Operating Instructions

Elektor Arduino® NANO Training Board MCCAB

Rev. 3.3

Dear customer,

The MCCAB Training Board is manufactured in accordance with the applicable European directives and therefore bears the CE mark.

Its intended use is described in these operating instructions. If you modify the MCCAB Training Board or do not use it in accordance with its intended purpose, you alone are responsible for compliance with the applicable rules.

Therefore, only use the MCCAB Training Board and all components on it as described in these operating instructions. You may only pass on the MCCAB Training Board together with this operating manual.

All information in this manual refers to the MCCAB Training Board with the edition level **Rev. 3.3**. The edition level of the Training Board is printed on its bottom side (see Figure 13 on page 20).

The current version of this manual can be downloaded from the website

www.elektor.com/20440 for download.

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1 Recycling

Used electrical and electronic equipment must be recycled as electronic waste and must not be disposed of in household waste.

The MCCAB Training Board contains valuable raw materials that can be recycled. Therefore, dispose of the device at the appropriate collection depot. (EU Directive 2012/19 / EU). Your municipal administration will tell you where to find the nearest free collection point.

2 Safety instructions

These operating instructions for the MCCAB Training Board contain important information on commissioning and operation!

Therefore, read the entire operating manual carefully before using the training board for the first time in order to avoid injury to life and limb due to electric shock, fire or operating errors as well as damage to the Training Board.

Make this manual available to all other users of the training board.

The product has been designed in accordance with the IEC 61010-031 standard and has been tested and left the factory in a safe condition. The user must observe the regulations applicable to the handling of electrical equipment, as well as all generally accepted safety practices and procedures. In particular, the VDE regulations VDE 0100 (planning, installation and testing of low-voltage electrical systems), VDE 0700 (safety of electrical equipment for domestic use) and VDE 0868 (equipment for audio/video, information and communication technology) should be mentioned here.

In commercial facilities, the accident prevention regulations of commercial employers' liability insurance associations also apply.

Safety symbols used

Electrical Hazard Warning

This sign indicates conditions or practices that could result in death or personal injury.

General Warning Sign

This sign indicates conditions or practices that may result in damage to the product itself or to connected equipment.

2.1 Power supply

Caution:

- Under no circumstances may negative voltages or voltages greater than +5 V be connected to the MCCAB Training Board. The only exceptions are the inputs VX1 and VX2, here the input voltages may be in the range of +8 V to +12 V (see section 4.2).
- Never connect any other electrical potential to the ground line (GND, 0 V).

- **Never interchange the connections for ground (GND, 0 V) and +5 V, as this would result in permanent damage to the MCCAB Training Board!**
- **In particular, never connect ~230 V or ~115 V mains voltage to the MCCAB Training Board!**

  There is a danger to life !!!

2.2 Handling and environmental conditions

To avoid death or injury and to protect the device from damage, the following rules must be strictly observed:

- Never operate the MCCAB Training Board in rooms with explosive vapors or gases.
- If young people or persons who are not familiar with the handling of electronic circuits work with the MCCAB Training Board, e.g., in the context of training, appropriately trained personnel in a responsible position must supervise these activities.
  The use by children under 14 years of age is not intended and must be avoided.
- If the MCCAB Training Board shows signs of damage (e.g., due to mechanical or electrical stress), it must not be used for safety reasons.
- The MCCAB Training Board may only be used in a clean and dry environment at temperatures up to +40 °C.

2.3 Repair and maintenance

- To avoid damage to property or personal injury, any repairs that may become necessary may only be carried out by appropriately trained specialist personnel and using original spare parts.
- The MCCAB Training Board does not contain any user-serviceable parts.

3 Intended use

The MCCAB Training Board has been developed for simple and fast teaching of knowledge about programming and the use of a microcontroller system.

The product is designed exclusively for training and practice purposes. Any other use, e.g., in industrial production facilities, is not permissible.

Caution:

The MCCAB Training Board is only intended for use with an Arduino® NANO microcontroller system (see Figure 2) or a microcontroller module that is 100% compatible with it. This module must be operated with an operating voltage of Vcc = +5V. Otherwise, there is a risk of irreversible damage or destruction of the microcontroller module, the training board and the devices connected to the training board.

Caution:

Voltages in the range of +8 V to +12 V may be connected to the inputs VX1 and VX2 of the training board (see section 4.2 of this manual). **The voltages at all other inputs of the training board must be in the range 0 V to +5 V**.

Caution:

These operating instructions describe how to correctly connect and operate the MCCAB Training Board with the user's PC and any external modules. Please note that we have no influence on operating and/or connection errors caused by the user.

The user alone is responsible for the correct connection of the training board to the user's PC and any external modules, as well as for its programming and proper operation!

For all damages resulting from wrong connection, wrong control, wrong programming and / or wrong operation the user is solely responsible! Liability claims against us are understandably excluded in these cases.

Any use other than that specified is not permitted! The MCCAB Training Board must not be modified or converted, as this could damage it or endanger the user (short circuit, risk of overheating and fire, risk of electric shock). If personal injury or damage to property occurs as a result of improper use of the training board, this is the sole responsibility of the operator and not of the manufacturer.

4 The *MCCAB Training Board* and its components

Figure 1 shows the MCCAB Training Board with its control elements. The training board is simply placed on an **electrically non-conductive work surface** and connected to the user's PC via a mini-USB cable (see section 4.3).

Especially in combination with the "Microcontrollers Hands-On Course for Arduino Starters" (ISBN 978-3-89576-545-2), published by Elektor, the MCCAB Training Board is perfectly suited for easy and fast learning of programming and usage of a microcontroller system.

The user creates his exercise programs for the MCCAB Training Board on his PC in the Arduino IDE, a development environment with an integrated C/C++ compiler, which he can download free of charge from the website

https://www.arduino.cc/en/main/software

After its successful compilation, the exercise program is loaded from the Arduino IDE into the microcontroller on the MCCAB Training Board via a mini USB cable and started directly.

Already "on board" on the MCCAB Training Board is an extensive hardware periphery (buttons, switches, potentiometers, buzzers, indicators, display, serial interfaces, transistor switches), which provides the necessary control elements for a variety of exercises. Furthermore, external circuit boards and modules for additional exercise units can be connected to the training board via the socket connector SV2 (arrow (26) in Figure 1).

To control external sensors, modules and devices that can be docked to the training board via the various connector strips, a comprehensive collection of libraries is available in the "Arduino world". These libraries can usually be downloaded free of charge from the Internet and integrated into the user's training program.

The MCCAB Training Board works with an operating voltage of Vcc = +5 V. The training board is usually supplied with power via the USB interface of the connected PC, which is also required for creating the exercise programs. Alternatively, power can be supplied by an external power supply unit (see section 4.2 and section 4.3).

The following Figure 1 shows the view of the training board. All hardware components on the board are described in detail below.

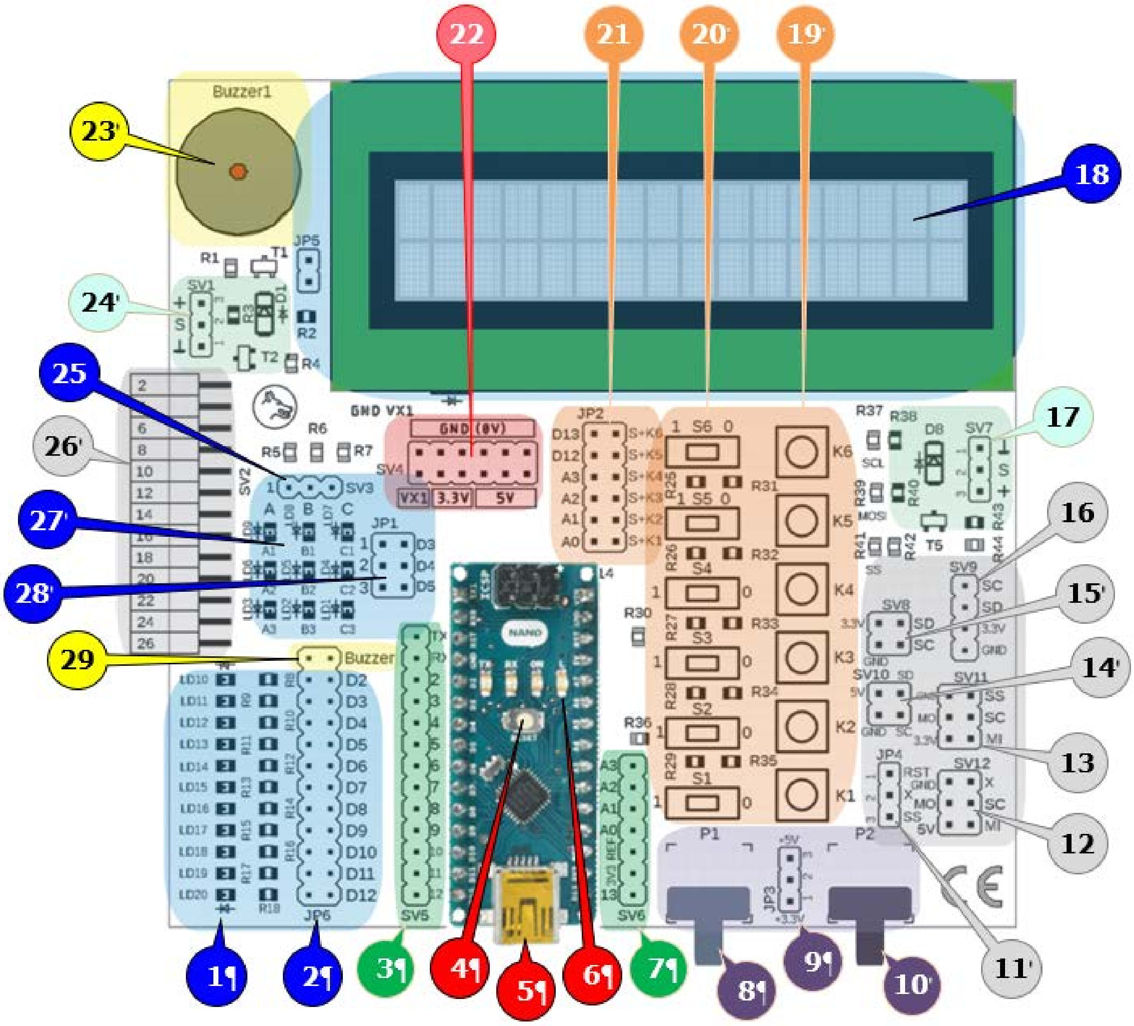


Figure 1: The *MCCAB Training Board*, Rev. 3.3

The operating and display elements on the MCCAB Training Board:

(1) 11 × LED (status indication for the inputs/outputs D2 ... D12)

(2) Header JP6 for connecting the LEDs LD10 ... LD20 with the GPIOs D2 ... D12 assigned to them

(3) Terminal block SV5 (distributor) for the inputs/outputs of the microcontroller

(4) RESET button

(5) Microcontroller module Arduino® NANO (or compatible) with mini USB - socket

(6) LED "L", connected to GPIO D13

(7) Connector SV6 (distributor) for the microcontroller inputs/outputs

(8) Potentiometer P1

(9) Pin header JP3 for selecting the operating voltage of potentiometers P1 and P2

(10) Potentiometer P2

(11) Pin header JP4 for selecting the signal at pin X of connector strip SV12

(12) Connector strip SV12: SPI-Interface 5 V (the signal at pin X is selected via JP4)

(13) Connector strip SV11:
SPI interface 3.3 V

(14) Terminal block SV10:
I^{2}C interface 5 V

(15) Terminal block SV8:
I^{2}C interface 3.3 V

(16) Terminal block SV9:
I^{2}C interface 3.3 V

(17) Terminal block SV7: Switching output for external devices

(18) LC display with 2 x 16 characters

(19) 6 × pushbutton switches K1 ... K6

(20) 6 × slide switches S1 ... S6

(21) Pin header JP2 for connecting the switches to the inputs of the micro-controller.

(22) Terminal block SV4: distributor for the operating voltages

(23) Piezo buzzer Buzzer1

(24) Terminal block SV1: Switching output for external devices

(25) Terminal strip SV3: Columns of the 3 × 3 LED matrix (outputs D6 ... D8 with series resistors 330 Ω)

(26) Connector strip SV2: 2 x 13 pins for connecting external modules

(27) 3 × 3 LED matrix (9 red LEDs)

(28) Pin header JP1 for connecting the rows of the 3 × 3 LED matrix with the microcontroller GPIOs D3 ... D5

(29) A jumper on the position "Buzzer" of the pin header JP6 connects Buzzer1 with the GPIO D9 of the microcontroller.

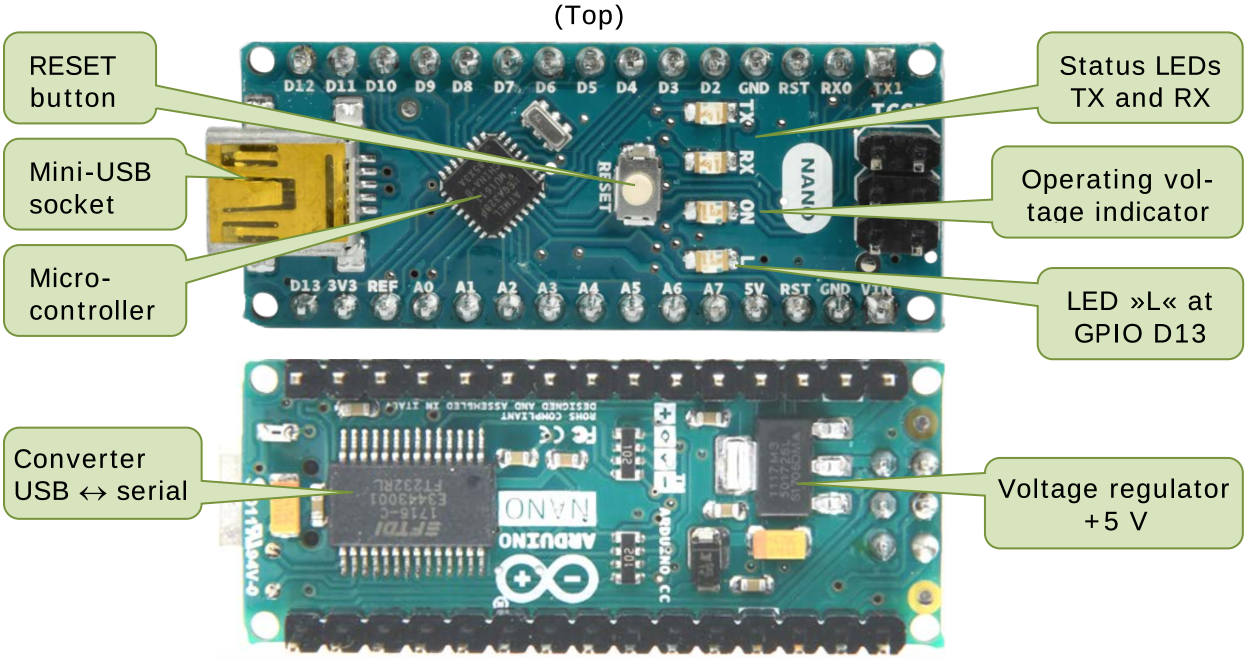
The individual controls on the training board are explained in detail in the following sections.

4.1 The *Arduino®* *NANO* microcontroller module

An Arduino® NANO or a microcontroller module compatible with it is plugged into the MCCAB Training Board (see arrow (5) in Figure 1 as well as Figure 2 and M1 in Figure 4). This module is equipped with the AVR microcontroller ATmega328P, which controls the peripheral components on the training board. Furthermore, there is an integrated converter circuit on the bottom side of the module, which connects the serial interface of the microcontroller UART (Universal Asynchronous Receiver Transmitter) with the USB interface of the PC. This interface is also used to load programs created by the user on his PC into the microcontroller or to transfer data to/from the serial monitor of the Arduino IDE (development environment).

The two LEDs TX and RX in Figure 2 indicate the data traffic on the serial lines TxD and RxD of the microcontroller.

(Top)



(Bottom)

Figure 2: Microcontroller module *Arduino® NANO* (Source: www.arduino.cc)

The LED L (see Figure 2 and arrow (6) in Figure 1 - the designation "L" may be different for Arduino® NANO compatible clones) is permanently connected to the GPIO D13 of the microcontroller via a series resistor and indicates its state LOW or HIGH.

The +5 V voltage regulator on the bottom side of the module stabilizes the voltage supplied externally to the MCCAB Training Board via the VIN input of the Arduino® NANO module (see section 4.2).

By pressing the RESET button on top of the Arduino® NANO module (see Figure 2 and arrow (4) in Figure 1) the microcontroller is set to a defined initial state and an already loaded program is restarted.

All inputs and outputs of the microcontroller that are important for the user are connected to the two terminal strips SV5 and SV6 (arrow (3) and arrow (7) in Figure 1).

By means of connectors – so-called *Dupont Cables* (see Figure 3) – the inputs/outputs of the microcontroller (also called ***GPIOs = General Purpose Inputs/Outputs***) led out at SV5 and SV6 can be connected to operating elements (buttons, switches, ...) on the MCCAB Training Board or to external parts.

Figure 3: Different types of *Dupont cables* for connecting the GPIOs to the control elements

The user has to configure each GPIO of the Arduino® NANO microcontroller module on the two connector strips SV5 and SV6 (arrow (3) and arrow (7) in Figure 1), which is connected via a Dupont cable to a connector on the training board or to an external connector, in his program for the required data direction as input or output!

The data direction is set with the instruction

```
pinMode(gpio, direction);   // for "gpio" insert the corresponding pin number
                            // for "direction" insert "INPUT" or "OUTPUT"
```

Examples:

```
pinMode(2, OUTPUT);   // GPIO D2 is set as output
pinMode(13, INPUT);   // GPIO D13 is set as input
```

Figure 4 shows the wiring of the Arduino® NANO microcontroller module M1 on the MCCAB Training Board.

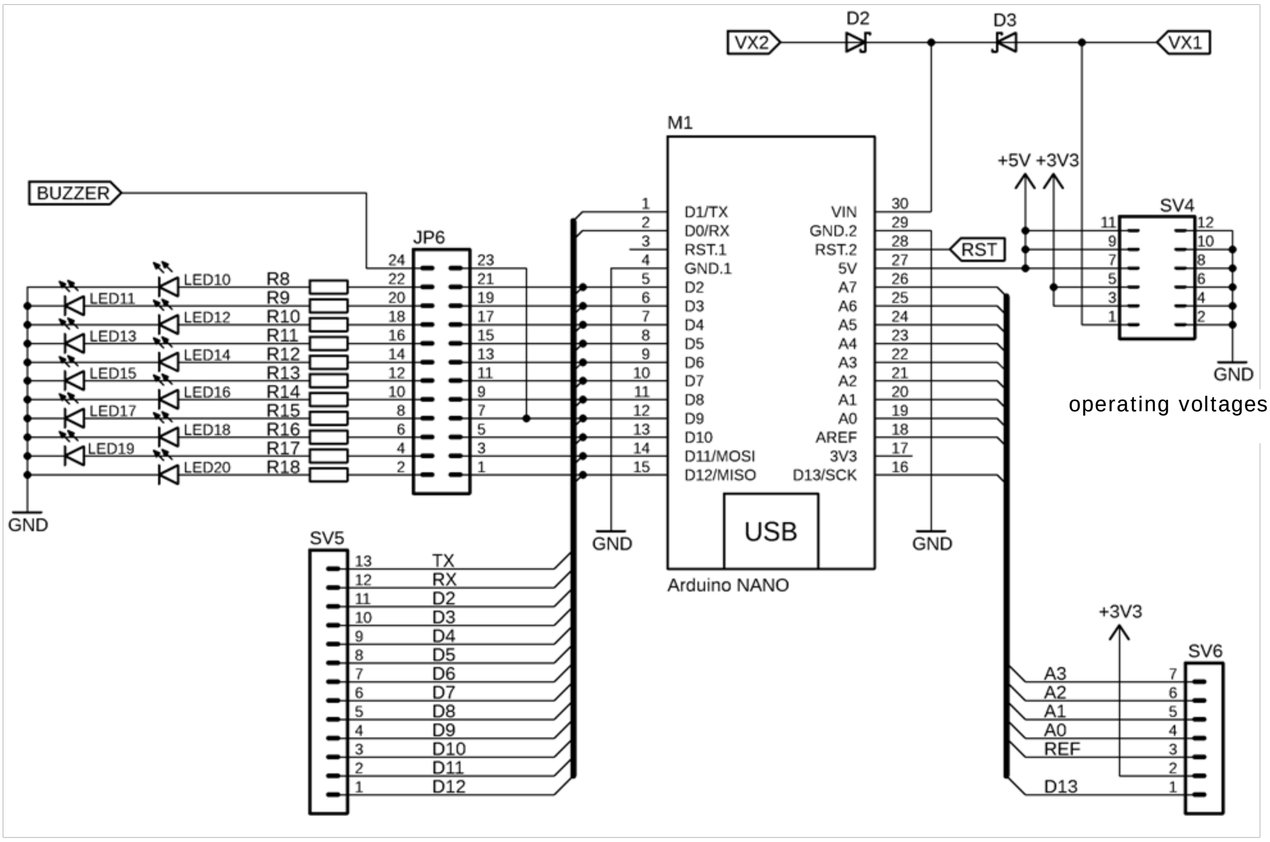


Figure 4: The wiring of the microcontroller module Arduino® NANO on the MCCAB Training Board

The most important data of the microcontroller module *Arduino® NANO*:

- Operating voltage Vcc: +5 V
- Externally supplied operating voltage at VIN: +8 V to +12 V (see section 4.2)
- Analog input pins of the ADC: 8 (A0 ... A7, see following ⓘ **notes**)
- Digital input/output pins: 12 (D2 ... D13) resp. 16 (see ⓘ **notes**)
- Current consumption of the NANO module: approx. 20 mA
- Max. input/output current of a GPIO: 40 mA
- Sum of input/output currents of all GPIOs: maximal 200 mA
- Instruction memory (Flash memory): 32 KB
- Working memory (RAM memory): 2 KB
- EEPROM memory: 1 KB
- Clock frequency: 16 MHz
- Serial interfaces: SPI, I^2C (for UART see ⓘ **notes**)

Notes

- The GPIOs **D0 and D1** (pin 2 and pin 1 of the module M1 in Figure 4) are assigned with the signals RxD and TxD of the microcontroller's UART and are used for the serial connection between the MCCAB Training Board and the USB port of the PC. They are therefore **only available to the user to a limited extent** (see also section 4.3).

- The GPIOs **A4 and A5** (pin 23 and pin 24 of the module M1 in Figure 4) are assigned to the signals SDA and SCL of the microcontroller's I^{2}C interface (see section 4.13) and are therefore reserved for the serial connection to the LC display on the MCCAB Training Board (see section 4.9) and to external I^{2}C modules connected to the connector strips SV8, SV9 and SV10 (arrows (15), (16) and (14) in Figure 1). They are therefore **only available to the user for I^{2}C applications**.
- The pins **A6 and A7** (pin 25 and pin 26 of the microcontroller ATmega328P in Figure 4 can only be used as analog inputs for the microcontroller's Analog/Digital-Converter (ADC). They **must not be configured by means of Function *pinMode()*** (not even as input!), this would lead to an incorrect behavior of the sketch. A6 and A7 are permanently connected to the wiper terminals of the **potentiometers P1 and P2** (arrow (8) and arrow (10) in Figure 1), see section 4.3.
- The connections **A0 ... A3** on pin header SV6 (arrow (7) in Figure 1) are in principle analog inputs for the Analog/Digital-Converter of the microcontroller. However, if the 12 digital GPIOs D2 … D13 are not sufficient for a specific application, A0 ... A3 can also be used as digital inputs/outputs. Then they are addressed via pin numbers 14 (A0) ... 17 (A3).

  Examples:

  ```
  pinMode(15, OUTPUT);   // A1 is used as digital output
  pinMode(17, INPUT);    // A3 is used as digital input
  ```
- The pin **D12** on pin header SV5 (arrow (3) in Figure 1) and the pins **D13** and **A0 ... A3** on pin header SV6 (arrow (7) in Figure 1) are routed to pin header JP2 (arrow (21) in Figure 1) and can be connected to the switches S1 … S6 or to the pushbuttons K1 ... K6 connected to them in parallel, see also section 4.6. In this case, the respective pin must be configured as a digital input with the *pinMode* instruction.

Accuracy of A/D conversion

Digital signals within the microcontroller chip generate electromagnetic interferences that can affect the accuracy of analog measurements.
If one of the GPIOs **A0 ... A3 is used as a digital output**, it is therefore important that this does not switch over while an analog/digital conversion is taking place at another analog input! A change of the digital output signal at A0 … A3 during an analog/digital conversion at one of the other analog inputs A0 … A7 can falsify the result of this conversion considerably.
The use of the I^{2}C interface (A4 and A5, see section 4.13) or the GPIOs A0 … A3 as digital inputs does not influence the quality of the analog/digital conversions.

4.2 The power supply of the MCCAB Training Board

The MCCAB Training Board works with a nominal operating DC voltage of Vcc = +5 V, which is usually supplied to it via the mini-USB socket of the Arduino® NANO microcontroller module from the connected PC (Figure 5, Figure 2 and arrow (5) in Figure 1). Since the PC is usually connected anyway for the creation and transmission of the exercise programs, this type of power supply is ideal.

For this purpose, the training board must be connected to a USB port of the user's PC via a mini-USB cable. The PC provides a stabilized DC voltage of approx. +5 V, which is galvanically isolated from the mains voltage and can be loaded with a maximum current of 0.5 A, via its USB interface. The presence of the +5 V operating voltage is indicated by the LED labeled ON (or POW, PWR) on the microcontroller module (Figure 5, Figure 2).

The +5 V voltage supplied via the mini-USB socket is connected to the actual operating voltage Vcc on the Arduino® NANO microcontroller module via the protective diode D. The actual operating voltage Vcc decreases slightly to Vcc ≈ +4.7 V due to the voltage drop at the protection diode D. This small reduction of the operating voltage does not affect the function of the Arduino® NANO microcontroller module.

Alternatively, the training board can be supplied by an external DC voltage source. This voltage, applied either to terminal VX1 or to terminal VX2, must be in the range V_{Ext} = +8 ... +12 V. The external voltage is fed into pin 30 (= VIN) of the Arduino® NANO microcontroller module either via connector SV4 or from an external module connected to connector SV2 (see Figure 5, Figure 4 and arrow (22) or arrow (26) in Figure 1).

Since the board is supplied with power from the connected PC via its USB socket, it is not possible to reverse the polarity of the operating voltage. The two external voltages that can be supplied to the VX1 and VX2 connections are decoupled by diodes, as shown in Figure 4.

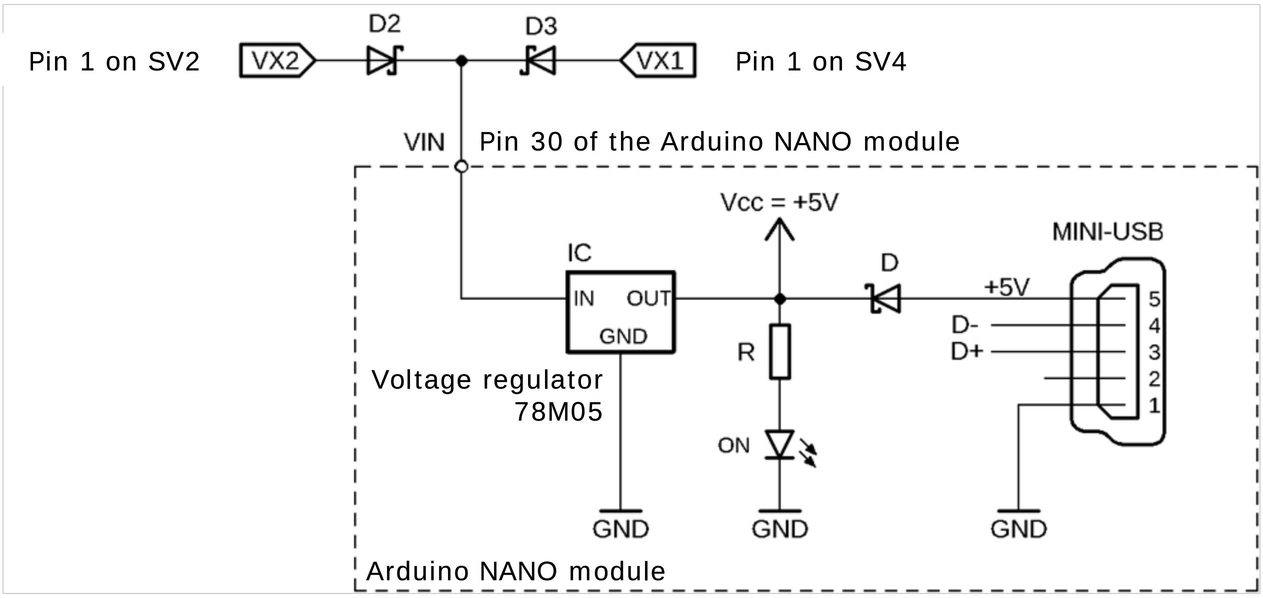


Figure 5: Generation of the operating voltage Vcc of the Arduino® microcontroller module

The diodes D2 and D3 provide a decoupling of the two external voltages at VX1 and VX2, in case voltage should be applied to both external inputs at the same time by mistake, because due to the diodes only the higher of the two voltages can reach the input VIN (pin 30, see Figure 5 and Figure 4) of the Arduino® NANO microcontroller module M1.

The external DC voltage supplied to the microcontroller module at its VIN connector is reduced to +5 V and stabilized by the integrated voltage regulator on the bottom side of the microcontroller module (see Figure 2). The +5 V operating voltage generated by the voltage regulator is connected to the cathode of diode D in Figure 5. The anode of D is also connected to the +5 V potential by the PC when the USB connection to the PC is plugged in. The diode D is thus blocked and has no effect on the function of the circuit. The power supply via the USB cable is switched off in this case.

The +3.3 V auxiliary voltage is generated on the MCCAB Training Board by a linear voltage regulator from the +5 V operating voltage Vcc of the microcontroller module and can supply a maximum current of 200 mA.

Often in projects, access to the operating voltages is required, e.g., for the voltage supply of external modules. For this purpose, the MCCAB Training Board provides the voltage distributor SV4 (Figure 4 and arrow (21) in Figure 1), on which two outputs for the voltage +3.3 V and three outputs for the voltage +5 V as well as six ground connections (GND, 0 V) are available in addition to the connection pin VX1 for the external voltage.

4.3 The USB connection between the MCCAB Training Board and the PC

The programs that the user develops in the Arduino IDE (development environment) on his PC are loaded into the ATmega328P microcontroller on the MCCAB Training Board via a USB cable. For this purpose, the microcontroller module on the MCCAB Training Board (arrow (5) in Figure 1) must be connected to a USB port of the user's PC via a mini-USB cable.

Since the microcontroller ATmega328P on the microcontroller module does not have its own USB interface on its chip, the module has an integrated circuit on its bottom side to convert the USB signals D+ and D- into the serial signals RxD and TxD of the ATmega328P's UART.

Furthermore, it is possible to output data to or read data from the *Serial Monitor* integrated into the Arduino IDE via the UART of the microcontroller and the subsequent USB connection. For this purpose, the library "Serial" is available to the user in the Arduino IDE.

The training board is normally also powered via the USB interface of the user's PC (see section 4.2).

It is not intended that the user uses the signals RX and TX of the microcontroller, which are connected to the pin header SV5 (arrow (3) in Figure 1), for serial communication with external devices (e.g. WLAN, Bluetooth transceivers or similar), because this can damage the integrated USB ⇔ UART converter circuit on the bottom side of the microcontroller module (see section 4.1) despite the existing protective resistors!
If the user does it anyway, he has to make sure that there is no communication between the PC and the Arduino® NANO microcontroller module at the same time! Signals supplied via the USB socket would lead to an impairment of the communication with the external device and, in the worst case, also to a damage to the hardware!

4.4 The eleven *LEDs D2 ... D12* for status indication of the microcontroller's GPIOs

In the lower left part of Figure 1 you can see the 11 LEDs LED10 ... LED20 (arrow (1) in Figure 1), which can indicate the status of the microcontroller's inputs/outputs (GPIOs) D2 ... D12. The corresponding circuit diagram is shown in Figure 4.

The respective light emitting diode is connected to the GPIO, if a jumper is plugged into the corresponding position of the pin header JP6 (arrow (2) in Figure 1).

If the corresponding GPIO D2 ... D12 is at HIGH level (+5 V) when the jumper on JP6 is plugged in, the assigned LED lights up, if the GPIO is at LOW (GND, 0 V), the LED is switched off.

If one of the GPIOs D2 … D12 is used as input, it may be necessary to deactivate the LED assigned to it by removing the jumper in order to avoid a load of the input signal by the operating current of the LED (approx. 2 … 3 mA).

The status of the GPIO D13 is indicated by its own LED L directly on the microcontroller module (see Figure 1 and Figure 2). The LED L cannot be deactivated.

Since the inputs/outputs A0 … A7 are basically used as analog inputs for the analog/digital converter of the microcontroller or for special tasks (TWI interface), they do not have a digital LED status display in order not to impair these functions.

4.5 The potentiometers *P1* and *P2*

The rotary axes of the two potentiometers P1 and P2 at the bottom of Figure 1 (arrow (8) and arrow (10) in Figure 1) can be used to set voltages in the range 0 ... V_{Pot} at their wiper connections. The wiring of the two potentiometers can be seen in Figure 6.

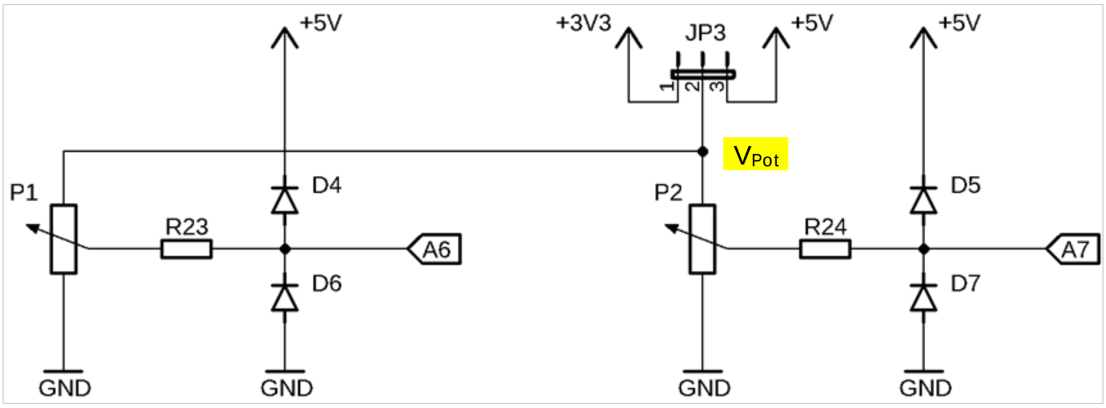


Figure 6: The wiring of the potentiometers P1 and P2

The wiper connections of the two potentiometers are connected to the analog inputs A6 and A7 of the Arduino® NANO microcontroller module via the protective resistors R23 and R24. The diodes D4, D6 or D5, D7 protect the respective analog input of the microcontroller from too high or negative voltages.

Caution:
The pins A6 and A7 of the ATmega328P are always analog inputs due to the internal chip architecture of the microcontroller. Their configuration with the function *pinMode()* of the Arduino IDE is not allowed and can lead to incorrect behavior of the program.

Via the microcontroller's analog/digital-converter, the set voltage can be measured in a simple way.

Example for reading the value of potentiometer P1 at connection A6:

```
int z = analogRead(A6);
```

The 10-bit numerical value Z, which is calculated from the voltage at A6 according to

$$Z = \frac{V_{ADC}}{V_{REF}} \cdot 1024 \qquad \text{(equation 1 from section 5)}$$

is read into the variable z.

The desired upper limit V_{Pot} = +3.3 V resp. V_{Pot} = +5 V of the setting range is set with the pin header JP3 (arrow (9) in Figure 1). To select V_{Pot}, either pin 1 or pin 3 of JP3 is connected to pin2 using a jumper.

Which voltage has to be set with JP3 for V_{Pot} depends on the reference voltage V_{REF} of the analog/digital-converter at the REF connector of the pin header SV6 (arrow (7) in Figure 1), see section 5.

The reference voltage V_{REF} of the A/D-converter at the REF terminal of the SV6 pin header and the voltage V_{Pot} specified with JP3 **must match**.

4.6 The switches *S1 ... S6* and the buttons *K1 ... K6*

The MCCAB Training Board provides the user with six pushbuttons and six-slide switches for his exercises (arrows (20) and (19) in Figure 1). Figure 7 shows their wiring.

To give the user the option of applying either a permanent or a pulse signal to one of the inputs of the microcontroller module M1, one-slide switch and one pushbutton switch are connected in parallel.

The common output of each of the six switch pairs is connected via a protective resistor (R25 ... R30) to the pin header JP2 (arrow (21) in Figure 1).

The parallel connection of a slide switch and a pushbutton switch with a common operating resistor (R31 ... R36) acts like a logical OR operation:

If via one of the two switches (or both switches at the same time) the +5 V voltage is present at the common working resistor, this logical HIGH level via the protective resistor is also present at the corresponding pin 2, 4, 6, 8, 10 or 12 of JP2. Only when both switches are open, their common connection is open and the corresponding pin of the pin header JP2 is pulled to LOW level (0 V, GND) via the series connection of the protective resistor and the working resistor.

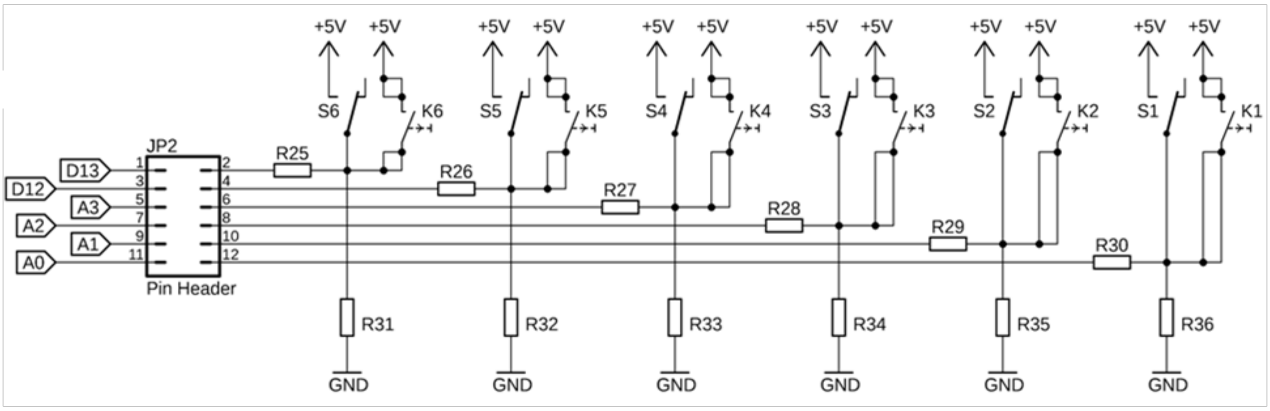


Figure 7: The wiring of the slide / pushbutton switches S1 ... S6 / K1 ... K6

Each pin of the pin header JP2 can be connected to its assigned input A0 ... A3, D12 or D13 of the Arduino® NANO microcontroller module via a jumper. The assignment is shown in Figure 7.

Alternatively, a switch connection on pins 2, 4, 6, 8, 10 or 12 of the pin header JP2 can be connected to any input D2 ... D13 or A0 ... A3 of the Arduino® microcontroller module on the pin headers SV5 or SV6 (arrow (3) and arrow (7) in Figure 1) using a Dupont cable. This flexible way of connection is preferable to the fixed assignment of each switch to a specific GPIO if the assigned GPIO of the ATmega328P microcontroller is used for a special function

(A/D-converter input, PWM output ...). This way the user can connect his switches to the GPIOs which are free in the respective application, i.e., not occupied by a special function.

In his program, the user has to configure each GPIO of the Arduino® NANO microcontroller module as *input*, which is connected to a switch port, using the instruction

pinMode(*gpio*, INPUT); // for "gpio" insert the corresponding pin number

Example:

pinMode(A1, INPUT); // A1 is set up as digital input for S2|K2

In case a GPIO of the microcontroller connected to a switch has been configured as an output by mistake, the protective resistors R25 ... R30 prevent a short between +5 V and GND (0 V) when the switch is actuated and the GPIO has LOW level at its output.

To be able **to use a pushbutton switch**, the slide switch connected in parallel to it must be open (position "0")! Otherwise, their common output is permanently at HIGH level, regardless of the position of the pushbutton switch.

The switch positions of the slide switches are marked "0" and "1" on the training board as shown in Figure 1.

Figure 8 shows: If the switch is in position "1", the switch output is connected to +5 V (HIGH), in position "0" the switch output is open.

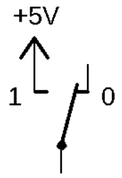


Figure 8

4.7 The piezo buzzer *Buzzer1*

The upper left part of Figure 1 shows *Buzzer1* (arrow (23) in Figure 1), which allows the user to emit tones of different frequencies. Its basic circuitry is shown in Figure 9.

Buzzer1 can be connected to the GPIO D9 of the microcontroller on the MCCAB Training Board via a jumper on the position "Buzzer" of pin header JP6 (arrow (29) in Figure 1) (see Figure 9, Figure 4 and arrow (2) in Figure 1). The jumper can be removed if the GPIO D9 is needed in a program for other purposes.

If the jumper is removed, it is also possible to apply an external signal to pin 24 of pin header JP6 via a Dupont cable and have it output by Buzzer1.

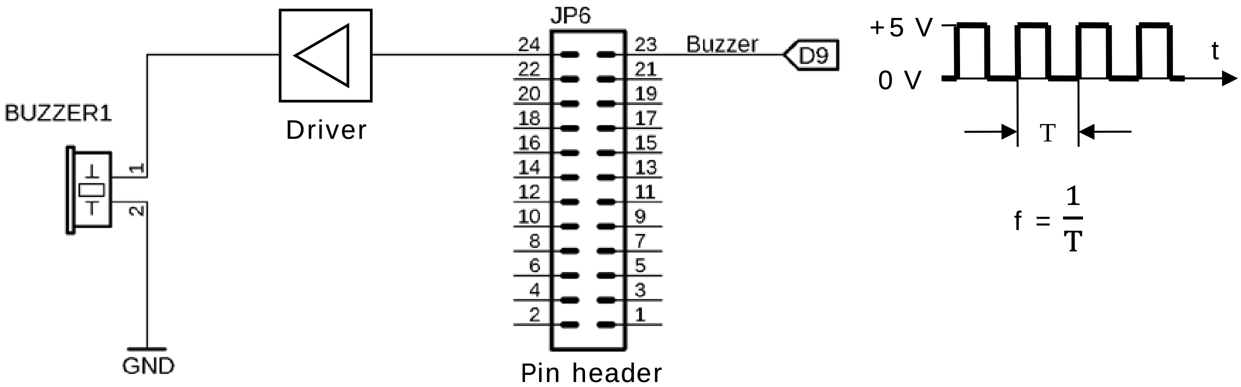


Figure 9: The wiring of Buzzer1

To generate tones, the user must generate a signal in his program that changes with the desired tone frequency at output D9 of the microcontroller (sketched on the right in Figure 9). This rapid sequence of HIGH and LOW levels applies a rectangular AC voltage to Buzzer1, which periodically deforms the ceramic plate inside the buzzer to produce sound vibrations at the appropriate tone frequency.

An even simpler way to generate a tone is to use T/C1 (Timer/Counter 1) of the microcontroller:

The T/C1 output OC1A of the AVR microcontroller ATmega328P on the Arduino® NANO microcontroller module can be connected to GPIO D9 inside the microcontroller chip. With appropriate programming of T/C1, it is very easy to generate a rectangle signal whose frequency f = $\frac{1}{T}$ (T is the period of the rectangle signal) is converted into the desired tone by the buzzer.

Figure 10 shows that a piezo buzzer is not a hi-fi loudspeaker. As can be seen, the frequency response of a piezo buzzer is anything but linear. The diagram in Figure 10 shows the sound pressure level (SPL) of the piezo transducer *SAST-2155* from *Sonitron* measured at a distance of 1 m as a function of the signal frequency. Due to physical properties and natural resonances, certain frequencies are reproduced louder and others softer. The corresponding diagram of the piezo buzzer on the MCCAB Training Board shows a similar curve.

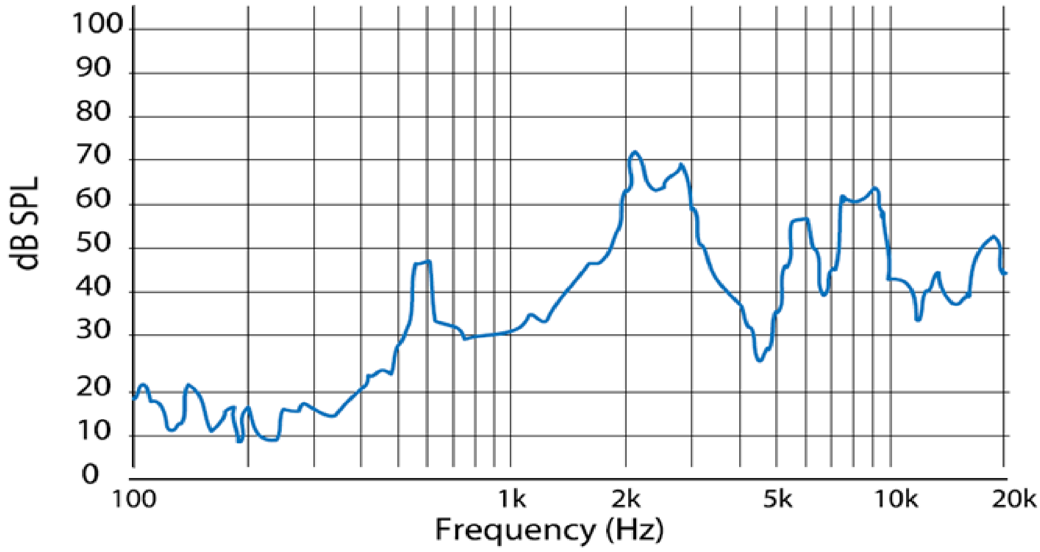


Figure 10: Typical frequency response of a piezo buzzer (Image: Sonitron)

Despite this limitation, a piezo buzzer is a good compromise between the reproduction quality of the sounds generated by the microcontroller and its footprint on the board, which allows it to be accommodated in a small space.

In cases where a higher quality of sound output is required, the piezo buzzer can be disconnected from output D9 by removing the jumper and D9 can be connected to external equipment for sound reproduction on the pin header SV5 e.g., via a Dupont cable (if necessary, via a voltage divider to reduce the amplitude to avoid damage to the input stage).

4.8 The *3 × 3 LED matrix*

The 9 LEDs in the left part of Figure 1 are arranged in a matrix with 3 columns and 3 rows (arrow (27) in Figure 1). Their circuitry is shown in Figure 11. 9 LEDs can be controlled with only 6 GPIOs of the microcontroller due to the matrix arrangement.

The three-column lines A, B and C are permanently connected to the pins D8, D7 and D6 of the microcontroller as shown in Figure 11. The three resistors R5 … R7 in the column lines limit the current through the LEDs. In addition, the column lines are connected to the connector SV3 (arrow (25) in Figure 1).

The three-row connections 1, 2 and 3 are routed to the pin header JP1 (arrow (28) in Figure 1). They can be connected to the microcontroller's pins D3 ... D5 by means of jumpers. Alternatively, the pins 1, 2 or 3 on header JP1 can be connected via Dupont cables to any output D2 ... D13 or A0 ... A3 of the Arduino® NANO microcontroller module on both headers SV5 and SV6 (arrow (3) and arrow (7) in Figure 1) if one of the assigned GPIOs D3 ... D5 of the microcontroller ATmega328P on the Arduino® NANO microcontroller module is used for a special function.

The 9 LEDs are labeled A1 ... C3 according to their arrangement within the matrix, e.g., LED B1 is located at column line B and at row line 1.

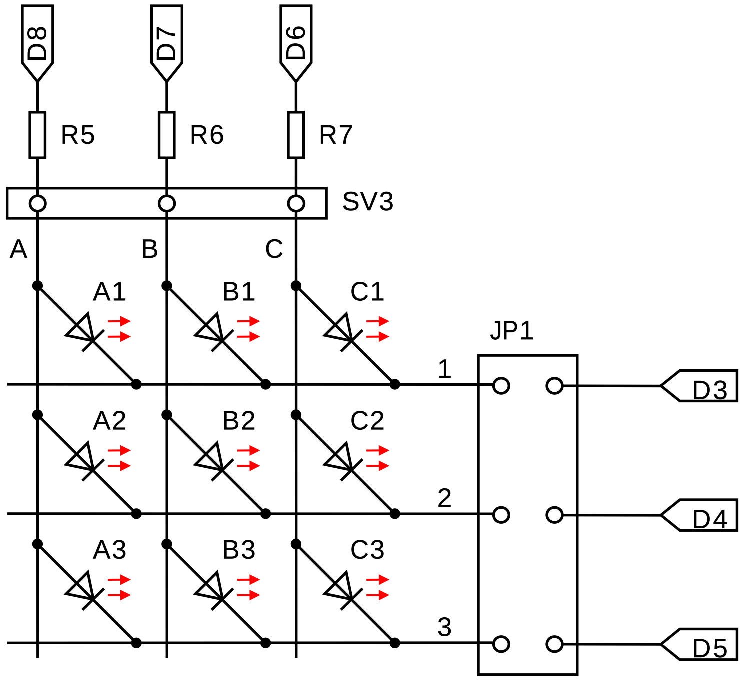


Figure 11: The nine LEDs in form of a 3 × 3 matrix

The LEDs are usually controlled by the user program in an endless loop, in which one of the three rows 1, 2 and 3 is cyclically set to LOW potential, while the other two rows are set to HIGH level or are in a high-impedance state (Hi-Z). If one or more of the LEDs in the row currently activated by LOW level is to be lit, its column terminal A, B or C is set to HIGH level. The column terminals of the LEDs in the active row that are not to be lit are at LOW potential.

For example, to make both LEDs A3 and C3 light up, row 3 must be at LOW level and columns A and C must be at HIGH level, while column B is at LOW level and both row lines 1 and 2 are at HIGH level or in high impedance state (Hi-Z).

Caution:

If the row lines of the 3 × 3 LED matrix are either connected to the GPIOs D3 ... D5 via jumpers on the pin header JP1 or to other GPIOs of the microcontroller via Dupont cables, these row lines as well as the column lines D6 ... D8 must never be used for other tasks in a program. A double assignment of the matrix GPIOs would lead to malfunctions or even to damage to the training board!

4.9 The LC-Display (*LCD*)

At the top right of Figure 1 is the LC display (LCD) for displaying text or numerical values (arrow (18) in Figure 1). The LCD has two rows; each row can display 16 characters. Its circuitry is shown in Figure 12.

The design of the LC display can vary depending on the manufacturer, e.g., white characters on a blue background or black characters on a yellow background or another appearance is possible.

Since the LCD is not needed in all programs, the +5 V operating voltage of the LCD can be interrupted by pulling the jumper on the pin header JP5, if the backlight of the LCD should interfere.

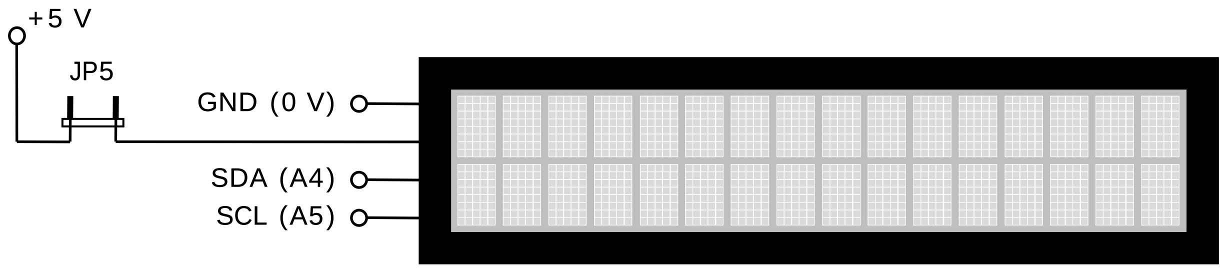


Figure 12: The connections of the LC display

Contrast setting

The purchaser of the MCCAB Training Board **must adjust the contrast of the LC display during the first start-up**! To do this, a text is output to the LCD and the contrast is adjusted by changing the trimming resistor shown in Figure 13 (white arrow mark in Figure 13) with a screwdriver from the bottom of the training board so that the characters on the display are shown optimally.

If a readjustment is necessary due to temperature fluctuations or aging, the user can correct the LCD contrast by adjusting this trimming resistor if necessary.

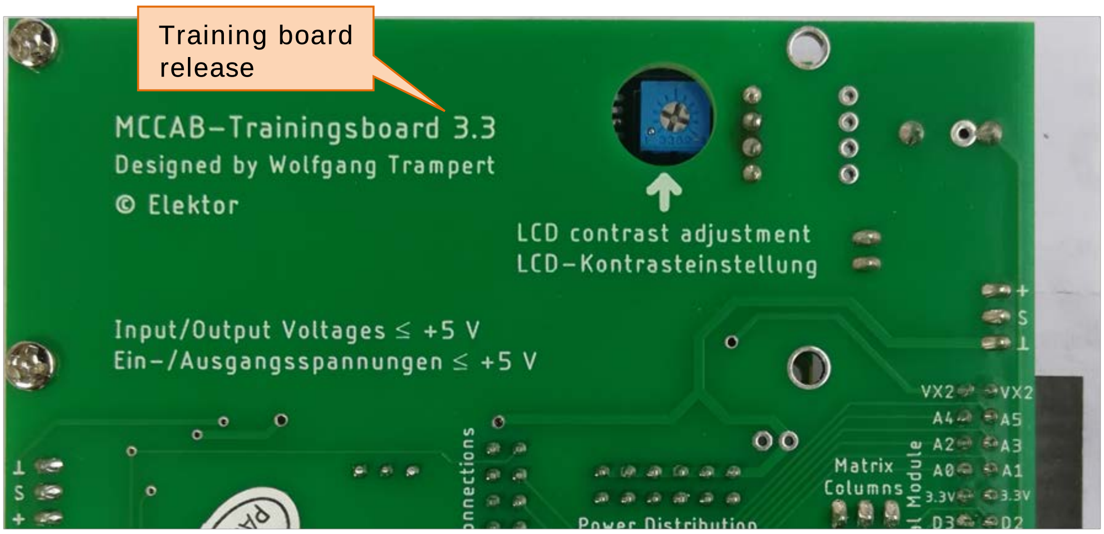


Figure 13: Adjustment of the LCD contrast with a screwdriver

Transmission of the data to the LC-Display

The LC-Display is controlled via the serial TWI (= I^2C) interface of the microcontroller ATmega328P. Connector A4 on pin header SV6 (arrow (7) in Figure 1) functions as data line SDA (Serial DAta) and A5 as clock line SCL (Serial CLock).

The LC display on the MCCAB Training Board normally has the **I^2C address 0x27**.

If another address should be used due to manufacturing reasons, this address is indicated by a sticker on the display. In the user's sketch, this address must then be used instead of the address 0x27.

The controller installed on the LC display is compatible with the widely used industrial standard HD44780, for which there are a large number of Arduino libraries (e.g., https://github.com/marcoschwartz/LiquidCrystal_I2C) on the Internet for control via the I^2C bus. The libraries can usually be downloaded free of charge from the respective website.

4.10 The driver outputs *SV1* and *SV7* for higher output currents and voltages

The pin headers SV1 (arrow (24) in Figure 1) and SV7 (arrow (17) in Figure 1) can be used to switch on and off loads that require higher currents than the approx. 40 mA that a normal microcontroller output can deliver as a maximum. The operating voltage of the external load can be up to +24 V and the output current can be up to 160 mA. This makes it possible to control smaller motors (e.g., fan motors), relays or smaller bulbs directly with the microcontroller of the training board.

Figure 14 shows the circuit diagram of the two driver outputs.

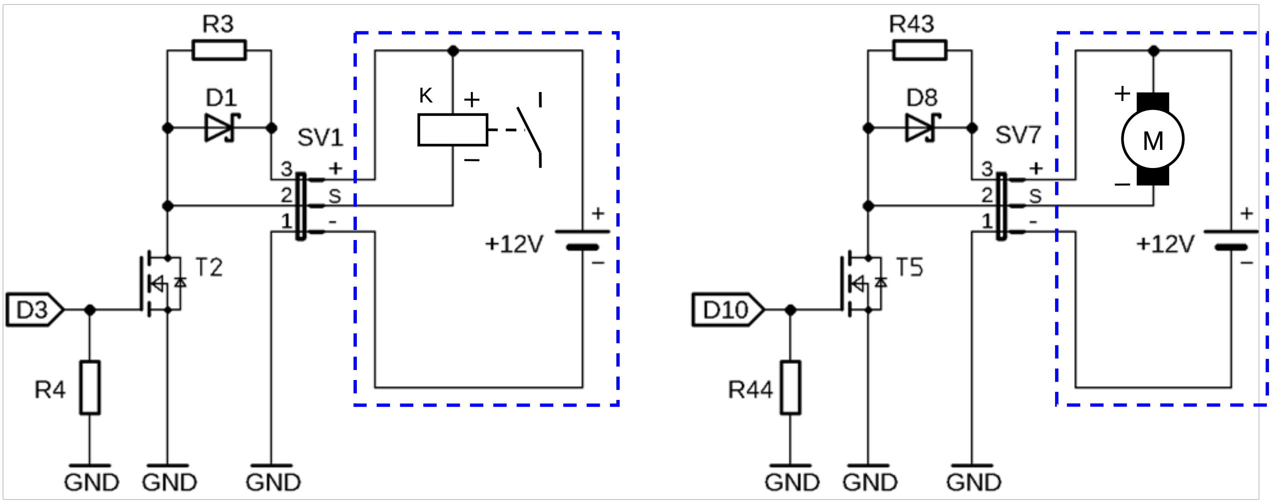


Figure 14: The driver outputs SV1 and SV7 for higher output currents

The dashed areas in Figure 14 show how loads are connected to the driver output, using the example of a relay and a motor:

- The positive pole of the external operating voltage is connected to pin 3 (labeled "+" on the board) of header SV1 resp. SV7. The more positive connection of the load is also connected to pin 3 of the pin header SV1 or SV7.
- The more negative connection of the load is connected to pin 2 (labeled "S" on the board) of header SV1 resp. SV7.

- The negative pole of the external operating voltage is connected to pin 1 (labeled "⊥" on the board) of header SV1 resp. SV7.

The driver stage SV1 is permanently connected to the GPIO D3 of the microcontroller and the driver stage SV7 is permanently connected to the GPIO D10 of the microcontroller. Since D3 and D10 are PWM-capable outputs of the microcontroller, it is possible to easily control, for example, the speed of a connected DC motor or the brightness of a light bulb. The protective diodes D1 and D8 ensure that voltage peaks, which occur when switching off inductive loads, cannot damage the output stage.

A HIGH signal at output D3 of the microcontroller switches on transistor T2 and the more negative connection of the load at SV1 is connected to ground (GND) via switching transistor T2. Thus, the load is switched on, because the entire external operating voltage now drops off at it.

A LOW signal at D3 blocks transistor T2 and the load connected to SV1 is switched off.

The same applies to the output D10 of the microcontroller and the header SV7.

4.11 The *SV2* socket connector for linking external modules

Via socket connector SV2 (arrow (26) in Figure 1) external modules and printed circuit boards can be docked to the MCCAB Training Board. These modules can be sensor boards, digital/analog converters, WLAN or radio modules, graphic displays or circuits to increase the number of input/output lines, to name just a few of the many options. Even complete application models, such as training modules for control engineering or traffic light control, which require many GPIOs for their control, can be connected to the SV2 socket connector of the MCCAB Training Board and controlled by its microcontroller.

The female connector strip SV2 consists of 26 contacts, which are arranged in 2 rows of 13 contacts each. The odd-numbered contacts are in the upper row, the even-numbered contacts are in the lower row of the SV2 socket strip.

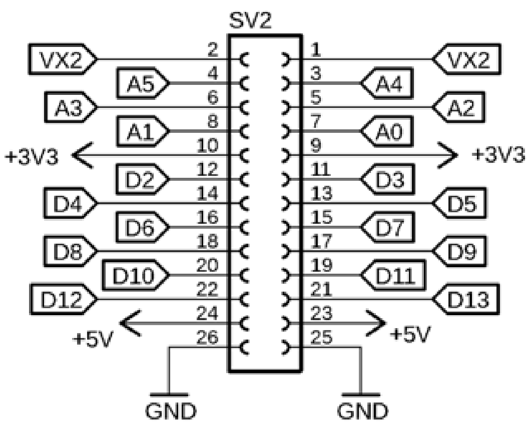


Figure 15: Pin assignment of socket connector SV2

The pin assignment of SV2 shows Figure 15. All connections relevant for an external module on the MCCAB Training Board are led out to the socket strip SV2.

The GPIOs D0 and D1 (RxD and TxD) and the analog inputs A6 and A7 are not connected to SV2, because D0 and D1 are reserved for the serial connection between the MCCAB Training Board and the PC and are only available to the user in a very limited way (see ⓘ **Notes** in section 4.1) and A6 and A7 are permanently connected to the wiper terminals of the potentiometers P1 and P2 on the MCCAB Training Board (see section 4.3) and therefore cannot be used otherwise.

In his program, the user has to configure each GPIO of the Arduino® NANO microcontroller module on the two pin headers SV5 and SV6 (arrow (3) and arrow (7) in Figure 1), which is used by an external module on SV2, for the required data direction as INPUT or OUTPUT (see section 4.1)!

Caution:
GPIOs of the microcontroller ATmega328P on the MCCAB Training Board, which are used by a module connected to SV2, must not be used for other tasks in a program. A double assignment of these GPIOs would lead to malfunctions or even to damage of the training board!

4.12 The pin headers for the connection of SPI modules

The pin headers SV11 (arrow (13) in Figure 1) and SV12 (arrow (12) in Figure 1) can be used to connect the MCCAB Training Board as SPI master with external slave modules that have an SPI interface (SPI = Serial Peripheral Interface). The Serial Peripheral Interface allows a fast synchronous data transfer between the training board and the peripheral module.

The AVR microcontroller ATmega328P has a hardware SPI on its chip, whose signals SS, MOSI, MISO and SCLK can be connected inside the microcontroller chip to the GPIOs D10 ... D13 on the pin headers SV5 and SV6 (arrow (3) and arrow (7) in Figure 1).

In the Arduino IDE, the *SPI library* is available for the control of SPI modules, which is integrated into the user program with

```
#include <SPI.h>
```

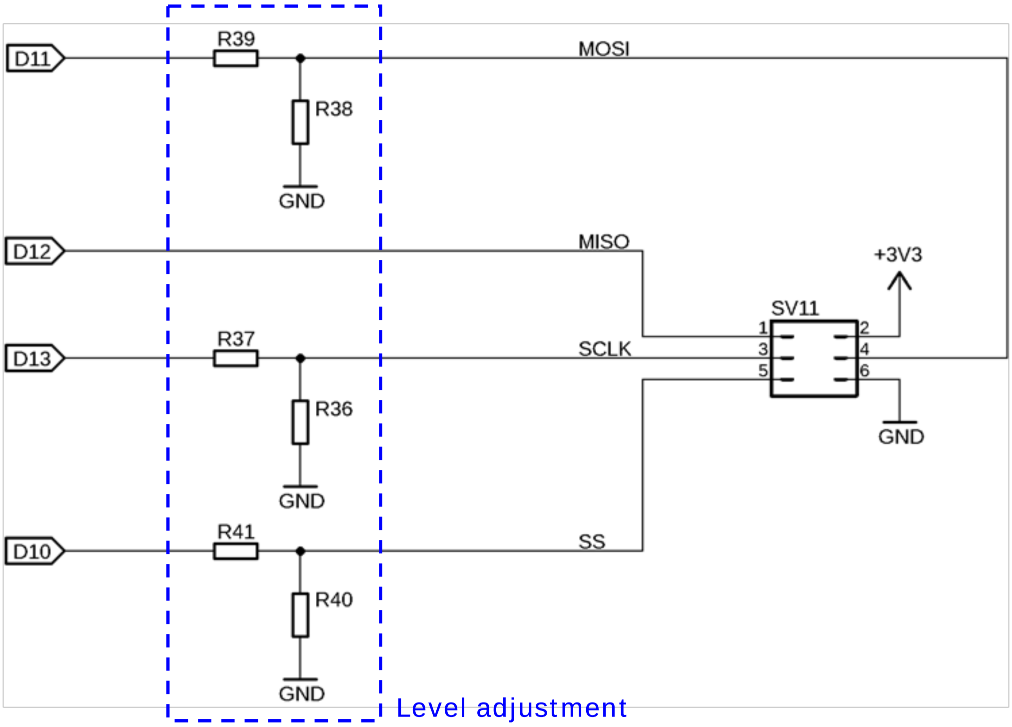


Figure 16: Pin assignment of SPI connector SV11

Since SPI modules with operating voltage +3.3 V as well as SPI modules with operating voltage +5 V are common, the MCCAB Training Board offers with SV11 and SV12 two correspondingly wired connection strips to cover both options.

If a jumper shorts pins 2 and 3 of header JP4 (see Figure 17 above), both SPI interfaces SV11 and SV12 use the same output pin D10 of the microcontroller as SS (Slave Select) line, as Figure 16 and Figure 17 show! Therefore, **only one of the two connectors SV11 or SV12 may be connected to an SPI module at the same time**, because the simultaneous use of the same SS line for different devices would lead to transmission errors and short circuits on the SPI lines!

Section 4.12.3 shows a possibility how nevertheless two SPI slaves can be connected to SV11 and SV12 at the same time.

4.12.1 The interface *SV11* for SPI modules with +3.3 V operating voltage

The connector SV11 (arrow (13) in Figure 1) enables the user to establish a serial SPI connection (SPI = Serial Peripheral Interface) between the MCCAB Training Board and an external SPI module with +3.3 V operating voltage, because the levels of the SPI output signals SS, MOSI and SCLK at interface SV11 are reduced to 3.3 V by voltage dividers. A 3.3 V level on the SPI input line MISO is recognized as HIGH signal by the AVR microcontroller ATmega328P and therefore does not have to be raised to 5 V level. The wiring of SV11 is shown in Figure 16.

4.12.2 The interface *SV12* for SPI modules with +5 V operating voltage

Interface SV12 (arrow (12) in Figure 1) enables the user to establish a serial SPI connection between the MCCAB Training Board and an external SPI slave with +5 V operating voltage, because the signals SS, MOSI, MISO and SCLK of interface SV12 operate with 5 V signal levels. The wiring of SV12 is shown in Figure 17.

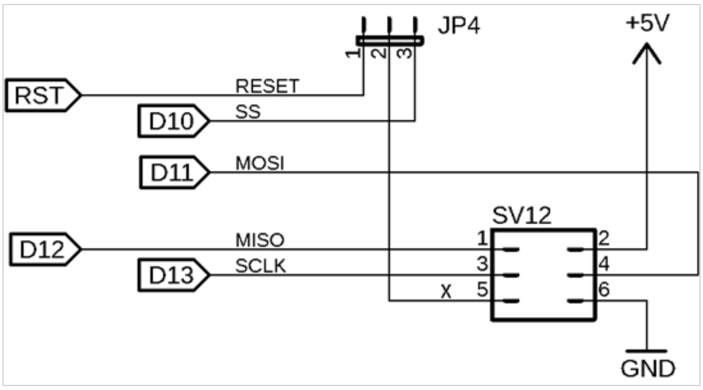


Figure 17: Pin assignment of SPI connector SV12

The pin arrangement on pin header SV12 corresponds to the recommended pin assignment of the AVR programming interface of the AVR manufacturer Microchip, which is shown in Figure 18. This gives the user the possibility to reprogram the bootloader of the ATmega328P with a suitable programming device via the SPI interface, e.g., if it needs an update to a new version or has been deleted by mistake.

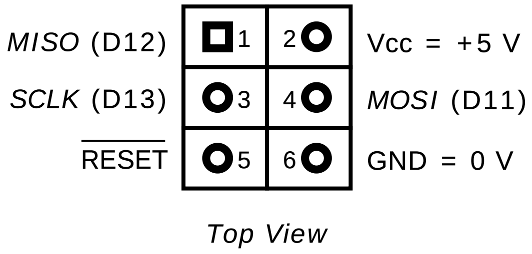


Figure 18: Recommended pin assignment of the AVR programming interface

Selection of signal X at pin 5 of SV12

Depending on the desired application, the connection X at pin 5 of SV12 (Figure 17) can be assigned with different signals:

1. A jumper connects pins 2 and 3 of pin header JP4.

If the pins 2 and 3 of pin header JP4 (see Figure 17 above and arrow (11) in Figure 1) are shorted by a jumper, the GPIO D10 (signal SS) of the microcontroller is connected to pin 5 of the connector SV12. SV12 is used then as a normal SPI interface with the SS (Slave Select) GPIO D10.

In this case, both SPI interfaces SV11 and SV12 use the same SS line D10! Therefore, only one of the two connector strips **SV11 <u>or</u> SV12** may be connected to an SPI module, because the simultaneous common use of the same SS line by different devices would lead to transmission errors and short circuits on the SPI lines!

2. A jumper connects pins 1 and 2 of pin header JP4.

In this case, the RESET line of the microcontroller is connected to pin 5 of pin header SV12. In this mode SV12 acts as a programming interface for the microcontroller ATmega328P, because for the programming process the RESET line of the ATmega328P must be connected to pin X (pin 5) of pin header SV12. In this mode, the ATmega328P is the SPI slave and the external programmer is the master.

4.12.3 Simultaneous connection of SPI modules to *SV11* and *SV12*

If there is a need to connect a 3.3 V module and a 5 V module to the MCCAB Training Board at the same time, this can be realized with the wiring shown in Figure 19. Pins 1 and 3 of the pin header JP4 are unconnected, pin 2 of JP4 is connected to one of the digital GPIOs D2 … D9 on pin header SV5 (arrow (3) in Figure 1) via a Dupont cable, as shown in Figure 19. This output of the microcontroller ATmega328P then fulfills the task of an additional SS signal at connector X (pin 5) of the pin header SV12. Figure 19 shows the procedure using the example of D9 as additional connector SS2.

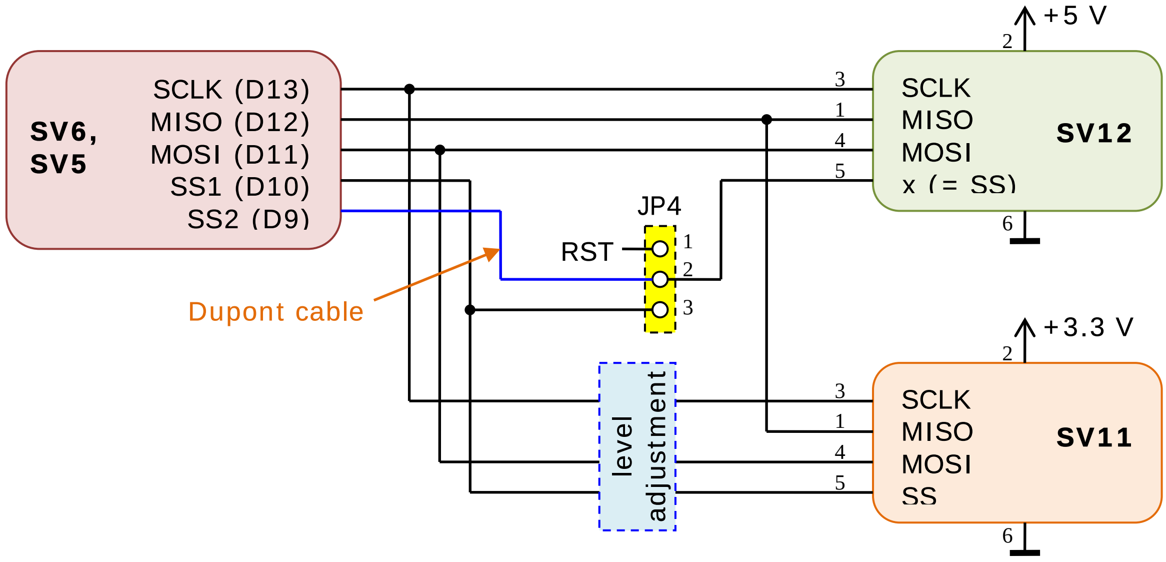


Figure 19: Simultaneous connection of two SPI modules to the MCCAB Training Board

In this case, both SPI interfaces SV11 and SV12 may be connected to external SPI slaves at the same time, because both SV11 and SV12 use different SS lines now: LOW level at GPIO D10 activates the SPI module at SV11 and LOW level at GPIO D9 activates the SPI module at SV12 (see Figure 19).

The microcontroller on the MCCAB Training Board may only exchange data with one module connected to the bus via SV11 or SV12 at the same time. As you can see in Figure 19, the MISO lines of both interfaces SV11 and SV12 are connected together. If both interfaces would be activated at the same time by LOW level at their SS-connector and would transfer data to the microcontroller, transmission errors and short circuits on the SPI lines would be the result!

4.13 The pin headers *SV8, SV9 and SV10* for the TWI (=I²C) interface

Via the pin headers SV8, SV9 and SV10 (arrows (15), (16) and (14) in Figure 1) the user can establish a serial I²C connection (I²C = Inter-Integrated Circuit) of the microcontroller on the training board with external I²C modules. In the data sheet of the AVR microcontroller ATmega328P the I²C interface is called TWI (Two Wire Interface). The wiring of the three connectors is shown in Figure 20.

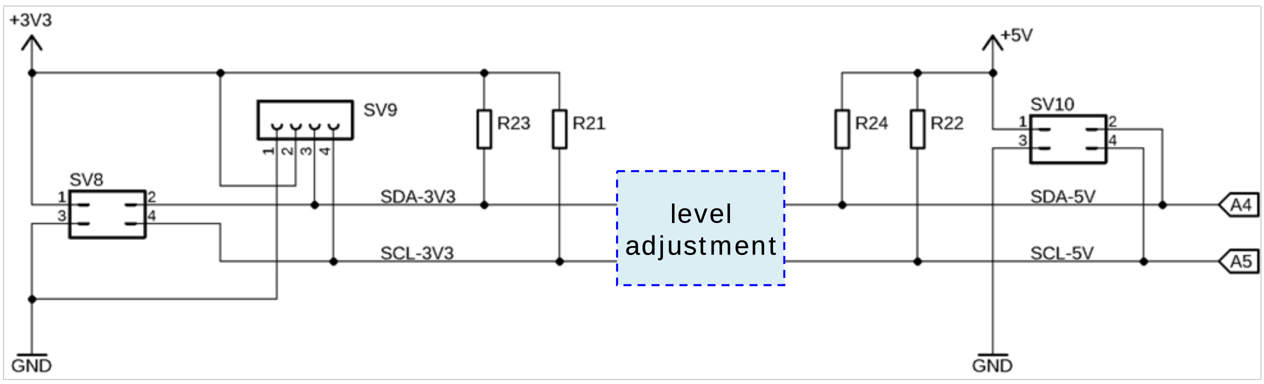


Figure 20: The TWI (=I²C)-Interface on the MCCAB Training Board

At SV10, those I^2C modules are connected, which work with the operating voltage +5 V. I^2C modules with +3.3 V operating voltage are connected to SV8 or SV9. A level adjustment stage on SV8 and SV9 reduces the 5 V signal level of the AVR microcontroller ATmega328P to the 3.3 V signal level of the external modules.

The I^2C interface consists only of the two bidirectional lines SDA (Serial DAta) and SCL (Serial CLock). For better distinction, in Figure 20 the lines SDA and SCL are marked with the suffix 5V before the level adjustment stage and with the suffix 3V3 after the level adjustment stage.

The AVR microcontroller ATmega328P has a hardware TWI (Two Wire Interface, functionally identical to the I^2C interface) on its chip, whose signals SDA and SCL can be connected inside the microcontroller chip to the GPIOs A4 and A5 on the pin header SV6 (arrow (7) in Figure 1).

In the Arduino IDE, the *wire* library is available for the control of I^2C modules, which is integrated into the user program with #include <Wire.h>.

5 Hints for the use of the ATmega328P's analog/digital converter

In the default setting after switching on the operating voltage of the microcontroller module Arduino® NANO, the analog/digital converter (ADC) of the microcontroller has the analog voltage range V_{ADC} = 0 … +5 V. In this case, the +5 V operating voltage Vcc of the microcontroller module is also the reference voltage V_{REF} of the ADC, provided that the REF terminal of the connector SV6 (arrow (7) in Figure 1) is unconnected.

The ADC of the ATmega328P converts an analog input voltage V_{ADC} at one of its inputs A0 … A7 into a digital 10-bit value Z. The numerical value Z is in the binary resp. hexadecimal number range

$$Z = 00\,0000\,0000_2 \ldots 11\,1111\,1111_2 = 000 \ldots 3FF_{16}.$$

This corresponds to the decimal number range

$$Z = 0 \ldots (2^{10} - 1) = 0 \ldots 1023_{10}.$$

The allowed range of the analog input voltage is $V_{ADC} = 0\,V \ldots \frac{1023}{1024} \cdot V_{REF}$.

The accuracy of the analog/digital conversion depends mainly on the quality of the reference voltage V_{REF}, because for the 10-bit numerical value Z generated by the analog/digital converter of the microcontroller applies:

$$Z = \frac{V_{ADC}}{V_{REF}} \cdot 1024 \qquad \text{(Equation 1)}$$

V_{ADC} is the input voltage of the analog/digital converter at one of its inputs A0 … A7 and V_{REF} is the reference voltage set for the converter. The reference voltage can be measured with a high-impedance voltmeter between the REF terminal of SV6 and the circuit ground GND.

The result of the analog/digital conversion is an integer value, i.e., any decimal places resulting from the division of the two voltages V_{ADC} and V_{REF} are cut off.

The +5 V operating voltage fed in by the PC via the USB cable is generated by the switching power supply of the PC. However, the output voltage of a switching power supply usually has a non-negligible AC voltage component superimposed on it, which reduces the accuracy of the analog/digital conversion.

Better results can be achieved by using the +3.3 V auxiliary voltage stabilized by the linear voltage regulator on the MCCAB Training Board as the reference voltage for the analog/digital converter. For this purpose, the analog/digital converter of the ATmega328P is initialized in the program with the instruction

```
analogReference(EXTERNAL);  // sets the voltage at pin REF as reference voltage
```

according to the changed reference voltage and pin REF of pin header SV6 (arrow (7) in Figure 1) is connected to the adjacent +3.3 V pin 3V3 on pin header SV6 via a Dupont cable or a jumper.

Please note that the analog voltage V_{ADC} at the reference voltage V_{REF} = 3.3 V is still converted into digital 10-bit values in the range 0 ... 1023_{10}, but the measuring range of the analog/digital converter is reduced to the range V_{ADC} = 0 ... +3.297 V. In return, a finer resolution of the conversion results is achieved, because the LSB (the smallest resolvable value) is now only 3.2 mV.

The input voltage V_{ADC} of the analog/digital converter at its analog inputs A0 ... A7 on the pin header SV6 must always be smaller than the value V_{REF} at terminal REF of SV6!

The user must ensure that V_{ADC} < V_{REF}!

For "Accuracy of A/D conversion" see also the note on page 11.

6 The Library "MCCAB_Lib" for the MCCAB Training Board

To support the user in controlling the many hardware components (switches, buttons, LEDs, 3 × 3 LED matrix, buzzer) on the MCCAB Training Board, the library "MCCAB_Lib" is available, which can be downloaded free of charge from the Internet site www.elektor.com/20440 by the purchasers of the training board.

7 Further Literature on the Use of the MCCAB Training Board

In the book "Microcontrollers Hands-On Course for Arduino Starters" (ISBN 978-3-89576-545-2) you will not only find a detailed introduction to the programming of microcontrollers and to the programming language C, which is used in the Arduino IDE for writing the programs, but also a detailed description of the methods of the library "MCCAB_Lib" and a variety of application examples and exercise programs for using the MCCAB Training Board.