registers instead of effective ones (buffered):

- PERB: through tcc_set_top_value()
- CCBx(x is 0~3): through tcc_set_compare_value()
- PATTB: through tcc_set_pattern()

Then on UPDATE condition the buffered registers are committed to regular ones to take effect.

Table 24-52. Parameters

Data direction	Parameter name	Description
[in]	module_inst	Pointer to the TCC software instance struct

Function tcc_disable_double_buffering()

Disable TCC double buffering Write.

```
void tcc_disable_double_buffering(
  struct tcc_module *const module_inst)
```

When double buffering write is disabled, following function will write values to effective registers (not buffered):

- PER: through tcc_set_top_value()
- CCx(x is 0~3): through tcc_set_compare_value()
- PATT: through tcc_set_pattern()

Note

This function does not lock double buffer update, which means on next UPDATE condition the last written buffered values will be committed to take effect. Invoke tcc_lock_double_buffer_update() before this function to disable double buffering update, if this change is not expected.

Table 24-53. Parameters

Data direction	Parameter name	Description
[in]	module_inst	Pointer to the TCC software instance struct

Function tcc_lock_double_buffer_update()

Lock the TCC double buffered registers updates.

```
void tcc_lock_double_buffer_update(
  struct tcc_module *const module_inst)
```

Locks the double buffered registers so they will not be updated through their buffered values on UPDATE conditions.

Table 24-54. Parameters

Data direction	Parameter name	Description
[in]	module_inst	Pointer to the TCC software instance struct

Function tcc_unlock_double_buffer_update()

Unlock the TCC double buffered registers updates.

```
void tcc_unlock_double_buffer_update(
```

```
  struct tcc_module *const module_inst)
```

Unlock the double buffered registers so they will be updated through their buffered values on UPDATE conditions.

Table 24-55. Parameters

Data direction	Parameter name	Description
[in]	module_inst	Pointer to the TCC software instance struct

Function tcc_force_double_buffer_update()

Force the TCC double buffered registers to update once.

```
void tcc_force_double_buffer_update(
  struct tcc_module *const module_inst)
```

Table 24-56. Parameters

Data direction	Parameter name	Description
[in]	module_inst	Pointer to the TCC software instance struct

Function tcc_enable_circular_buffer_top()

Enable Circular option for double buffered Top/Period Values.

```
void tcc_enable_circular_buffer_top(
  struct tcc_module *const module_inst)
```

Enable circular option for the double buffered top/period values. On each UPDATE condition, the contents of PERB and PER are switched, meaning that the contents of PERB are transferred to PER and the contents of PER are transferred to PERB.

Table 24-57. Parameters

Data direction	Parameter name	Description
[in]	module_inst	Pointer to the TCC software instance struct

Function tcc_disable_circular_buffer_top()

Disable Circular option for double buffered Top/Period Values.

```
void tcc_disable_circular_buffer_top(
  struct tcc_module *const module_inst)
```

Stop circularing the double buffered top/period values.

Table 24-58. Parameters

Data direction	Parameter name	Description
[in]	module_inst	Pointer to the TCC software instance struct

Function tcc_set_double_buffer_top_values()

Set the timer TOP/PERIOD value and buffer value.

```
enum status_code tcc_set_double_buffer_top_values(
  const struct tcc_module *const module_inst,
  const uint32_t top_value,
  const uint32_t top_buffer_value)
```

This function writes the given value to the PER and PERB register. Usually as preparation for double buffer or circulared double buffer (circular buffer).

When using MFRQ, the top values are defined by the CC0 and CCB0, the PER and PERB values are ignored, so tcc_set_double_buffer_compare_values(module,channel_0,value,buffer) must be used instead of this function to change the actual top values in that case. For all other waveforms operation the top values are defined by PER and PERB registers values.

Table 24-59. Parameters

Data direction	Parameter name	Description
[in]	module_inst	Pointer to the software module instance struct
[in]	top_value	New value to be loaded into the PER register
[in]	top_buffer_value	New value to be loaded into the PERB register

Returns Status of the TOP set procedure.

Table 24-60. Return Values

Return value	Description
STATUS_OK	The timer TOP value was updated successfully
STATUS_ERR_INVALID_ARG	An invalid channel index was supplied or top/period value exceed resolution

Function tcc_enable_circular_buffer_compare()

Enable Circular option for double buffered Compare Values.

```
enum status_code tcc_enable_circular_buffer_compare(
  struct tcc_module *const module_inst,
  enum tcc_match_capture_channel channel_index)
```

Enable circular option for the double buffered channel compare values. On each UPDATE condition, the contents of CCBx and CCx are switched, meaning that the contents of CCBx are transferred to CCx and the contents of CCx are transferred to CCBx.

Table 24-61. Parameters

Data direction	Parameter name	Description
[in]	module_inst	Pointer to the TCC software instance struct

Data direction	Parameter name	Description
[in]	channel_index	Index of the compare channel to set up to

Table 24-62. Return Values

Return value	Description
STATUS_OK	The module was initialized successfully
STATUS_INVALID_ARG	An invalid channel index is supplied

Function tcc_disable_circular_buffer_compare()

Disable Circular option for double buffered Compare Values.

```
enum status_code tcc_disable_circular_buffer_compare(
  struct tcc_module *const module_inst,
  enum tcc_match_capture_channel channel_index)
```

Stop circularing the double buffered compare values.

Table 24-63. Parameters

Data direction	Parameter name	Description
[in]	module_inst	Pointer to the TCC software instance struct
[in]	channel_index	Index of the compare channel to set up to

Table 24-64. Return Values

Return value	Description
STATUS_OK	The module was initialized successfully
STATUS_INVALID_ARG	An invalid channel index is supplied

Function tcc_set_double_buffer_compare_values()

Sets a TCC module compare value and buffer value.

```
enum status_code tcc_set_double_buffer_compare_values(
  struct tcc_module *const module_inst,
  enum tcc_match_capture_channel channel_index,
  const uint32_t compare,
  const uint32_t compare_buffer)
```

Writes compare value and buffer to the given TCC module compare/capture channel. Usually as preparation for double buffer or circulared double buffer (circular buffer).

Table 24-65. Parameters

Data direction	Parameter name	Description
[in]	module_inst	Pointer to the software module instance struct
[in]	channel_index	Index of the compare channel to write to

Data direction	Parameter name	Description
[in]	compare	New compare value to set
[in]	compare_buffer	New compare buffer value to set

Returns Status of the compare update procedure.

Table 24-66. Return Values

Return value	Description
STATUS_OK	The compare value was updated successfully
STATUS_ERR_INVALID_ARG	An invalid channel index was supplied or compare value exceed resolution

24.6.5 Enumeration Definitions

24.6.5.1 Enum tcc_callback

Enum for the possible callback types for the TCC module.

Table 24-67. Members

Enum value	Description
TCC_CALLBACK_OVERFLOW	Callback for TCC overflow.
TCC_CALLBACK_RETRIGGER	Callback for TCC Retrigger.
TCC_CALLBACK_COUNTER_EVENT	Callback for TCC counter event.
TCC_CALLBACK_ERROR	Callback for capture overflow error.
TCC_CALLBACK_FAULTA	Callback for Recoverable Fault A.
TCC_CALLBACK_FAULTB	Callback for Recoverable Fault B.
TCC_CALLBACK_FAULT0	Callback for Non-Recoverable Fault. 0
TCC_CALLBACK_FAULT1	Callback for Non-Recoverable Fault. 1
TCC_CALLBACK_CHANNEL_n	Channel callback type table for TCC Each TCC module may contain several callback types for channels; each channel will have its own callback type in the table, with the channel index number substituted for "n" in the channel callback type (e.g. TCC_MATCH_CAPTURE_CHANNEL_0).

24.6.5.2 Enum tcc_channel_function

To set a timer channel either in compare or in capture mode

Table 24-68. Members

Enum value	Description
TCC_CHANNEL_FUNCTION_COMPARE	TCC channel performs compare operation.
TCC_CHANNEL_FUNCTION_CAPTURE	TCC channel performs capture operation.

24.6.5.3 Enum tcc_clock_prescaler

This enum is used to choose the clock prescaler configuration. The prescaler divides the clock frequency of the TCC module to operate TCC at a slower clock rate.

Table 24-69. Members

Enum value	Description
TCC_CLOCK_PRESCALER_DIV1	Divide clock by 1
TCC_CLOCK_PRESCALER_DIV2	Divide clock by 2
TCC_CLOCK_PRESCALER_DIV4	Divide clock by 4
TCC_CLOCK_PRESCALER_DIV8	Divide clock by 8
TCC_CLOCK_PRESCALER_DIV16	Divide clock by 16
TCC_CLOCK_PRESCALER_DIV64	Divide clock by 64
TCC_CLOCK_PRESCALER_DIV256	Divide clock by 256
TCC_CLOCK_PRESCALER_DIV1024	Divide clock by 1024

24.6.5.4 Enum tcc_count_direction

Used when selecting the Timer/Counter count direction.

Table 24-70. Members

Enum value	Description
TCC_COUNT_DIRECTION_UP	Timer should count upward
TCC_COUNT_DIRECTION_DOWN	Timer should count downward

24.6.5.5 Enum tcc_event0_action

Event action to perform when the module is triggered by event0.

Table 24-71. Members

Enum value	Description
TCC_EVENT0_ACTION_OFF	No event action.
TCC_EVENT0_ACTION_RETRIGGER	Re-trigger Counter on event.
TCC_EVENT0_ACTION_COUNT_EVENT	Count events (increment or decrement, depending on count direction)
TCC_EVENT0_ACTION_START	Start counter on event.
TCC_EVENT0_ACTION_INCREMENT	Increment counter on event.
TCC_EVENT0_ACTION_COUNT_DURING_ACTIVE	Count during active state of asynchronous event.
TCC_EVENT0_ACTION_NON_RECOVERABLE_FAULT	Generate Non-Recoverable Fault on event.

24.6.5.6 Enum tcc_event1_action

Event action to perform when the module is triggered by event1.

Table 24-72. Members

Enum value	Description
TCC_EVENT1_ACTION_OFF	No event action.

Enum value	Description
TCC_EVENT1_ACTION_RETRIGGER	Re-trigger Counter on event.
TCC_EVENT1_ACTION_DIR_CONTROL	The event source must be an asynchronous event, input value will override the direction settings If TCEINVx is 0 and input event is LOW: counter will count up. If TCEINVx is 0 and input event is HIGH: counter will count down
TCC_EVENT1_ACTION_STOP	Stop counter on event.
TCC_EVENT1_ACTION_DECREMENT	Decrement on event
TCC_EVENT1_ACTION_PERIOD_PULSE_WIDTH_CAPTURI	Store period in capture register 0, pulse width in capture register 1.
TCC_EVENT1_ACTION_PULSE_WIDTH_PERIOD_CAPTURI	Store pulse width in capture register 0, period in capture register 1.
TCC_EVENT1_ACTION_NON_RECOVERABLE_FAULT	Generate Non-Recoverable Fault on event.

24.6.5.7 Enum tcc_event_action

Event action to perform when the module is triggered by events.

Table 24-73. Members

Enum value	Description
TCC_EVENT_ACTION_OFF	No event action.
TCC_EVENT_ACTION_STOP	Stop counting, the counter will maintain its current value, waveforms are set to a defined Non-Recoverable State output (tcc_non_recoverable_state_output).
TCC_EVENT_ACTION_RETRIGGER	Re-trigger counter on event, may generate an event if the re-trigger event output is enabled. **Note** When re-trigger event action is enabled, enabling the counter will not start until the next incoming event appears.
TCC_EVENT_ACTION_START	Start counter when previously stopped. Start counting on the event rising edge. Further events will not restart the counter; the counter keeps on counting using prescaled GCLK_TCCx, until it reaches TOP or Zero depending on the direction
TCC_EVENT_ACTION_COUNT_EVENT	Count events; ie; Increment or decrement depending on count direction
TCC_EVENT_ACTION_DIR_CONTROL	The event source must be an asynchronous event, input value will overrides the direction settings (input low: counting up, input high counting down).
TCC_EVENT_ACTION_INCREMENT	Increment the counter on event, irrespective of count direction
TCC_EVENT_ACTION_DECREMENT	Decrement the counter on event, irrespective of count direction

Enum value	Description
TCC_EVENT_ACTION_COUNT_DURING_ACTIVE	Count during active state of asynchronous event. In this case, depending on the count direction, the count will be incremented or decremented on each prescaled GCLK_TCCx, as long as the input event remains active
TCC_EVENT_ACTION_PERIOD_PULSE_WIDTH_CAPTURE	Store period in capture register 0, pulse width in capture register 1.
TCC_EVENT_ACTION_PULSE_WIDTH_PERIOD_CAPTURE	Store pulse width in capture register 0, period in capture register 1.
TCC_EVENT_ACTION_NON_RECOVERABLE_FAULT	Generate Non-Recoverable Fault on event.

24.6.5.8 Enum tcc_event_generation_selection

This enum is used to define the point at which the counter event is generated

Table 24-74. Members

Enum value	Description
TCC_EVENT_GENERATION_SELECTION_START	Counter Event is generated when a new counter cycle starts
TCC_EVENT_GENERATION_SELECTION_END	Counter Event is generated when a counter cycle ends
TCC_EVENT_GENERATION_SELECTION_BETWEEN	Counter Event is generated when a counter cycle ends, except for the first and last cycles
TCC_EVENT_GENERATION_SELECTION_BOUNDARY	Counter Event is generated when a new counter cycle starts or ends

24.6.5.9 Enum tcc_fault_blanking

Table 24-75. Members

Enum value	Description
TCC_FAULT_BLANKING_DISABLE	No blanking
TCC_FAULT_BLANKING_RISING_EDGE	Blanking applied from rising edge of the output waveform
TCC_FAULT_BLANKING_FALLING_EDGE	Blanking applied from falling edge of the output waveform
TCC_FAULT_BLANKING_BOTH_EDGE	Blanking applied from each toggle of the output waveform

24.6.5.10 Enum tcc_fault_capture_action

Table 24-76. Members

Enum value	Description
TCC_FAULT_CAPTURE_DISABLE	Capture disabled
TCC_FAULT_CAPTURE_EACH	Capture on Fault, each value is captured
TCC_FAULT_CAPTURE_MINIMUM	Capture the minimum detection, but notify on smaller ones

Enum value	Description
TCC_FAULT_CAPTURE_MAXIMUM	Capture the maximum detection, but notify on bigger ones
TCC_FAULT_CAPTURE_SMALLER	Capture if the value is smaller than last, notify event or interrupt if previous stamp is confirmed to be "local minimum" (not bigger than current stamp)
TCC_FAULT_CAPTURE_BIGGER	Capture if the value is bigger than last, notify event or interrupt if previous stamp is confirmed to be "local maximum" (not smaller than current stamp)
TCC_FAULT_CAPTURE_CHANGE	Capture if the time stamps changes its increment direction

24.6.5.11 Enum tcc_fault_capture_channel

Table 24-77. Members

Enum value	Description
TCC_FAULT_CAPTURE_CHANNEL_0	Recoverable fault triggers channel 0 capture operation
TCC_FAULT_CAPTURE_CHANNEL_1	Recoverable fault triggers channel 1 capture operation
TCC_FAULT_CAPTURE_CHANNEL_2	Recoverable fault triggers channel 2 capture operation
TCC_FAULT_CAPTURE_CHANNEL_3	Recoverable fault triggers channel 3 capture operation

24.6.5.12 Enum tcc_fault_halt_action

Table 24-78. Members

Enum value	Description
TCC_FAULT_HALT_ACTION_DISABLE	Halt action disabled
TCC_FAULT_HALT_ACTION_HW_HALT	Hardware halt action, counter is halted until restart
TCC_FAULT_HALT_ACTION_SW_HALT	Software halt action, counter is halted until fault bit cleared
TCC_FAULT_HALT_ACTION_NON_RECOVERABLE	Non-Recoverable fault, force output to pre-defined level

24.6.5.13 Enum tcc_fault_keep

Table 24-79. Members

Enum value	Description
TCC_FAULT_KEEP_DISABLE	Disable keeping, wave output released as soon as fault is released
TCC_FAULT_KEEP_TILL_END	Keep wave output until end of TCC cycle

24.6.5.14 Enum tcc_fault_qualification

Table 24-80. Members

Enum value	Description
TCC_FAULT_QUALIFICATION_DISABLE	The input is not disabled on compare condition
TCC_FAULT_QUALIFICATION_BY_OUTPUT	The input is disabled when match output signal is at inactive level

24.6.5.15 Enum tcc_fault_restart

Table 24-81. Members

Enum value	Description
TCC_FAULT_RESTART_DISABLE	Restart Action disabled
TCC_FAULT_RESTART_ENABLE	Restart Action enabled

24.6.5.16 Enum tcc_fault_source

Table 24-82. Members

Enum value	Description
TCC_FAULT_SOURCE_DISABLE	Fault input is disabled
TCC_FAULT_SOURCE_ENABLE	Match Capture Event x (MCE 0,1) input
TCC_FAULT_SOURCE_INVERT	Inverted MCEx (x=0,1) event input
TCC_FAULT_SOURCE_ALTFAULT	Alternate fault (A or B) state at the end of the previous period

24.6.5.17 Enum tcc_fault_state_output

Table 24-83. Members

Enum value	Description
TCC_FAULT_STATE_OUTPUT_OFF	Non-recoverable fault output is tri-stated
TCC_FAULT_STATE_OUTPUT_0	Non-recoverable fault force output 0
TCC_FAULT_STATE_OUTPUT_1	Non-recoverable fault force output 1

24.6.5.18 Enum tcc_match_capture_channel

This enum is used to specify which capture/match channel to do operations on.

Table 24-84. Members

Enum value	Description
TCC_MATCH_CAPTURE_CHANNEL_n	Match capture channel index table for TCC Each TCC module may contain several match capture channels; each channel will have its own index in the table, with the index number

Enum value	Description
	substituted for "n" in the index name (e.g. TCC_MATCH_CAPTURE_CHANNEL_0).

24.6.5.19 Enum tcc_output_invertion

Used when enabling or disabling output inversion

Table 24-85. Members

Enum value	Description
TCC_OUTPUT_INVERTION_DISABLE	Output inversion not to be enabled
TCC_OUTPUT_INVERTION_ENABLE	Invert the output from WO[x]

24.6.5.20 Enum tcc_output_pattern

Used when disabling output pattern or to selecting a specific pattern

Table 24-86. Members

Enum value	Description
TCC_OUTPUT_PATTERN_DISABLE	SWAP Output pattern is not used
TCC_OUTPUT_PATTERN_0	Pattern 0 is applied to SWAP output
TCC_OUTPUT_PATTERN_1	Pattern 1 is applied to SWAP output

24.6.5.21 Enum tcc_ramp

Ramp Operations which are supported in single-slope PWM generation

Table 24-87. Members

Enum value	Description
TCC_RAMP_RAMP1	Default timer/counter PWM operation.
TCC_RAMP_RAMP2A	Uses a single channel (CC0) to control both CC0/CC1 compare outputs. In cycle A, the channel 0 output is disabled, and in cycle B, the channel 1 output is disabled.
TCC_RAMP_RAMP2	Uses channels CC0 and CC1 to control compare outputs. In cycle A, the channel 0 output is disabled, and in cycle B, the channel 1 output is disabled.

24.6.5.22 Enum tcc_ramp_index

In ramp operation, each two period cycles are marked as cycle A and B, the index 0 represents cycle A and 1 represents cycle B.

Table 24-88. Members

Enum value	Description
TCC_RAMP_INDEX_DEFAULT	Default, cycle index toggles.

Enum value	Description
TCC_RAMP_INDEX_FORCE_B	Force next cycle to be cycle B (set to 1).
TCC_RAMP_INDEX_FORCE_A	Force next cycle to be cycle A (clear to 0).
TCC_RAMP_INDEX_FORCE_KEEP	Force next cycle keeping the same as current.

24.6.5.23 Enum tcc_reload_action

This enum specify how the counter is reloaded and whether the prescaler should be restarted

Table 24-89. Members

Enum value	Description
TCC_RELOAD_ACTION_GCLK	The counter is reloaded/reset on the next GCLK and starts counting on the prescaler clock.
TCC_RELOAD_ACTION_PRESC	The counter is reloaded/reset on the next prescaler clock
TCC_RELOAD_ACTION_RESYNC	The counter is reloaded/reset on the next GCLK, and the prescaler is restarted as well.

24.6.5.24 Enum tcc_wave_generation

This enum is used to specify the waveform generation mode

Table 24-90. Members

Enum value	Description
TCC_WAVE_GENERATION_NORMAL_FREQ	Normal Frequency: Top is the PER register, output toggled on each compare match.
TCC_WAVE_GENERATION_MATCH_FREQ	Match Frequency: Top is CC0 register, output toggles on each update condition.
TCC_WAVE_GENERATION_SINGLE_SLOPE_PWM	Single-Slope PWM: Top is the PER register, CCx controls duty cycle (output active when count is greater than CCx).
TCC_WAVE_GENERATION_DOUBLE_SLOPE_CRITICAL	Double-slope (count up and down), non centre-aligned: Top is the PER register, CC[x] controls duty cycle while counting up and CC[x+N/2] controls it while counting down
TCC_WAVE_GENERATION_DOUBLE_SLOPE_BOTTOM	Double-slope (count up and down), interrupt/ event at Bottom (Top is the PER register, output active when count is greater than CCx).
TCC_WAVE_GENERATION_DOUBLE_SLOPE_BOTH	Double-slope (count up and down), interrupt/ event at Bottom and Top: (Top is the PER register, output active when count is lower than CCx).
TCC_WAVE_GENERATION_DOUBLE_SLOPE_TOP	Double-slope (count up and down), interrupt/ event at Top (Top is the PER register, output active when count is greater than CCx).

24.6.5.25 Enum tcc_wave_output

This enum is used to specify which wave output to do operations on.

Table 24-91. Members

Enum value	Description
TCC_WAVE_OUTPUT_n	Waveform output index table for TCC Each TCC module may contain several wave outputs; each output will have its own index in the table, with the index number substituted for "n" in the index name (e.g. TCC_WAVE_OUTPUT_0).

24.6.5.26 Enum tcc_wave_polarity

Specifies whether the wave output needs to be inverted or not

Table 24-92. Members

Enum value	Description
TCC_WAVE_POLARITY_0	Wave output is not inverted
TCC_WAVE_POLARITY_1	Wave output is inverted

24.7 Extra Information for TCC Driver

24.7.1 Acronyms

The table below presents the acronyms used in this module:

Acronym	Description
DMA	Direct Memory Access
TCC	Timer Counter for Control Applications
PWM	Pulse Width Modulation
PWP	Pulse Width Period
PPW	Period Pulse Width

24.7.2 Dependencies

This driver has the following dependencies:

- System Pin Multiplexer Driver

24.7.3 Errata

There are no errata related to this driver.

24.7.4 Module History

An overview of the module history is presented in the table below, with details on the enhancements and fixes made to the module since its first release. The current version of this corresponds to the newest version in the table.

Changelog
Add double buffering functionality
Add fault handling functionality
Initial Release

24.8 Examples for TCC Driver

This is a list of the available Quick Start guides (QSGs) and example applications for SAM D21 Timer Counter for Control Applications Driver (TCC). QSGs are simple examples with step-by-step instructions to configure and use this driver in a selection of use cases. Note that QSGs can be compiled as a standalone application or be added to the user application.

- Quick Start Guide for TCC - Basic
- Quick Start Guide for TCC - Double Buffering & Circular
- Quick Start Guide for TCC - Timer
- Quick Start Guide for TCC - Callback
- Quick Start Guide for TCC - Non-Recoverable Fault
- Quick Start Guide for TCC - Recoverable Fault
- Quick Start Guide for Using DMA with TCC

24.8.1 Quick Start Guide for TCC - Basic

The supported board list:

- SAM D21 Xplained Pro

In this use case, the TCC will be used to generate a PWM signal. Here the pulse width is set to one quarter of the period. When connect PWM output to LED it makes the LED light. To see the waveform, you may need an oscilloscope.

The PWM output is set up as follows:

Board	Pin	Connect to
SAMD21 Xpro	PB30	LED0

The TCC module will be set up as follows:

- GCLK generator 0 (GCLK main) clock source
- Use double buffering write when set top, compare or pattern through API
- No dithering on the counter or compare
- No prescaler
- Single Slope PWM wave generation
- GCLK reload action
- Don't run in standby
- No fault or waveform extensions
- No inversion of waveform output
- No capture enabled
- Count upward
- Don't perform one-shot operations
- No event input enabled
- No event action

- No event generation enabled
- Counter starts on 0
- Counter top set to 0xFFFF
- Capture compare channel 0 set to 0xFFFF/4

24.8.1.1 Quick Start

Prerequisites

There are no prerequisites for this use case.

Code

Add to the main application source file, before any functions:

```
#define PWM_MODULE      EXT1_PWM_MODULE

#define PWM_OUT_PIN     EXT1_PWM_0_PIN

#define PWM_OUT_MUX     EXT1_PWM_0_MUX
```

Add to the main application source file, outside of any functions:

```
struct tcc_module tcc_instance;
```

Copy-paste the following setup code to your user application:

```
static void configure_tcc(void)
{
    struct tcc_config config_tcc;
    tcc_get_config_defaults(&config_tcc, CONF_PWM_MODULE);

    config_tcc.counter.period = 0xFFFF;
    config_tcc.compare.wave_generation = TCC_WAVE_GENERATION_SINGLE_SLOPE_PWM;
    config_tcc.compare.match[CONF_PWM_CHANNEL] = (0xFFFF / 4);

    config_tcc.pins.enable_wave_out_pin[CONF_PWM_OUTPUT] = true;
    config_tcc.pins.wave_out_pin[CONF_PWM_OUTPUT]        = CONF_PWM_OUT_PIN;
    config_tcc.pins.wave_out_pin_mux[CONF_PWM_OUTPUT]    = CONF_PWM_OUT_MUX;

    tcc_init(&tcc_instance, CONF_PWM_MODULE, &config_tcc);

    tcc_enable(&tcc_instance);
}
```

Add to user application initialization (typically the start of `main()`):

```
configure_tcc();
```

Workflow

1. Create a module software instance structure for the TCC module to store the TCC driver state while it is in use.

   ```
   struct tcc_module tcc_instance;
   ```

Note This should never go out of scope as long as the module is in use. In most cases, this should be global.

2. Configure the TCC module.

   a. Create a TCC module configuration struct, which can be filled out to adjust the configuration of a physical TCC peripheral.

```
struct tcc_config config_tcc;
```

   b. Initialize the TCC configuration struct with the module's default values.

```
tcc_get_config_defaults(&config_tcc, CONF_PWM_MODULE);
```

Note This should always be performed before using the configuration struct to ensure that all values are initialized to known default settings.

   c. Alter the TCC settings to configure the counter width, wave generation mode and the compare channel 0 value.

```
config_tcc.counter.period = 0xFFFF;
config_tcc.compare.wave_generation = TCC_WAVE_GENERATION_SINGLE_SLOPE_PWM;
config_tcc.compare.match[CONF_PWM_CHANNEL] = (0xFFFF / 4);
```

   d. Alter the TCC settings to configure the PWM output on a physical device pin.

```
config_tcc.pins.enable_wave_out_pin[CONF_PWM_OUTPUT] = true;
config_tcc.pins.wave_out_pin[CONF_PWM_OUTPUT]        = CONF_PWM_OUT_PIN;
config_tcc.pins.wave_out_pin_mux[CONF_PWM_OUTPUT]    = CONF_PWM_OUT_MUX;
```

   e. Configure the TCC module with the desired settings.

```
tcc_init(&tcc_instance, CONF_PWM_MODULE, &config_tcc);
```

   f. Enable the TCC module to start the timer and begin PWM signal generation.

```
tcc_enable(&tcc_instance);
```

24.8.1.2 Use Case

Code

Copy-paste the following code to your user application:

```
while (true) {
    /* Infinite loop */
}
```

Workflow

1. Enter an infinite loop while the PWM wave is generated via the TCC module.

```
while (true) {
    /* Infinite loop */
}
```

24.8.2 Quick Start Guide for TCC - Double Buffering & Circular

The supported board list:

- SAM D21 Xplained Pro

In this use case, the TCC will be used to generate a PWM signal. Here the pulse width alters in one quarter and three quarter of the period. When connect PWM output to LED it makes the LED light. To see the waveform, you may need an oscilloscope.

The PWM output is set up as follows:

Board	Pin	Connect to
SAMD21 Xpro	PB30	LED0

The TCC module will be set up as follows:

- GCLK generator 0 (GCLK main) clock source
- Use double buffering write when set top, compare or pattern through API
- No dithering on the counter or compare
- Prescaler is set to 1024
- Single Slope PWM wave generation
- GCLK reload action
- Don't run in standby
- No fault or waveform extensions
- No inversion of waveform output
- No capture enabled
- Count upward
- Don't perform one-shot operations
- No event input enabled
- No event action
- No event generation enabled
- Counter starts on 0
- Counter top set to 8000
- Capture compare channel set to 8000/4
- Capture compare channel buffer set to 8000*3/4
- Circular option for compare channel is enabled so that the compare values keep switching on update condition

24.8.2.1 Quick Start

Prerequisites

There are no prerequisites for this use case.

Code

Add to the main application source file, before any functions:

```
#define CONF_PWM_MODULE      LED_0_PWM_MODULE

#define CONF_PWM_CHANNEL     LED_0_PWM_CHANNEL

#define CONF_PWM_OUTPUT      LED_0_PWM_OUTPUT

#define CONF_PWM_OUT_PIN     LED_0_PWM_PIN

#define CONF_PWM_OUT_MUX     LED_0_PWM_MUX
```

Add to the main application source file, outside of any functions:

```
struct tcc_module tcc_instance;
```

Copy-paste the following setup code to your user application:

```
static void configure_tcc(void)
{
    struct tcc_config config_tcc;
    tcc_get_config_defaults(&config_tcc, CONF_PWM_MODULE);

    config_tcc.counter.clock_prescaler = TCC_CLOCK_PRESCALER_DIV1024;
    config_tcc.counter.period = 8000;
    config_tcc.compare.wave_generation = TCC_WAVE_GENERATION_SINGLE_SLOPE_PWM;
    config_tcc.compare.match[CONF_PWM_CHANNEL] = (8000 / 4);

    config_tcc.pins.enable_wave_out_pin[CONF_PWM_OUTPUT] = true;
    config_tcc.pins.wave_out_pin[CONF_PWM_OUTPUT]        = CONF_PWM_OUT_PIN;
    config_tcc.pins.wave_out_pin_mux[CONF_PWM_OUTPUT]    = CONF_PWM_OUT_MUX;

    tcc_init(&tcc_instance, CONF_PWM_MODULE, &config_tcc);

    tcc_set_compare_value(&tcc_instance, CONF_PWM_CHANNEL, 8000*3/4);
    tcc_enable_circular_buffer_compare(&tcc_instance, CONF_PWM_CHANNEL);

    tcc_enable(&tcc_instance);
}
```

Add to user application initialization (typically the start of `main()`):

```
configure_tcc();
```

Workflow

1. Create a module software instance structure for the TCC module to store the TCC driver state while it is in use.

   ```
   struct tcc_module tcc_instance;
   ```

Note This should never go out of scope as long as the module is in use. In most cases, this should be global.

2. Configure the TCC module.

   a. Create a TCC module configuration struct, which can be filled out to adjust the configuration of a physical TCC peripheral.

```
struct tcc_config config_tcc;
```

   b. Initialize the TCC configuration struct with the module's default values.

```
tcc_get_config_defaults(&config_tcc, CONF_PWM_MODULE);
```

Note This should always be performed before using the configuration struct to ensure that all values are initialized to known default settings.

   c. Alter the TCC settings to configure the counter width, wave generation mode and the compare channel 0 value.

```
config_tcc.counter.clock_prescaler = TCC_CLOCK_PRESCALER_DIV1024;
config_tcc.counter.period = 8000;
config_tcc.compare.wave_generation = TCC_WAVE_GENERATION_SINGLE_SLOPE_PWM;
config_tcc.compare.match[CONF_PWM_CHANNEL] = (8000 / 4);
```

   d. Alter the TCC settings to configure the PWM output on a physical device pin.

```
config_tcc.pins.enable_wave_out_pin[CONF_PWM_OUTPUT] = true;
config_tcc.pins.wave_out_pin[CONF_PWM_OUTPUT]        = CONF_PWM_OUT_PIN;
config_tcc.pins.wave_out_pin_mux[CONF_PWM_OUTPUT]    = CONF_PWM_OUT_MUX;
```

   e. Configure the TCC module with the desired settings.

```
tcc_init(&tcc_instance, CONF_PWM_MODULE, &config_tcc);
```

   f. Set to compare buffer value and enable circular of double buffered compare values.

```
tcc_set_compare_value(&tcc_instance, CONF_PWM_CHANNEL, 8000*3/4);
tcc_enable_circular_buffer_compare(&tcc_instance, CONF_PWM_CHANNEL);
```

   g. Enable the TCC module to start the timer and begin PWM signal generation.

```
tcc_enable(&tcc_instance);
```

24.8.2.2 Use Case

Code

Copy-paste the following code to your user application:

```
while (true) {
```

```
    /* Infinite loop */
}
```

Workflow

1. Enter an infinite loop while the PWM wave is generated via the TCC module.

```
while (true) {
    /* Infinite loop */
}
```

24.8.3 Quick Start Guide for TCC - Timer

The supported board list:

- SAM D21 Xplained Pro

In this use case, the TCC will be used as a timer, to generate overflow and compare match callbacks. In the callbacks the on-board LED is toggled.

The TCC module will be set up as follows:

- GCLK generator 1 (GCLK 32K) clock source
- Use double buffering write when set top, compare or pattern through API
- No dithering on the counter or compare
- Prescaler is divided by 64
- GCLK reload action
- Count upward
- Don't run in standby
- No waveform outputs
- No capture enabled
- Don't perform one-shot operations
- No event input enabled
- No event action
- No event generation enabled
- Counter starts on 0
- Counter top set to 2000 (about 4s) and generate overflow callback
- Channel 0 is set to compare and match value 900 and generate callback
- Channel 1 is set to compare and match value 930 and generate callback
- Channel 2 is set to compare and match value 1100 and generate callback
- Channel 3 is set to compare and match value 1250 and generate callback

24.8.3.1 Quick Start

Prerequisites

For this use case, XOSC32K should be enabled and available through GCLK generator 1 clock source selection. Within Atmel Software Framework (ASF) it can be done through modifying *conf_clocks.h*. See System Clock Management Driver for more details about clock configuration.

Code

Add to the main application source file, outside of any functions:

```
struct tcc_module tcc_instance;
```

Copy-paste the following callback function code to your user application:

```
static void tcc_callback_to_toggle_led(
        struct tcc_module *const module_inst)
{
    port_pin_toggle_output_level(LED0_PIN);
}
```

Copy-paste the following setup code to your user application:

```
static void configure_tcc(void)
{
    struct tcc_config config_tcc;
    tcc_get_config_defaults(&config_tcc, TCC0);

    config_tcc.counter.clock_source = GCLK_GENERATOR_1;
    config_tcc.counter.clock_prescaler = TCC_CLOCK_PRESCALER_DIV64;
    config_tcc.counter.period =   2000;
    config_tcc.compare.match[0] =  900;
    config_tcc.compare.match[1] =  930;
    config_tcc.compare.match[2] = 1100;
    config_tcc.compare.match[3] = 1250;

    tcc_init(&tcc_instance, TCC0, &config_tcc);

    tcc_enable(&tcc_instance);
}

static void configure_tcc_callbacks(void)
{
    tcc_register_callback(&tcc_instance, tcc_callback_to_toggle_led,
            TCC_CALLBACK_OVERFLOW);
    tcc_register_callback(&tcc_instance, tcc_callback_to_toggle_led,
            TCC_CALLBACK_CHANNEL_0);
    tcc_register_callback(&tcc_instance, tcc_callback_to_toggle_led,
            TCC_CALLBACK_CHANNEL_1);
    tcc_register_callback(&tcc_instance, tcc_callback_to_toggle_led,
            TCC_CALLBACK_CHANNEL_2);
    tcc_register_callback(&tcc_instance, tcc_callback_to_toggle_led,
            TCC_CALLBACK_CHANNEL_3);

    tcc_enable_callback(&tcc_instance, TCC_CALLBACK_OVERFLOW);
    tcc_enable_callback(&tcc_instance, TCC_CALLBACK_CHANNEL_0);
    tcc_enable_callback(&tcc_instance, TCC_CALLBACK_CHANNEL_1);
    tcc_enable_callback(&tcc_instance, TCC_CALLBACK_CHANNEL_2);
    tcc_enable_callback(&tcc_instance, TCC_CALLBACK_CHANNEL_3);
```

```
}
```

Add to user application initialization (typically the start of `main()`):

```
configure_tcc();
configure_tcc_callbacks();
```

Workflow

1. Create a module software instance structure for the TCC module to store the TCC driver state while it is in use.

   ```
   struct tcc_module tcc_instance;
   ```

Note This should never go out of scope as long as the module is in use. In most cases, this should be global.

2. Configure the TCC module.

   a. Create a TCC module configuration struct, which can be filled out to adjust the configuration of a physical TCC peripheral.

      ```
      struct tcc_config config_tcc;
      ```

   b. Initialize the TCC configuration struct with the module's default values.

      ```
      tcc_get_config_defaults(&config_tcc, TCC0);
      ```

Note This should always be performed before using the configuration struct to ensure that all values are initialized to known default settings.

   c. Alter the TCC settings to configure the GCLK source, prescaler, period and compare channel values.

      ```
      config_tcc.counter.clock_source = GCLK_GENERATOR_1;
      config_tcc.counter.clock_prescaler = TCC_CLOCK_PRESCALER_DIV64;
      config_tcc.counter.period =   2000;
      config_tcc.compare.match[0] =  900;
      config_tcc.compare.match[1] =  930;
      config_tcc.compare.match[2] = 1100;
      config_tcc.compare.match[3] = 1250;
      ```

   d. Configure the TCC module with the desired settings.

      ```
      tcc_init(&tcc_instance, TCC0, &config_tcc);
      ```

   e. Enable the TCC module to start the timer.

      ```
      tcc_enable(&tcc_instance);
      ```

3. Configure the TCC callbacks.

   a. Register the Overflow and Compare Channel Match callback functions with the driver.

```
tcc_register_callback(&tcc_instance, tcc_callback_to_toggle_led,
        TCC_CALLBACK_OVERFLOW);
tcc_register_callback(&tcc_instance, tcc_callback_to_toggle_led,
        TCC_CALLBACK_CHANNEL_0);
tcc_register_callback(&tcc_instance, tcc_callback_to_toggle_led,
        TCC_CALLBACK_CHANNEL_1);
tcc_register_callback(&tcc_instance, tcc_callback_to_toggle_led,
        TCC_CALLBACK_CHANNEL_2);
tcc_register_callback(&tcc_instance, tcc_callback_to_toggle_led,
        TCC_CALLBACK_CHANNEL_3);
```

b. Enable the Overflow and Compare Channel Match callbacks so that it will be called by the driver when appropriate.

```
tcc_enable_callback(&tcc_instance, TCC_CALLBACK_OVERFLOW);
tcc_enable_callback(&tcc_instance, TCC_CALLBACK_CHANNEL_0);
tcc_enable_callback(&tcc_instance, TCC_CALLBACK_CHANNEL_1);
tcc_enable_callback(&tcc_instance, TCC_CALLBACK_CHANNEL_2);
tcc_enable_callback(&tcc_instance, TCC_CALLBACK_CHANNEL_3);
```

24.8.3.2 Use Case

Code

Copy-paste the following code to your user application:

```
system_interrupt_enable_global();

while (true) {
}
```

Workflow

1. Enter an infinite loop while the timer is running.

```
while (true) {
}
```

24.8.4 Quick Start Guide for TCC - Callback

The supported board list:

- SAM D21 Xplained Pro

In this use case, the TCC will be used to generate a PWM signal, with a varying duty cycle. Here the pulse width is increased each time the timer count matches the set compare value. When connect PWM output to LED it makes the LED vary its light. To see the waveform, you may need an oscilloscope.

The PWM output is set up as follows:

Board	Pin	Connect to
SAMD21 Xpro	PB30	LED0

The TCC module will be set up as follows:

- GCLK generator 0 (GCLK main) clock source

- Use double buffering write when set top, compare or pattern through API
- No dithering on the counter or compare
- No prescaler
- Single Slope PWM wave generation
- GCLK reload action
- Don't run in standby
- No faults or waveform extensions
- No inversion of waveform output
- No capture enabled
- Count upward
- Don't perform one-shot operations
- No event input enabled
- No event action
- No event generation enabled
- Counter starts on 0

24.8.4.1 Quick Start

Prerequisites

There are no prerequisites for this use case.

Code

Add to the main application source file, before any functions:

```
#define PWM_MODULE      EXT1_PWM_MODULE

#define PWM_OUT_PIN     EXT1_PWM_0_PIN

#define PWM_OUT_MUX     EXT1_PWM_0_MUX
```

Add to the main application source file, outside of any functions:

```
struct tcc_module tcc_instance;
```

Copy-paste the following callback function code to your user application:

```
static void tcc_callback_to_change_duty_cycle(
        struct tcc_module *const module_inst)
{
    static uint32_t delay = 10;
    static uint32_t i = 0;

    if (--delay) {
        return;
```

```
    }
    delay = 10;
    i = (i + 0x0800) & 0xFFFF;
    tcc_set_compare_value(module_inst,
            TCC_MATCH_CAPTURE_CHANNEL_0 + CONF_PWM_CHANNEL, i + 1);
}
```

Copy-paste the following setup code to your user application:

```
static void configure_tcc(void)
{
    struct tcc_config config_tcc;
    tcc_get_config_defaults(&config_tcc, CONF_PWM_MODULE);

    config_tcc.counter.period = 0xFFFF;
    config_tcc.compare.wave_generation = TCC_WAVE_GENERATION_SINGLE_SLOPE_PWM;
    config_tcc.compare.match[CONF_PWM_CHANNEL] = 0xFFFF;

    config_tcc.pins.enable_wave_out_pin[CONF_PWM_OUTPUT] = true;
    config_tcc.pins.wave_out_pin[CONF_PWM_OUTPUT]        = CONF_PWM_OUT_PIN;
    config_tcc.pins.wave_out_pin_mux[CONF_PWM_OUTPUT]    = CONF_PWM_OUT_MUX;

    tcc_init(&tcc_instance, CONF_PWM_MODULE, &config_tcc);

    tcc_enable(&tcc_instance);
}

static void configure_tcc_callbacks(void)
{
    tcc_register_callback(
            &tcc_instance,
            tcc_callback_to_change_duty_cycle,
            TCC_CALLBACK_CHANNEL_0 + CONF_PWM_CHANNEL);

    tcc_enable_callback(&tcc_instance,
            TCC_CALLBACK_CHANNEL_0 + CONF_PWM_CHANNEL);
}
```

Add to user application initialization (typically the start of `main()`):

```
configure_tcc();
configure_tcc_callbacks();
```

Workflow

1. Create a module software instance structure for the TCC module to store the TCC driver state while it is in use.

   ```
   struct tcc_module tcc_instance;
   ```

Note This should never go out of scope as long as the module is in use. In most cases, this should be global.

2. Configure the TCC module.

   a. Create a TCC module configuration struct, which can be filled out to adjust the configuration of a physical TCC peripheral.

```
struct tcc_config config_tcc;
```

b. Initialize the TCC configuration struct with the module's default values.

```
tcc_get_config_defaults(&config_tcc, CONF_PWM_MODULE);
```

Note This should always be performed before using the configuration struct to ensure that all values are initialized to known default settings.

c. Alter the TCC settings to configure the counter width, wave generation mode and the compare channel 0 value.

```
config_tcc.counter.period = 0xFFFF;
config_tcc.compare.wave_generation = TCC_WAVE_GENERATION_SINGLE_SLOPE_PWM;
config_tcc.compare.match[CONF_PWM_CHANNEL] = 0xFFFF;
```

d. Alter the TCC settings to configure the PWM output on a physical device pin.

```
config_tcc.pins.enable_wave_out_pin[CONF_PWM_OUTPUT] = true;
config_tcc.pins.wave_out_pin[CONF_PWM_OUTPUT]        = CONF_PWM_OUT_PIN;
config_tcc.pins.wave_out_pin_mux[CONF_PWM_OUTPUT]    = CONF_PWM_OUT_MUX;
```

e. Configure the TCC module with the desired settings.

```
tcc_init(&tcc_instance, CONF_PWM_MODULE, &config_tcc);
```

f. Enable the TCC module to start the timer and begin PWM signal generation.

```
tcc_enable(&tcc_instance);
```

3. Configure the TCC callbacks.

a. Register the Compare Channel 0 Match callback functions with the driver.

```
tcc_register_callback(
        &tcc_instance,
        tcc_callback_to_change_duty_cycle,
        TCC_CALLBACK_CHANNEL_0 + CONF_PWM_CHANNEL);
```

b. Enable the Compare Channel 0 Match callback so that it will be called by the driver when appropriate.

```
tcc_enable_callback(&tcc_instance,
        TCC_CALLBACK_CHANNEL_0 + CONF_PWM_CHANNEL);
```

24.8.4.2 Use Case

Code

Copy-paste the following code to your user application:

```
system_interrupt_enable_global();
```

```
while (true) {
}
```

Workflow

1. Enter an infinite loop while the PWM wave is generated via the TCC module.

```
while (true) {
}
```

24.8.5 Quick Start Guide for TCC - Non-Recoverable Fault

The supported board list:

- SAM D21 Xplained Pro

In this use case, the TCC will be used to generate a PWM signal, with a varying duty cycle. Here the pulse width is increased each time the timer count matches the set compare value. There is a non-recoverable faul input which controls PWM output, when this fault is active (low) the PWM output will be forced to be high. When fault is released (input high) the PWM output then will go on.

When connect PWM output to LED it makes the LED vary its light. If fault input is from a button, the LED will be off when the button is down and on when the button is up. To see the PWM waveform, you may need an oscilloscope.

The PWM output and fault input is set up as follows:

Board	Pin	Connect to
SAMD21 Xpro	PB30	LED0
SAMD21 Xpro	PA15	SW0

The TCC module will be set up as follows:

- GCLK generator 0 (GCLK main) clock source
- Use double buffering write when set top, compare or pattern through API
- No dithering on the counter or compare
- No prescaler
- Single Slope PWM wave generation
- GCLK reload action
- Don't run in standby
- No waveform extentions
- No inversion of waveform output
- No capture enabled
- Count upward
- Don't perform one-shot operations
- No event input except TCC event0 enabled
- No event action except TCC event0 acts as Non-Recoverable Fault

- No event generation enabled
- Counter starts on 0

24.8.5.1 Quick Start

Prerequisites

There are no prerequisites for this use case.

Code

Add to the main application source file, before any functions:

```
#define CONF_PWM_MODULE      LED_0_PWM_MODULE

#define CONF_PWM_CHANNEL     LED_0_PWM_CHANNEL

#define CONF_PWM_OUTPUT      LED_0_PWM_OUTPUT

#define CONF_PWM_OUT_PIN     LED_0_PWM_PIN

#define CONF_PWM_OUT_MUX     LED_0_PWM_MUX
```

```
#define CONF_FAULT_EIC_PIN       SW0_EIC_PIN

#define CONF_FAULT_EIC_PIN_MUX   SW0_EIC_PINMUX

#define CONF_FAULT_EIC_LINE      SW0_EIC_LINE

#define CONF_FAULT_EVENT_GENERATOR EVSYS_ID_GEN_EIC_EXTINT_15

#define CONF_FAULT_EVENT_USER      EVSYS_ID_USER_TCC0_EV_0
```

Add to the main application source file, before any functions:

```
#include <string.h>
```

Add to the main application source file, outside of any functions:

```
struct tcc_module tcc_instance;
```

```
struct events_resource event_resource;
```

Copy-paste the following callback function code to your user application:

```
static void tcc_callback_to_change_duty_cycle(
        struct tcc_module *const module_inst)
{
    static uint32_t delay = 10;
    static uint32_t i = 0;

    if (--delay) {
        return;
    }
    delay = 10;
    i = (i + 0x0800) & 0xFFFF;
```

```
    tcc_set_compare_value(module_inst,
            TCC_MATCH_CAPTURE_CHANNEL_0 + CONF_PWM_CHANNEL, i + 1);
}
```

```
static void eic_callback_to_clear_halt(void)
{
    if (port_pin_get_input_level(CONF_FAULT_EIC_PIN)) {
        tcc_clear_status(&tcc_instance,
                TCC_STATUS_NON_RECOVERABLE_FAULT_PRESENT(0) |
                TCC_STATUS_NON_RECOVERABLE_FAULT_OCCUR(0));
    }
}
```

Copy-paste the following setup code to your user application:

```
static void configure_tcc(void)
{
    struct tcc_config config_tcc;
    tcc_get_config_defaults(&config_tcc, CONF_PWM_MODULE);

    config_tcc.counter.period = 0xFFFF;
    config_tcc.compare.wave_generation = TCC_WAVE_GENERATION_SINGLE_SLOPE_PWM;
    config_tcc.compare.match[CONF_PWM_CHANNEL] = 0xFFFF;
    config_tcc.wave_ext.non_recoverable_fault[0].output = TCC_FAULT_STATE_OUTPUT_1;
    config_tcc.pins.enable_wave_out_pin[CONF_PWM_OUTPUT] = true;
    config_tcc.pins.wave_out_pin[CONF_PWM_OUTPUT]        = CONF_PWM_OUT_PIN;
    config_tcc.pins.wave_out_pin_mux[CONF_PWM_OUTPUT]    = CONF_PWM_OUT_MUX;

    tcc_init(&tcc_instance, CONF_PWM_MODULE, &config_tcc);

    struct tcc_events events;
    memset(&events, 0, sizeof(struct tcc_events));

    events.on_input_event_perform_action[0] = true;
    events.input_config[0].modify_action = true;
    events.input_config[0].action = TCC_EVENT_ACTION_NON_RECOVERABLE_FAULT;

    tcc_enable_events(&tcc_instance, &events);

    tcc_enable(&tcc_instance);
}

static void configure_tcc_callbacks(void)
{
    tcc_register_callback(
            &tcc_instance,
            tcc_callback_to_change_duty_cycle,
            TCC_CALLBACK_CHANNEL_0 + CONF_PWM_CHANNEL);

    tcc_enable_callback(&tcc_instance,
            TCC_CALLBACK_CHANNEL_0 + CONF_PWM_CHANNEL);
}
```

```
static void configure_eic(void)
{
    struct extint_chan_conf config;
    extint_chan_get_config_defaults(&config);
    config.filter_input_signal = true;
```

```
    config.detection_criteria  = EXTINT_DETECT_BOTH;
    config.gpio_pin     = CONF_FAULT_EIC_PIN;
    config.gpio_pin_mux = CONF_FAULT_EIC_PIN_MUX;
    extint_chan_set_config(CONF_FAULT_EIC_LINE, &config);

    struct extint_events events;
    memset(&events, 0, sizeof(struct extint_events));
    events.generate_event_on_detect[CONF_FAULT_EIC_LINE] = true;
    extint_enable_events(&events);

    extint_register_callback(eic_callback_to_clear_halt,
            CONF_FAULT_EIC_LINE, EXTINT_CALLBACK_TYPE_DETECT);
    extint_chan_enable_callback(CONF_FAULT_EIC_LINE,
            EXTINT_CALLBACK_TYPE_DETECT);
}
```

```
static void configure_event(void)
{
    struct events_config config;

    events_get_config_defaults(&config);

    config.generator = CONF_FAULT_EVENT_GENERATOR;
    config.path      = EVENTS_PATH_ASYNCHRONOUS;

    events_allocate(&event_resource, &config);

    events_attach_user(&event_resource, CONF_FAULT_EVENT_USER);
}
```

Add to user application initialization (typically the start of `main()`):

```
configure_tcc();
configure_tcc_callbacks();

configure_eic();
configure_event();
```

Workflow

Configure TCC

1. Create a module software instance struct for the TCC module to store the TCC driver state while it is in use.

   ```
   struct tcc_module tcc_instance;
   ```

Note This should never go out of scope as long as the module is in use. In most cases, this should be global.

2. Create a TCC module configuration struct, which can be filled out to adjust the configuration of a physical TCC peripheral.

   ```
   struct tcc_config config_tcc;
   ```

3. Initialize the TCC configuration struct with the module's default values.

```
tcc_get_config_defaults(&config_tcc, CONF_PWM_MODULE);
```

Note This should always be performed before using the configuration struct to ensure that all values are initialized to known default settings.

4. Alter the TCC settings to configure the counter width, wave generation mode and the compare channel 0 value and fault options. Here the Non- Recoverable Fault output is enabled and set to high level (1).

```
config_tcc.counter.period = 0xFFFF;
config_tcc.compare.wave_generation = TCC_WAVE_GENERATION_SINGLE_SLOPE_PWM;
config_tcc.compare.match[CONF_PWM_CHANNEL] = 0xFFFF;
```

```
config_tcc.wave_ext.non_recoverable_fault[0].output = TCC_FAULT_STATE_OUTPUT_1;
```

5. Alter the TCC settings to configure the PWM output on a physical device pin.

```
config_tcc.pins.enable_wave_out_pin[CONF_PWM_OUTPUT] = true;
config_tcc.pins.wave_out_pin[CONF_PWM_OUTPUT]        = CONF_PWM_OUT_PIN;
config_tcc.pins.wave_out_pin_mux[CONF_PWM_OUTPUT]    = CONF_PWM_OUT_MUX;
```

6. Configure the TCC module with the desired settings.

```
tcc_init(&tcc_instance, CONF_PWM_MODULE, &config_tcc);
```

7. Create a TCC events configuration struct, which can be filled out to enable/disable events and configure event settings. Reset all fields to zero.

```
struct tcc_events events;
memset(&events, 0, sizeof(struct tcc_events));
```

8. Alter the TCC events settings to enable/disable desired events, to change event generating options and modify event actions. Here TCC event0 will act as Non-Recoverable Fault input.

```
events.on_input_event_perform_action[0] = true;
events.input_config[0].modify_action = true;
events.input_config[0].action = TCC_EVENT_ACTION_NON_RECOVERABLE_FAULT;
```

9. Enable and apply events settings.

```
tcc_enable_events(&tcc_instance, &events);
```

10. Enable the TCC module to start the timer and begin PWM signal generation.

```
tcc_enable(&tcc_instance);
```

11. Register the Compare Channel 0 Match callback functions with the driver.

```
tcc_register_callback(
        &tcc_instance,
```

```
        tcc_callback_to_change_duty_cycle,
        TCC_CALLBACK_CHANNEL_0 + CONF_PWM_CHANNEL);
```

12. Enable the Compare Channel 0 Match callback so that it will be called by the driver when appropriate.

```
tcc_enable_callback(&tcc_instance,
        TCC_CALLBACK_CHANNEL_0 + CONF_PWM_CHANNEL);
```

Configure EXTINT for fault input

1. Create an EXTINT module channel configuration struct, which can be filled out to adjust the configuration of a single external interrupt channel.

```
struct extint_chan_conf config;
```

2. Initialize the channel configuration struct with the module's default values.

```
extint_chan_get_config_defaults(&config);
```

Note This should always be performed before using the configuration struct to ensure that all values are initialized to known default settings.

3. Adjust the configuration struct to configure the pin MUX (to route the desired physical pin to the logical channel) to the board button, and to configure the channel to detect both rising and falling edges.

```
config.filter_input_signal = true;
config.detection_criteria  = EXTINT_DETECT_BOTH;
config.gpio_pin     = CONF_FAULT_EIC_PIN;
config.gpio_pin_mux = CONF_FAULT_EIC_PIN_MUX;
```

4. Configure external interrupt channel with the desired channel settings.

```
extint_chan_set_config(CONF_FAULT_EIC_LINE, &config);
```

5. Create a TXTINT events configuration struct, which can be filled out to enable/disable events. Reset all fields to zero.

```
struct extint_events events;
memset(&events, 0, sizeof(struct extint_events));
```

6. Adjust the configuration struct, set the channels to be enabled to `true`. Here the channel to the board button is used.

```
events.generate_event_on_detect[CONF_FAULT_EIC_LINE] = true;
```

7. Enable the events.

```
extint_enable_events(&events);
```

8. Define the EXTINT callback that will be fired when a detection event occurs. For this example, when fault line is released, the TCC fault state is cleared to go on PWM generating.

```
static void eic_callback_to_clear_halt(void)
{
    if (port_pin_get_input_level(CONF_FAULT_EIC_PIN)) {
        tcc_clear_status(&tcc_instance,
                TCC_STATUS_NON_RECOVERABLE_FAULT_PRESENT(0) |
                TCC_STATUS_NON_RECOVERABLE_FAULT_OCCUR(0));
    }
}
```

9. Register a callback function `eic_callback_to_clear_halt()` to handle detections from the External Interrupt Controller (EIC).

```
extint_register_callback(eic_callback_to_clear_halt,
        CONF_FAULT_EIC_LINE, EXTINT_CALLBACK_TYPE_DETECT);
```

10. Enable the registered callback function for the configured External Interrupt channel, so that it will be called by the module when the channel detects an edge.

```
extint_chan_enable_callback(CONF_FAULT_EIC_LINE,
        EXTINT_CALLBACK_TYPE_DETECT);
```

Configure EVENTS for fault input

1. Create a event resource instance struct for the EVENTS module to store

```
struct events_resource event_resource;
```

Note This should never go out of scope as long as the resource is in use. In most cases, this should be global.

2. Create an event channel configuration struct, which can be filled out to adjust the configuration of a single event channel.

```
struct events_config config;
```

3. Initialize the event channel configuration struct with the module's default values.

```
events_get_config_defaults(&config);
```

Note This should always be performed before using the configuration struct to ensure that all values are initialized to known default settings.

4. Adjust the configuration struct to request that the channel be attached to the specified event generator, and that the asynchronous event path be used. Here the EIC channel connected to board button is the event generator.

```
config.generator = CONF_FAULT_EVENT_GENERATOR;
config.path      = EVENTS_PATH_ASYNCHRONOUS;
```

5. Allocate and configure the channel using the configuration structure.

```
events_allocate(&event_resource, &config);
```

Note The existing configuration struct may be re-used, as long as any values that have been altered from the default settings are taken into account by the user application.

6. Attach an user to the channel. Here the user is TCC event0, which has been configured as input of Non-Recoverable Fault.

```
events_attach_user(&event_resource, CONF_FAULT_EVENT_USER);
```

24.8.5.2 Use Case

Code

Copy-paste the following code to your user application:

```
system_interrupt_enable_global();

while (true) {
}
```

Workflow

1. Enter an infinite loop while the PWM wave is generated via the TCC module.

```
while (true) {
}
```

24.8.6 Quick Start Guide for TCC - Recoverable Fault

The supported board list:

- SAM D21 Xplained Pro

In this use case, the TCC will be used to generate a PWM signal, with a varying duty cycle. Here the pulse width is increased each time the timer count matches the set compare value. There is a recoverable faul input which controls PWM output, when this fault is active (low) the PWM output will be frozen (could be off or on, no light changing). When fault is released (input high) the PWM output then will go on.

When connect PWM output to LED it makes the LED vary its light. If fault input is from a button, the LED will be frozen and not changing it's light when the button is down and will go on when the button is up. To see the PWM waveform, you may need an oscilloscope.

The PWM output and fault input is set up as follows:

Board	Pin	Connect to
SAMD21 Xpro	PB30	LED0
SAMD21 Xpro	PA15	SW0

The TCC module will be set up as follows:

- GCLK generator 0 (GCLK main) clock source
- Use double buffering write when set top, compare or pattern through API
- No dithering on the counter or compare

- No prescaler
- Single Slope PWM wave generation
- GCLK reload action
- Don't run in standby
- No waveform extentions
- No inversion of waveform output
- No capture enabled
- Count upward
- Don't perform one-shot operations
- No event input except channel 0 event enabled
- No event action
- No event generation enabled
- Counter starts on 0
- Recoverable Fault A is generated from channel 0 event input, fault halt acts as software halt, other actions or options are all disabled

24.8.6.1 Quick Start

Prerequisites

There are no prerequisites for this use case.

Code

Add to the main application source file, before any functions:

```
#define CONF_PWM_MODULE      LED_0_PWM_MODULE
#define CONF_PWM_CHANNEL     LED_0_PWM_CHANNEL
#define CONF_PWM_OUTPUT      LED_0_PWM_OUTPUT
#define CONF_PWM_OUT_PIN     LED_0_PWM_PIN
#define CONF_PWM_OUT_MUX     LED_0_PWM_MUX
```

```
#define CONF_FAULT_EIC_PIN       SW0_EIC_PIN
#define CONF_FAULT_EIC_PIN_MUX   SW0_EIC_PINMUX
#define CONF_FAULT_EIC_LINE      SW0_EIC_LINE
#define CONF_FAULT_EVENT_GENERATOR EVSYS_ID_GEN_EIC_EXTINT_15
#define CONF_FAULT_EVENT_USER      EVSYS_ID_USER_TCC0_MC_0
```

Add to the main application source file, before any functions:

```
#include <string.h>
```

Add to the main application source file, outside of any functions:

```
struct tcc_module tcc_instance;
```

```
struct events_resource event_resource;
```

Copy-paste the following callback function code to your user application:

```
static void tcc_callback_to_change_duty_cycle(
        struct tcc_module *const module_inst)
{
    static uint32_t delay = 10;
    static uint32_t i = 0;

    if (--delay) {
        return;
    }
    delay = 10;
    i = (i + 0x0800) & 0xFFFF;
    tcc_set_compare_value(module_inst,
            TCC_MATCH_CAPTURE_CHANNEL_0 + CONF_PWM_CHANNEL, i + 1);
}
```

```
static void eic_callback_to_clear_halt(void)
{
    if (port_pin_get_input_level(CONF_FAULT_EIC_PIN)) {
        tcc_clear_status(&tcc_instance,
                TCC_STATUS_RECOVERABLE_FAULT_PRESENT(CONF_PWM_CHANNEL) |
                TCC_STATUS_RECOVERABLE_FAULT_OCCUR(CONF_PWM_CHANNEL));
    }
}
```

Copy-paste the following setup code to your user application:

```
static void configure_tcc(void)
{
    struct tcc_config config_tcc;
    tcc_get_config_defaults(&config_tcc, CONF_PWM_MODULE);

    config_tcc.counter.period = 0xFFFF;
    config_tcc.compare.wave_generation = TCC_WAVE_GENERATION_SINGLE_SLOPE_PWM;
    config_tcc.compare.match[CONF_PWM_CHANNEL] = 0xFFFF;
    config_tcc.wave_ext.recoverable_fault[CONF_PWM_CHANNEL].source =
            TCC_FAULT_SOURCE_ENABLE;
    config_tcc.wave_ext.recoverable_fault[CONF_PWM_CHANNEL].halt_action =
            TCC_FAULT_HALT_ACTION_SW_HALT;
    config_tcc.pins.enable_wave_out_pin[CONF_PWM_OUTPUT] = true;
    config_tcc.pins.wave_out_pin[CONF_PWM_OUTPUT]        = CONF_PWM_OUT_PIN;
    config_tcc.pins.wave_out_pin_mux[CONF_PWM_OUTPUT]    = CONF_PWM_OUT_MUX;

    tcc_init(&tcc_instance, CONF_PWM_MODULE, &config_tcc);

    struct tcc_events events;
    memset(&events, 0, sizeof(struct tcc_events));

    events.on_event_perform_channel_action[CONF_PWM_CHANNEL] = true;
```

```
    tcc_enable_events(&tcc_instance, &events);

    tcc_enable(&tcc_instance);
}

static void configure_tcc_callbacks(void)
{
    tcc_register_callback(
            &tcc_instance,
            tcc_callback_to_change_duty_cycle,
            TCC_CALLBACK_CHANNEL_0 + CONF_PWM_CHANNEL);

    tcc_enable_callback(&tcc_instance,
            TCC_CALLBACK_CHANNEL_0 + CONF_PWM_CHANNEL);
}
```

```
static void configure_eic(void)
{
    struct extint_chan_conf config;
    extint_chan_get_config_defaults(&config);
    config.filter_input_signal = true;
    config.detection_criteria  = EXTINT_DETECT_BOTH;
    config.gpio_pin     = CONF_FAULT_EIC_PIN;
    config.gpio_pin_mux = CONF_FAULT_EIC_PIN_MUX;
    extint_chan_set_config(CONF_FAULT_EIC_LINE, &config);

    struct extint_events events;
    memset(&events, 0, sizeof(struct extint_events));
    events.generate_event_on_detect[CONF_FAULT_EIC_LINE] = true;
    extint_enable_events(&events);

    extint_register_callback(eic_callback_to_clear_halt,
            CONF_FAULT_EIC_LINE, EXTINT_CALLBACK_TYPE_DETECT);
    extint_chan_enable_callback(CONF_FAULT_EIC_LINE,
            EXTINT_CALLBACK_TYPE_DETECT);
}
```

```
static void configure_event(void)
{
    struct events_config config;

    events_get_config_defaults(&config);

    config.generator = CONF_FAULT_EVENT_GENERATOR;
    config.path      = EVENTS_PATH_ASYNCHRONOUS;

    events_allocate(&event_resource, &config);

    events_attach_user(&event_resource, CONF_FAULT_EVENT_USER);
}
```

Add to user application initialization (typically the start of `main()`):

```
configure_tcc();
configure_tcc_callbacks();

configure_eic();
configure_event();
```

Workflow

Configure TCC

1. Create a module software instance struct for the TCC module to store the TCC driver state while it is in use.

```
struct tcc_module tcc_instance;
```

Note This should never go out of scope as long as the module is in use. In most cases, this should be global.

2. Create a TCC module configuration struct, which can be filled out to adjust the configuration of a physical TCC peripheral.

```
struct tcc_config config_tcc;
```

3. Initialize the TCC configuration struct with the module's default values.

```
tcc_get_config_defaults(&config_tcc, CONF_PWM_MODULE);
```

Note This should always be performed before using the configuration struct to ensure that all values are initialized to known default settings.

4. Alter the TCC settings to configure the counter width, wave generation mode and the compare channel 0 value and fault options. Here the Recoverable Fault input is enabled and halt action is set to software mode (must use software to clear halt state).

```
config_tcc.counter.period = 0xFFFF;
config_tcc.compare.wave_generation = TCC_WAVE_GENERATION_SINGLE_SLOPE_PWM;
config_tcc.compare.match[CONF_PWM_CHANNEL] = 0xFFFF;
```

```
config_tcc.wave_ext.recoverable_fault[CONF_PWM_CHANNEL].source =
        TCC_FAULT_SOURCE_ENABLE;
config_tcc.wave_ext.recoverable_fault[CONF_PWM_CHANNEL].halt_action =
        TCC_FAULT_HALT_ACTION_SW_HALT;
```

5. Alter the TCC settings to configure the PWM output on a physical device pin.

```
config_tcc.pins.enable_wave_out_pin[CONF_PWM_OUTPUT] = true;
config_tcc.pins.wave_out_pin[CONF_PWM_OUTPUT]        = CONF_PWM_OUT_PIN;
config_tcc.pins.wave_out_pin_mux[CONF_PWM_OUTPUT]    = CONF_PWM_OUT_MUX;
```

6. Configure the TCC module with the desired settings.

```
tcc_init(&tcc_instance, CONF_PWM_MODULE, &config_tcc);
```

7. Create a TCC events configuration struct, which can be filled out to enable/disable events and configure event settings. Reset all fields to zero.

```
struct tcc_events events;
memset(&events, 0, sizeof(struct tcc_events));
```

8. Alter the TCC events settings to enable/disable desired events, to change event generating options and modify event actions. Here channel event 0 input is enabled as source of recoverable fault.

```
events.on_event_perform_channel_action[CONF_PWM_CHANNEL] = true;
```

9. Enable and apply events settings.

```
tcc_enable_events(&tcc_instance, &events);
```

10. Enable the TCC module to start the timer and begin PWM signal generation.

```
tcc_enable(&tcc_instance);
```

11. Register the Compare Channel 0 Match callback functions with the driver.

```
tcc_register_callback(
        &tcc_instance,
        tcc_callback_to_change_duty_cycle,
        TCC_CALLBACK_CHANNEL_0 + CONF_PWM_CHANNEL);
```

12. Enable the Compare Channel 0 Match callback so that it will be called by the driver when appropriate.

```
tcc_enable_callback(&tcc_instance,
        TCC_CALLBACK_CHANNEL_0 + CONF_PWM_CHANNEL);
```

Configure EXTINT for fault input

1. Create an EXTINT module channel configuration struct, which can be filled out to adjust the configuration of a single external interrupt channel.

```
struct extint_chan_conf config;
```

2. Initialize the channel configuration struct with the module's default values.

```
extint_chan_get_config_defaults(&config);
```

Note This should always be performed before using the configuration struct to ensure that all values are initialized to known default settings.

3. Adjust the configuration struct to configure the pin MUX (to route the desired physical pin to the logical channel) to the board button, and to configure the channel to detect both rising and falling edges.

```
config.filter_input_signal = true;
config.detection_criteria  = EXTINT_DETECT_BOTH;
config.gpio_pin     = CONF_FAULT_EIC_PIN;
config.gpio_pin_mux = CONF_FAULT_EIC_PIN_MUX;
```

4. Configure external interrupt channel with the desired channel settings.

```
extint_chan_set_config(CONF_FAULT_EIC_LINE, &config);
```

5. Create a TXTINT events configuration struct, which can be filled out to enable/disable events. Reset all fields to zero.

```
struct extint_events events;
memset(&events, 0, sizeof(struct extint_events));
```

6. Adjust the configuration struct, set the channels to be enabled to `true`. Here the channel to the board button is used.

```
events.generate_event_on_detect[CONF_FAULT_EIC_LINE] = true;
```

7. Enable the events.

```
extint_enable_events(&events);
```

8. Define the EXTINT callback that will be fired when a detection event occurs. For this example, when fault line is released, the TCC fault state is cleared to go on PWM generating.

```
static void eic_callback_to_clear_halt(void)
{
    if (port_pin_get_input_level(CONF_FAULT_EIC_PIN)) {
        tcc_clear_status(&tcc_instance,
                TCC_STATUS_RECOVERABLE_FAULT_PRESENT(CONF_PWM_CHANNEL) |
                TCC_STATUS_RECOVERABLE_FAULT_OCCUR(CONF_PWM_CHANNEL));
    }
}
```

9. Register a callback function `eic_callback_to_clear_halt()` to handle detections from the External Interrupt Controller (EIC).

```
extint_register_callback(eic_callback_to_clear_halt,
        CONF_FAULT_EIC_LINE, EXTINT_CALLBACK_TYPE_DETECT);
```

10. Enable the registered callback function for the configured External Interrupt channel, so that it will be called by the module when the channel detects an edge.

```
extint_chan_enable_callback(CONF_FAULT_EIC_LINE,
        EXTINT_CALLBACK_TYPE_DETECT);
```

Configure EVENTS for fault input

1. Create a event resource instance struct for the EVENTS module to store

```
struct events_resource event_resource;
```

Note

This should never go out of scope as long as the resource is in use. In most cases, this should be global.

2. Create an event channel configuration struct, which can be filled out to adjust the configuration of a single event channel.

```
struct events_config config;
```

3. Initialize the event channel configuration struct with the module's default values.

```
events_get_config_defaults(&config);
```

Note This should always be performed before using the configuration struct to ensure that all values are initialized to known default settings.

4. Adjust the configuration struct to request that the channel be attached to the specified event generator, and that the asynchronous event path be used. Here the EIC channel connected to board button is the event generator.

```
config.generator = CONF_FAULT_EVENT_GENERATOR;
config.path      = EVENTS_PATH_ASYNCHRONOUS;
```

5. Allocate and configure the channel using the configuration structure.

```
events_allocate(&event_resource, &config);
```

Note The existing configuration struct may be re-used, as long as any values that have been altered from the default settings are taken into account by the user application.

6. Attach an user to the channel. Here the user is TCC channel 0 event, which has been configured as input of Recoverable Fault.

```
events_attach_user(&event_resource, CONF_FAULT_EVENT_USER);
```

24.8.6.2 Use Case

Code

Copy-paste the following code to your user application:

```
system_interrupt_enable_global();

while (true) {
}
```

Workflow

1. Enter an infinite loop while the PWM wave is generated via the TCC module.

```
while (true) {
}
```

24.8.7 Quick Start Guide for Using DMA with TCC

The supported board list:

- SAM D21 Xplained Pro

In this use case, the TCC will be used to generate a PWM signal. Here the pulse width varies through following values with the help of DMA transfer: one quarter of the period, half of the period and three quarters of the period. The PWM output can be used to drive an LED. The waveform can also be viewed using an oscilloscope. The

output signal is also fed back to another TCC channel by event system, the event stamps are captured and transferred to a buffer by DMA.

The PWM output is set up as follows:

Board	Pin	Connect to
SAMD21 Xpro	PB30	LED0

The TCC module will be setup as follows:

- GCLK generator 0 (GCLK main) clock source
- Use double buffering write when set top, compare or pattern through API
- No dithering on the counter or compare
- No prescaler
- Single Slope PWM wave generation
- GCLK reload action
- Don't run in standby
- No fault or waveform extensions
- No inversion of waveform output
- No capture enabled
- Count upward
- Don't perform one-shot operations
- Counter starts on 0
- Counter top set to 0x1000
- Channel 0 is set to compare and match value 0x1000*3/4 and generate event
- Channel 1 is set to capture on input event

The event resource of EVSYS module will be setup as follows:

- TCC match capture channel 0 is selected as event generator
- Event generation is synchronous, with rising edge detected
- TCC match capture channel 1 is the event user

The DMA resource of DMAC module will be setup as follows:

- Two DMA resources are used
- Both DMA resources use peripheral trigger
- Both DMA resources perform beat transfer on trigger
- Both DMA resources use beat size of 16-bits
- Both DMA resources are configured to transfer 3 beats and then repeat again in same buffer
- On DMA resource which controls the compare value
    - TCC0 overflow triggers DMA transfer

- The source address increment is enabled
- The destination address is fixed to TCC channel 0 Compare/Capture register

- On DMA resource which reads the captured value
  - TCC0 capture on channel 1 triggers DMA transfer
  - The source address is fixed to TCC channel 1 Compare/Capture register
  - The destination address increment is enabled
  - The captured value is transferred to an array in SRAM

24.8.7.1 Quick Start

Prerequisites

There are no prerequisites for this use case.

Code

Add to the main application source file, before any functions:

```
#define CONF_PWM_MODULE      LED_0_PWM_MODULE

#define CONF_PWM_CHANNEL     LED_0_PWM_CHANNEL

#define CONF_PWM_OUTPUT      LED_0_PWM_OUTPUT

#define CONF_PWM_OUT_PIN     LED_0_PWM_PIN

#define CONF_PWM_OUT_MUX     LED_0_PWM_MUX
```

```
#define CONF_TCC_CAPTURE_CHANNEL      1

#define CONF_TCC_EVENT_GENERATOR      EVSYS_ID_GEN_TCC0_MCX_0

#define CONF_TCC_EVENT_USER           EVSYS_ID_USER_TCC0_MC_1
```

```
#define CONF_COMPARE_TRIGGER TCC0_DMAC_ID_OVF
```

```
#define CONF_CAPTURE_TRIGGER TCC0_DMAC_ID_MC_1
```

Add to the main application source file, outside of any functions:

```
struct tcc_module tcc_instance;
```

```
uint16_t capture_values[3] = {0, 0, 0};
struct dma_resource capture_dma_resource;
COMPILER_ALIGNED(16) DmacDescriptor capture_dma_descriptor;
struct events_resource capture_event_resource;
```

```
uint16_t compare_values[3] = {
    (0x1000 / 4), (0x1000 * 2 / 4), (0x1000 * 3 / 4)
};
```

```
struct dma_resource compare_dma_resource;
COMPILER_ALIGNED(16) DmacDescriptor compare_dma_descriptor;
```

Copy-paste the following setup code to your user application:

```
static void config_event_for_capture(void)
{
    struct events_config config;

    events_get_config_defaults(&config);

    config.generator      = CONF_TCC_EVENT_GENERATOR;
    config.edge_detect    = EVENTS_EDGE_DETECT_RISING;
    config.path           = EVENTS_PATH_SYNCHRONOUS;
    config.clock_source   = GCLK_GENERATOR_0;

    events_allocate(&capture_event_resource, &config);

    events_attach_user(&capture_event_resource, CONF_TCC_EVENT_USER);
}
```

```
static void config_dma_for_capture(void)
{
    struct dma_resource_config config;

    dma_get_config_defaults(&config);

    config.trigger_action = DMA_TRIGGER_ACTON_BEAT;
    config.peripheral_trigger = CONF_CAPTURE_TRIGGER;

    dma_allocate(&capture_dma_resource, &config);

    struct dma_descriptor_config descriptor_config;

    dma_descriptor_get_config_defaults(&descriptor_config);

    descriptor_config.block_transfer_count = 3;
    descriptor_config.beat_size = DMA_BEAT_SIZE_HWORD;
    descriptor_config.step_selection = DMA_STEPSEL_SRC;
    descriptor_config.src_increment_enable = false;
    descriptor_config.source_address =
            (uint32_t)&CONF_PWM_MODULE->CC[CONF_TCC_CAPTURE_CHANNEL];
    descriptor_config.destination_address =
            (uint32_t)capture_values + sizeof(capture_values);

    dma_descriptor_create(&capture_dma_descriptor, &descriptor_config);

    dma_add_descriptor(&capture_dma_resource, &capture_dma_descriptor);
    dma_add_descriptor(&capture_dma_resource, &capture_dma_descriptor);
    dma_start_transfer_job(&capture_dma_resource);
}
```

```
static void config_dma_for_wave(void)
{
    struct dma_resource_config config;
    dma_get_config_defaults(&config);
    config.trigger_action = DMA_TRIGGER_ACTON_BEAT;
    config.peripheral_trigger = CONF_COMPARE_TRIGGER;
```

```
    dma_allocate(&compare_dma_resource, &config);

    struct dma_descriptor_config descriptor_config;

    dma_descriptor_get_config_defaults(&descriptor_config);

    descriptor_config.block_transfer_count = 3;
    descriptor_config.beat_size = DMA_BEAT_SIZE_HWORD;
    descriptor_config.dst_increment_enable = false;
    descriptor_config.source_address =
            (uint32_t)compare_values + sizeof(compare_values);
    descriptor_config.destination_address =
            (uint32_t)&CONF_PWM_MODULE->CC[CONF_PWM_CHANNEL];

    dma_descriptor_create(&compare_dma_descriptor, &descriptor_config);

    dma_add_descriptor(&compare_dma_resource, &compare_dma_descriptor);
    dma_add_descriptor(&compare_dma_resource, &compare_dma_descriptor);
    dma_start_transfer_job(&compare_dma_resource);
}
```

```
static void configure_tcc(void)
{
    struct tcc_config config_tcc;
    tcc_get_config_defaults(&config_tcc, CONF_PWM_MODULE);

    config_tcc.counter.period = 0x1000;
    config_tcc.compare.channel_function[CONF_TCC_CAPTURE_CHANNEL] =
            TCC_CHANNEL_FUNCTION_CAPTURE;
    config_tcc.compare.wave_generation = TCC_WAVE_GENERATION_SINGLE_SLOPE_PWM;
    config_tcc.compare.wave_polarity[CONF_PWM_CHANNEL] = TCC_WAVE_POLARITY_0;
    config_tcc.compare.match[CONF_PWM_CHANNEL] = compare_values[2];

    config_tcc.pins.enable_wave_out_pin[CONF_PWM_OUTPUT] = true;
    config_tcc.pins.wave_out_pin[CONF_PWM_OUTPUT]        = CONF_PWM_OUT_PIN;
    config_tcc.pins.wave_out_pin_mux[CONF_PWM_OUTPUT]    = CONF_PWM_OUT_MUX;

    tcc_init(&tcc_instance, CONF_PWM_MODULE, &config_tcc);

    struct tcc_events events_tcc = {
        .input_config[0].modify_action = false,
        .input_config[1].modify_action = false,
        .output_config.modify_generation_selection = false,
        .generate_event_on_channel[CONF_PWM_CHANNEL] = true,
        .on_event_perform_channel_action[CONF_TCC_CAPTURE_CHANNEL] = true
    };
    tcc_enable_events(&tcc_instance, &events_tcc);

    config_event_for_capture();

    config_dma_for_capture();
    config_dma_for_wave();

    tcc_enable(&tcc_instance);
}
```

Add to user application initialization (typically the start of `main()`):

```
configure_tcc();
```

Workflow

Configure the TCC

1. Create a module software instance structure for the TCC module to store the TCC driver state while it is in use.

```
struct tcc_module tcc_instance;
```

Note This should never go out of scope as long as the module is in use. In most cases, this should be global.

2. Create a TCC module configuration struct, which can be filled out to adjust the configuration of a physical TCC peripheral.

```
struct tcc_config config_tcc;
```

3. Initialize the TCC configuration struct with the module's default values.

```
tcc_get_config_defaults(&config_tcc, CONF_PWM_MODULE);
```

Note This should always be performed before using the configuration struct to ensure that all values are initialized to known default settings.

4. Alter the TCC settings to configure the counter width, wave generation mode and the compare channel 0 value.

```
config_tcc.counter.period = 0x1000;
config_tcc.compare.channel_function[CONF_TCC_CAPTURE_CHANNEL] =
        TCC_CHANNEL_FUNCTION_CAPTURE;
config_tcc.compare.wave_generation = TCC_WAVE_GENERATION_SINGLE_SLOPE_PWM;
config_tcc.compare.wave_polarity[CONF_PWM_CHANNEL] = TCC_WAVE_POLARITY_0;
config_tcc.compare.match[CONF_PWM_CHANNEL] = compare_values[2];
```

5. Alter the TCC settings to configure the PWM output on a physical device pin.

```
config_tcc.pins.enable_wave_out_pin[CONF_PWM_OUTPUT] = true;
config_tcc.pins.wave_out_pin[CONF_PWM_OUTPUT]        = CONF_PWM_OUT_PIN;
config_tcc.pins.wave_out_pin_mux[CONF_PWM_OUTPUT]    = CONF_PWM_OUT_MUX;
```

6. Configure the TCC module with the desired settings.

```
tcc_init(&tcc_instance, CONF_PWM_MODULE, &config_tcc);
```

7. Configure and enable the desired events for the TCC module.

```
struct tcc_events events_tcc = {
    .input_config[0].modify_action = false,
    .input_config[1].modify_action = false,
    .output_config.modify_generation_selection = false,
    .generate_event_on_channel[CONF_PWM_CHANNEL] = true,
    .on_event_perform_channel_action[CONF_TCC_CAPTURE_CHANNEL] = true
};
```

```
tcc_enable_events(&tcc_instance, &events_tcc);
```

Configure the Event System

Configure the EVSYS module to wire channel 0 event to channel 1.

1. Create an event resource instance.

```
struct events_resource capture_event_resource;
```

Note This should never go out of scope as long as the resource is in use. In most cases, this should be global.

2. Create an event resource configuration struct.

```
struct events_config config;
```

3. Initialize the event resource configuration struct with default values.

```
events_get_config_defaults(&config);
```

Note This should always be performed before using the configuration struct to ensure that all values are initialized to known default settings.

4. Adjust the event resource configuration to desired values.

```
config.generator      = CONF_TCC_EVENT_GENERATOR;
config.edge_detect    = EVENTS_EDGE_DETECT_RISING;
config.path           = EVENTS_PATH_SYNCHRONOUS;
config.clock_source   = GCLK_GENERATOR_0;
```

5. Allocate and configure the resource using the configuration structure.

```
events_allocate(&capture_event_resource, &config);
```

6. Attach a user to the resource

```
events_attach_user(&capture_event_resource, CONF_TCC_EVENT_USER);
```

Configure the DMA for Capture TCC Channel 1

Configure the DMAC module to obtain captured value from TCC channel 1.

1. Create a DMA resource instance.

```
struct dma_resource capture_dma_resource;
```

Note This should never go out of scope as long as the resource is in use. In most cases, this should be global.

2. Create a DMA resource configuration struct.

```
struct dma_resource_config config;
```

3. Initialize the DMA resource configuration struct with default values.

```
dma_get_config_defaults(&config);
```

Note This should always be performed before using the configuration struct to ensure that all values are initialized to known default settings.

4. Adjust the DMA resource configurations.

```
config.trigger_action = DMA_TRIGGER_ACTON_BEAT;
config.peripheral_trigger = CONF_CAPTURE_TRIGGER;
```

5. Allocate a DMA resource with the configurations.

```
dma_allocate(&capture_dma_resource, &config);
```

6. Prepare DMA transfer descriptor

   a. Create a DMA transfer descriptor.

```
COMPILER_ALIGNED(16) DmacDescriptor capture_dma_descriptor;
```

Note When multiple descriptors are linked. The linked item should never go out of scope before it's loaded (to DMA Write-Back memory section). In most cases, if more than one descriptors are used, they should be global except the very first one.

   b. Create a DMA transfer descriptor struct.

   c. Create a DMA transfer descriptor configuration structure, which can be filled out to adjust the configuration of a single DMA transfer.

```
struct dma_descriptor_config descriptor_config;
```

   d. Initialize the DMA transfer descriptor configuration struct with default values.

```
dma_descriptor_get_config_defaults(&descriptor_config);
```

Note This should always be performed before using the configuration struct to ensure that all values are initialized to known default settings.

   e. Adjust the DMA transfer descriptor configurations.

```
descriptor_config.block_transfer_count = 3;
descriptor_config.beat_size = DMA_BEAT_SIZE_HWORD;
descriptor_config.step_selection = DMA_STEPSEL_SRC;
descriptor_config.src_increment_enable = false;
```

```
descriptor_config.source_address =
        (uint32_t)&CONF_PWM_MODULE->CC[CONF_TCC_CAPTURE_CHANNEL];
descriptor_config.destination_address =
        (uint32_t)capture_values + sizeof(capture_values);
```

f. Create the DMA transfer descriptor with the given configuration.

```
dma_descriptor_create(&capture_dma_descriptor, &descriptor_config);
```

7. Start DMA transfer job with prepared descriptor

a. Add the DMA transfer descriptor to the allocated DMA resource.

```
dma_add_descriptor(&capture_dma_resource, &capture_dma_descriptor);
dma_add_descriptor(&capture_dma_resource, &capture_dma_descriptor);
```

Note

When adding multiple descriptors, the last added one is linked at the end of descriptor queue. If ringed list is needed, just add the first descriptor again to build the circle.

b. Start the DMA transfer job with the allocated DMA resource and transfer descriptor.

```
dma_start_transfer_job(&capture_dma_resource);
```

Configure the DMA for Compare TCC Channel 0

Configure the DMAC module to update TCC channel 0 compare value. The flow is similar to last DMA configure step for capture.

1. Allocate and configure the DMA resource

```
struct dma_resource compare_dma_resource;
```

```
struct dma_resource_config config;
dma_get_config_defaults(&config);
config.trigger_action = DMA_TRIGGER_ACTON_BEAT;
config.peripheral_trigger = CONF_COMPARE_TRIGGER;
dma_allocate(&compare_dma_resource, &config);
```

2. Prepare DMA transfer descriptor

```
COMPILER_ALIGNED(16) DmacDescriptor compare_dma_descriptor;
```

```
struct dma_descriptor_config descriptor_config;

dma_descriptor_get_config_defaults(&descriptor_config);

descriptor_config.block_transfer_count = 3;
descriptor_config.beat_size = DMA_BEAT_SIZE_HWORD;
descriptor_config.dst_increment_enable = false;
descriptor_config.source_address =
        (uint32_t)compare_values + sizeof(compare_values);
descriptor_config.destination_address =
        (uint32_t)&CONF_PWM_MODULE->CC[CONF_PWM_CHANNEL];
```

```
dma_descriptor_create(&compare_dma_descriptor, &descriptor_config);
```

3. Start DMA transfer job with prepared descriptor

```
dma_add_descriptor(&compare_dma_resource, &compare_dma_descriptor);
dma_add_descriptor(&compare_dma_resource, &compare_dma_descriptor);
dma_start_transfer_job(&compare_dma_resource);
```

4. Enable the TCC module to start the timer and begin PWM signal generation.

```
tcc_enable(&tcc_instance);
```

24.8.7.2 Use Case

Code

Copy-paste the following code to your user application:

```
while (true) {
    /* Infinite loop */
}
```

Workflow

1. Enter an infinite loop while the PWM wave is generated via the TCC module.

```
while (true) {
    /* Infinite loop */
}
```

25. SAM D21 Universal Serial Bus (USB)

The Universal Serial Bus (USB) module complies with the USB 2.1 specification.

The USB module covers following mode:

- USB Device Mode
- USB Host Mode

The USB module covers following speed:

- USB Full Speed (12Mbit/s)
- USB Low Speed (1.5Mbit/s)

The USB module supports Link Power Management (LPM-L1) protocol.

USB support needs whole set of enumeration process, to make the device recognizable and usable. The USB driver is designed to interface to the USB Stack in Atmel Software Framework (ASF).

25.1 USB Device Mode

The ASF USB Device Stack has defined the USB Device Driver (UDD) interface, to support USB device operations. The USB module device driver complies with this interface, so that the USB Device Stack can work based on the USB module.

Refer to "ASF - USB Device Stack"[1] for more details.

25.2 USB Host Mode

The ASF USB Host Stack has defined the USB Host Driver (UHD) interface, to support USB host operations. The USB module host driver complies with this interface, so that the USB Host Stack can work based on the USB module.

Refer to "ASF - USB Host Stack"[2] for more details.

[1] http://www.atmel.com/images/doc8360.pdf
[2] http://www.atmel.com/images/doc8486.pdf

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Document Revision History

Doc. Rev.	Date	Comments
A	01/2014	Initial release.

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