Optimus.2 SAS 2.5" SSD Product Line
(Ascend, Ultra, and Extreme)

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Revision History

Date	Revision	Section(s)	Description
June 2016	3	All	Western Digital corporate branding applied. No technical information changed.
March 2015	2	All	Made changes to the functional block diagram. Deleted tables 15, 16, and 17. Included sections for Ultra and Extreme product information and updated Disclaimer.
May 2014	A	All	Preliminary release.

NOTE:	Because it now uses improved storage software, SanDisk has changed its naming convention for document revisions. Going forward, document revisions will be numbered. This revised document, for example, is designated Rev 2. In the past, revisions were designated by letters.

ESD Caution – Handling

Static electricity may be discharged through this disk subsystem. In extreme cases, this may temporarily interrupt the operation or damage components. To prevent this, make sure you are working in an ESD-safe environment. For example, before handling the disk subsystem, touch a grounded device, such as a computer case.

1.0   General Description

1.1   Overview

SanDisk Optimus.2 Solid State Drive (SSD) product family ushers in a new era of flash storage, bringing together the industry's best combination of performance, capacity, endurance and reliability, while using the most cost-effective flash available. This combination makes the Optimus.2 product family SSD the ideal solution for a wide variety of enterprise applications, including the custom built hyper-scale architectures many organizations are developing on their own by combining best-in-class hardware and software.

Original Equipment Manufacturers (OEMs) and IT managers no longer have to compromise on performance, endurance, or reliability to obtain affordability. The Optimus.2 product family SSD offers all four in a single package through a combination of the Guardian™ technology platform, SanDisk's unique and innovative IP, and the use of the SanDisk 19 nm Multi-Level Cell (MLC) flash.

Optimus.2 product family SSDs are designed for the mixed workloads common in enterprise applications and delivers the endurance required to last for the full five-year warranty. The Optimus.2 product family also includes a broad set of enterprise reliability, security, and data recovery features, giving OEMs and IT managers the confidence their data will not be compromised during any common data center occurrence.

Optimus.2 product family SSDs are powered by the SanDisk proprietary Guardian technology platform, a comprehensive suite of innovative features comprised of FlashGuard™ and EverGuard™ technologies.

FlashGuard extends the native endurance of 19 nm consumer-grade MLC flash based SSDs to deliver 10 - 45 Drive Writes per Day (DWPD) for a period of five years. FlashGuard combines Aggregated Flash Management, which treats all flash elements as a single system, and Advanced Signal Processing, which dynamically adjusts flash parameters throughout the life of the SSD, to reliably extract significantly more life from the most cost-effective MLC flash, making it suitable for mixed workload enterprise applications.

DataGuard features full data path protection, safeguarding user data from corruption along all data paths in the SSD. DataGuard also protects the SSD against loss of data at the page and block levels using a unique feature called Flexible Redundant Array of Memory Elements (FRAME). FRAME enables the recovery of user data even after catastrophic events such as flash page or block failures.

EverGuard protects against loss of user data in the event of unexpected power interruptions using a third-generation backup power circuit design and high-reliability discrete capacitors.

SanDisk has built its foundation by providing proven technology featuring quality products to the most demanding Fortune 100 OEMs. SanDisk engineers its products to perform at the highest degree of reliability and compatibility while backing these products with outstanding services and expertise.

1.2   Features

- Type: 2.5" SAS SSD

- Interface: Dual Port Serial Attached SCSI-2

- Supported Transport Mode: Serial SCSI Protocol (SSP)

- Interface Transfer Rate: 6 Gbits/sec standard

- Capacities:

  - Ascend: 200 GBytes, 400 GBytes, 800 GBytes, 1600 GBytes

  - Ultra: 150 GBytes, 300 GBytes, 600 GBytes, and 1200 GBytes

  - Extreme: 100 GBytes, 200 GBytes, 400 GBytes, 800 GBytes

- Data Rates:

  - Sequential Read/Write[1]: Up to 550 MBytes/sec

  - Random Write[2]: Up to 40,000 I/Os/sec

  - Random Read[2]: Up to 95,000 I/Os/sec

- Access Time: 120 μsecs (typical)

- Operating Temperature[3]: 0 °C to 70 °C (internal)

- Compliance:

  - RoHS

  - Halogen Free

- Warranty: Five Years

1. Based on 128 KByte transfers.
2. Based on 4 KByte transfers.
3. As measured by the drive thermal sensor.

1.3   Unique Features

- Drive-specific Self-Monitoring, Analysis, and Reporting Technology (SMART) Attributes

- Maximum 5% Performance Degradation Throughout Warrantied Life

- Full Drive Writes Per Day (DWPD)

- Random Workload:

  - Ascend – 10 DWPD

  - Ultra – 25 DWPD

  - Extreme – 45 DWPD

- FlashGuard Technology:

  - Extension of the Native Endurance of Commercial MLC Flash

  - Aggregated Flash Management

  - Advanced Signal Processing

  - Enhanced Error Correction

- DataGuard Technology:

  - Protection Against Data Corruption and Loss

  - Full Data Path Protection

  - FRAME Technology

  - EverGuard Technology

  - Data Protection in the Event of Unanticipated Power Outages

  - High-reliability Backup Power Circuitry

- External LED Activity Support

- Temperature Throttling

- Variable Sector Sizes (512 and 520 bytes)

1.4   Operational Characteristics

All listed values are typical unless otherwise stated.

1.4.1   Performance

Table 1: Performance Characteristics

Item	Optimus.2 Product Family Performance
Sequential Read (Maximum)	Up to 550 MBytes/sec[4]
Sequential Write (Maximum)	Up to 550 MBytes/sec[4]
Random Read I/Os Per Second (Maximum)	Up to 95,000[5]
Random Write I/Os Per Second (Maximum)	Up to 40,000[5]
Access Time	120 µsecs (typical)[5]

1.4.2   Reliability

Table 2: Reliability Characteristics

Item	Value		
	Ascend	Ultra	Extreme
Data Reliability	< 1 unrecovered error in 10^{17} bits read[6]		
Data Retention	3 months @ 100% P/E cycles[7]		
DWPD (Random/Sequential Workload) for Five-years	10	25	45

1.4.3   Power

Table 3: Power Requirements

Parameter	Value (Typical)	Value (Max)	Unit
Read	4.57	7.24	W
Write	6.21	9.50	W
Idle	3.44	3.70	W

4.   Based on 128 KByte transfers. Capacities of 200 GBytes or less, sequential writes are up to 380 MBytes/sec.

5.   Random performance values are based on 4 KByte transfers.

6.   The JEDEC 64.8 specification requires 1 in 10^{16} for enterprise-class SSDs.

7.   Three-month data retention is based on non-operational storage at less than 40 ℃.

1.5   Environmental Conditions

Table 4: Environment Tests

Test	Condition	Limits
Altitude	Operating	-1,000 feet to 18,000 feet
	Shipping	-1,000 feet to 40,000 feet
	Storage	-1,000 feet to 40,000 feet
Temperature and Humidity	Operating	Temperature: 0 °C to + 70 °C (internal) Humidity: 5% to 95% non-condensing relative humidity **NOTE:** Warranty coverage is voided for drives that record temperatures in excess of 70 °C.
	Shipping/Storage	Temperature: -40 °C to + 85 °C Humidity: 5% to 95% non-condensing, relative humidity **NOTE:** Avoid non-operational exposure to temperatures in excess of 40 °C for periods exceeding three months. The three-month End of Life (EOL) data retention specification requires storage temperatures do not exceed 40 °C. If necessary, contact SanDisk for further information.
Vibration–Swept Sine	Operating	5.0 – 400 Hz sine, 1.0 g peak 5 – 300 Hz and 0.5 g peak 300 – 400 Hz for each [x,y,z] axis; sweep 1.0 g peak 5– 300 Hz and 0.5 g peak 300 – 400 Hz; sweep rate is 0.5 Hz/sec @ 26 min per axis
	Non-operating	2.0 - 200 Hz sine, 0.5 g peak 2 – 5 Hz and 3.0 g peak 5 – 200 Hz for each [x,y,z] axis; sweep 0.4 g peak 2.0 – 2.3 Hz, 0.5 g peak 2.3 – 5.0 Hz, 2.42 g peak 5.0 – 5.6 Hz, and 3.0 g peak 5.6 – 200 Hz; sweep rate is 0.4 decades per min @ 10 min per axis.
Shock	Operating	15 g @ 11.0 msec 400 g @ 2.0 msec 1000 g @ 0.5 msec
	Non-operating	35 g @ 20.0 msec 80 g @ 11.0 msec 150 g @ 10.0 msec 500 g @ 2.0 msec
Common Mode Noise	– – –	220 mV, 10 KHz – 10 MHz
V_{cc} Ripple Noise	– – –	50 mV, 10 KHz –50 KHz 100 mV, 50 KHz –10 MHz

1.5.1 Physical Specifications of 9.5 mm SSD

Table 5: 9.5 mm Physical Characteristics

Parameter	Value
Length	100.00 ± 0.25 mm
Width	69.85 ± 0.25 mm
Height (Mounted)	9.24 ± 0.25 mm
Weight (Typical)	99.3 g [3.5 oz]

1.5.2 Physical Specifications of 15 mm SSD

Table 6: 15 mm Physical Characteristics

Parameter	Value
Length	100.20 ± 0.25 mm
Width	69.85 ± 0.25 mm
Height (Mounted)	14.75 ± 0.25 mm
Weight (Typical)	153.40 g [5.4 oz]

2.0   Product Description

2.1   Functional Block Diagram

Optimus.2 product family 2.5" SAS SSDs contain a NAND flash controller that provides a 6 Gbits/sec SAS interface to the host system. Parallel access to multiple flash sites rapidly allows overlapped multi-block access to complete data transfer requests. A thermal sensor provides input to the controller regarding over heating conditions. EverGuard technology ensures data integrity during power failures.

Figure 1: Optimus.2 SAS Product Family Functional Block Diagram
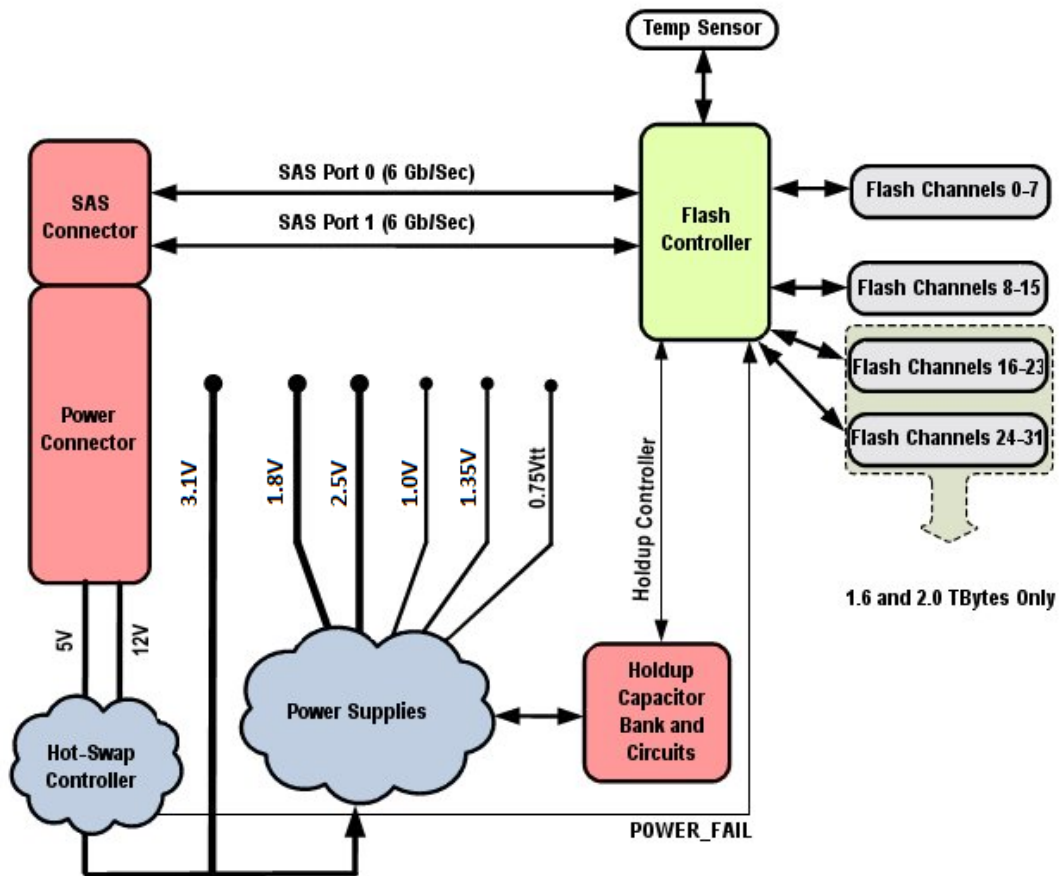
2.2   Flash Management

Optimus.2 product family 2.5" SAS SSDs support the following techniques for enhanced flash management:

- **Static Wear Leveling**: This feature eliminates overstressing flash media by spreading the data writes across all flash physical address space, including logical areas that are not written by the user.

- **ECC**: The drives utilize advanced two-level BCH code and a FRAME data recovery algorithm. The drive activates this second tier of error correction if the ECC engine is unable to correct the data located in failed NAND pages.

- **Bad-block Management**: This feature tracks all manufacturing and run-time bad blocks of flash media and replaces them with new ones from the spare pool.

- **Data Retention Management**: As flash is used over the life of the drive, data retention capability declines. The Optimus.2 product family incorporates multiple data-retention management techniques to ensure the highest data reliability and integrity, even toward the end of the drive life.

- **Minimal Write Amplification**: Write amplification is defined as the ratio of total data written to the flash compared to the total data written by the host. This ratio varies continually as a function of workload. The controller utilizes write optimization, effective wear leveling, intelligent bad-block management, and efficient recycling to deliver an unprecedented low write-amplification factor. This translates directly to higher and more stable performance over a longer life.

2.3   Endurance

Optimus.2 product family 2.5" SAS SSDs provide the innovative FlashGuard technology feature to extract higher endurance from MLC flash. FlashGuard incorporates two important technology breakthroughs in flash and SSD system management:

- Aggregated Flash Management

- Advanced Signal Processing

2.3.1   Aggregated Flash Management

SanDisk's Aggregated Flash Management technology prolongs the life of SSDs by treating all flash elements as a system instead of as a collection of discrete elements. Aggregating the management of the flash over multiple pages within a block and over multiple blocks within the SSD reduces the limitations imposed at the page and block levels, thus extending the life of the drive.

FlashGuard treats each flash cell individually, thereby maximizing the effects of stronger flash elements (i.e., those that exhibit higher performance capability) while minimizing the effects of weaker elements. The capability of FlashGuard to distinguish between, and take advantage of, flash elements at the cellular level extends the endurance of the drive. See for an illustration.

Figure 2: Optimus.2 2.5" SAS Product Family Increased SSD Endurance
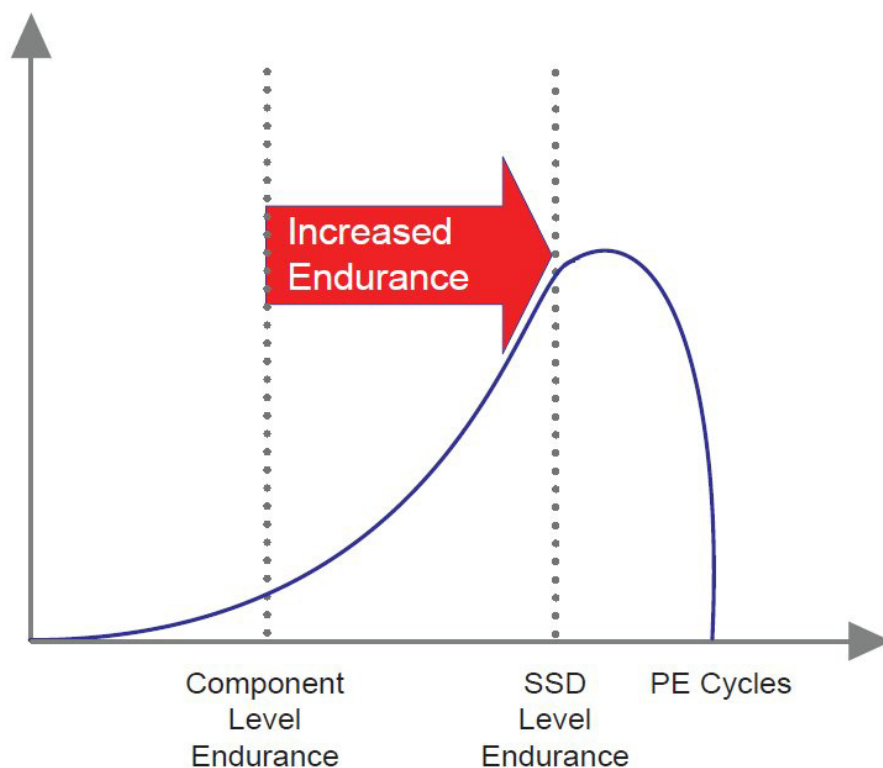
2.3.2   Advanced Signal Processing

The controller's Advanced Signal Processing technology is used to periodically monitor the flash and collect detailed statistics of its performance. This information is used to dynamically adjust the flash operating parameters to attain maximum endurance from the drive throughout its operational life. To further extend the life of the drive, FlashGuard incorporates a proprietary enhanced error correction technology that corrects more data errors than is possible with standard error correction schemes.

2.4   Temperature Throttling

The Optimus.2 product family 2.5" SAS SSDs support temperature throttling to protect the drive from premature failure. With this feature, the drive throttles the write performance based on a pre-configured temperature level of 65 °C.

When the critical temperature (65 °C) is reached, the drive returns a sense key of 01/0B to indicate a threshold was exceeded and records the data to the Informational Exceptions log page (2Fh). Write performance remains throttled until the temperature falls below 65 °C. See "SCSI Sense Code Key," on page 22 for more information about log pages. If the drive reaches 70 °C, a SMART trip will occur, voiding the warranty.

2.5   Sector Sizes

Because the Optimus.2 product family SSD supports variable sector sizes, the formatted number of blocks differs depending on the sector size. By default, the block size is set to 512 bytes, but the drive configuration supports 520-byte blocks.

2.6   Mean Time Between Failures (MTBF)

The MTBF statistic for all Optimus.2 product family 2.5" SAS SSDs is calculated based on the MIL-HDBK-217 standard.

Table 7: MTBF Value

Drive Capacity	MTBF (Hours)
All	2,500,000

2.7   Regulatory Standards Compliance

Optimus.2 product family 2.5" SAS SSDs meet all regulatory, safety, and electromagnetic compatibility (EMC) standards listed in the following table.

Table 8: Optimus.2 2.5" SAS SSD Regulatory Compliance

Category	Region	Compliance/Agency	Standard	Additional Information
Safety	USA	UL	UL 60950-1, Second Edition	UL File No. E351027
	Canada	CSA	CSA C22.2 No. 60950-1-07, Second Edition	CSA Certificate
	European Union	EU Directive 2006/95/EC (LVD)	EN 60950-1:2006/A11	TÜV Bauart Certificate
	International	UL	IEC 60950-1:2005, Second Edition	UL CB Certificate
EMC	USA	FCC	FCC Part 15 Class B	FCC Declaration of Conformity
	Canada	Industry Canada	ICES-003 Class B	IC Declaration of Conformity
	European Union	EU Directive 2004/108/EC (EMC)	EN 55022:2010 Class B	CE Declaration of Conformity
	South Korea	KCC	KN22:2009 Class B, KN24:2009	KCC Certificate
	Taiwan	BSMI	CNS 13438 (2006) Class B	BSMI Declaration of Conformity
	Australia	ACMA	AS/NZS CISPR22:2006, Class B	C-Tick Declaration of Conformity
RoHS	European Union	EU Directive 2011/65/EU (RoHS)	EU Directive 2011/65/EU (RoHS)	CE Declaration of Conformity

3.0   Mechanical Specifications

3.1   9.5 mm Thickness

Figure 3: Optimus.2 2.5" SAS Drive Dimensions (in mm)
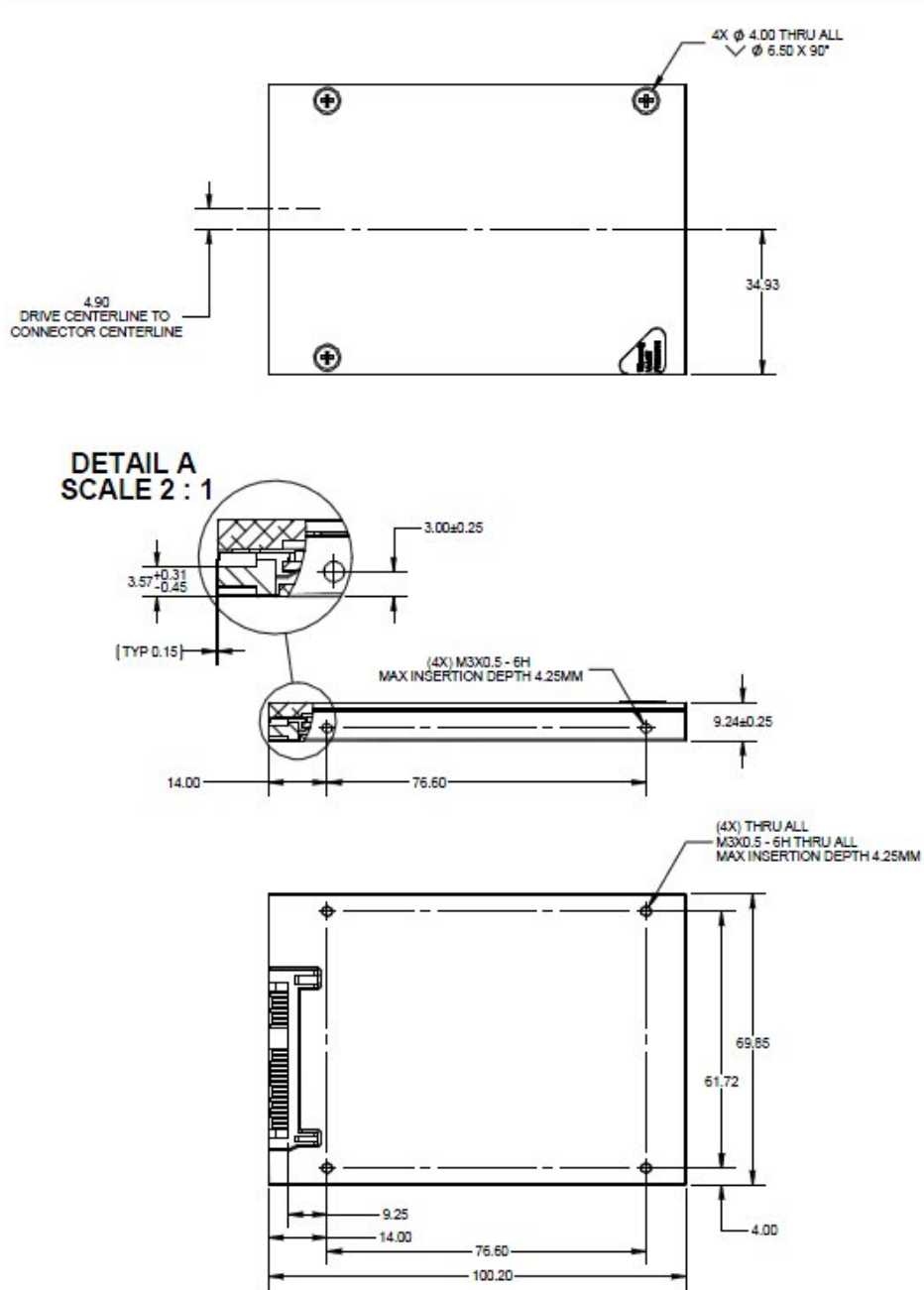
| **Note:** | The warranty is voided if the label is removed. |

3.2   15 mm Thickness

Figure 4: Optimus.2 2.5" SAS Drive Dimensions (in mm)
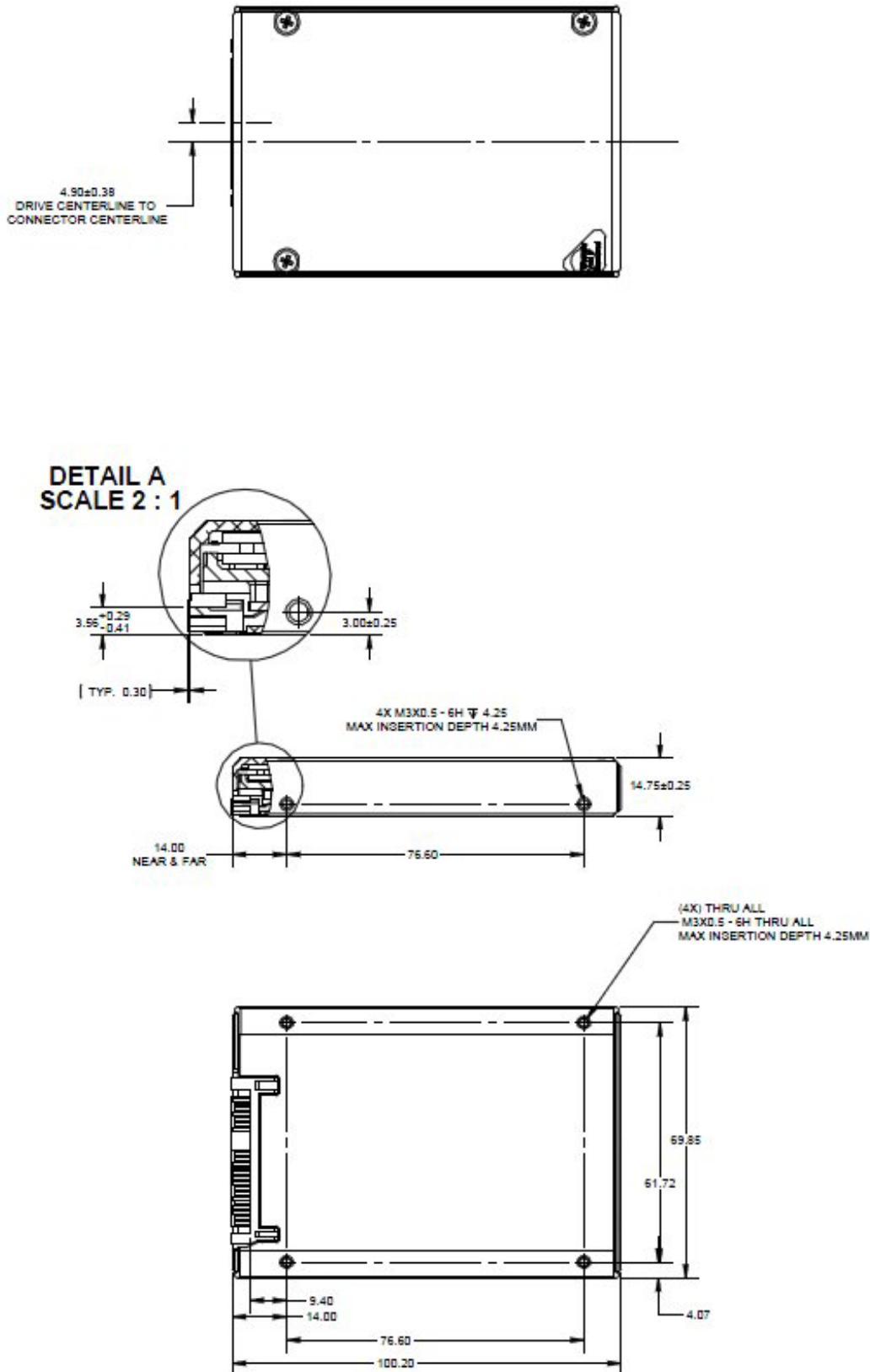
4.0   Electrical Specifications

4.1   Electrical Interface

The Optimus.2 product family 2.5" SAS drive complies with the SAS-2, 6.0 Gbits/sec standard.

4.1.1   Optimus.2 Product Family Interface Connector

The SAS drives include two signal bays: a primary signal segment (S1 to S7), and a secondary signal segment (S8 to S14). The power bay is a standard 15-pin SAS power connector that supports both cabled and backplane plug-in connections.

Figure 5: SAS Interface Connector for the Optimus.2 Product Family
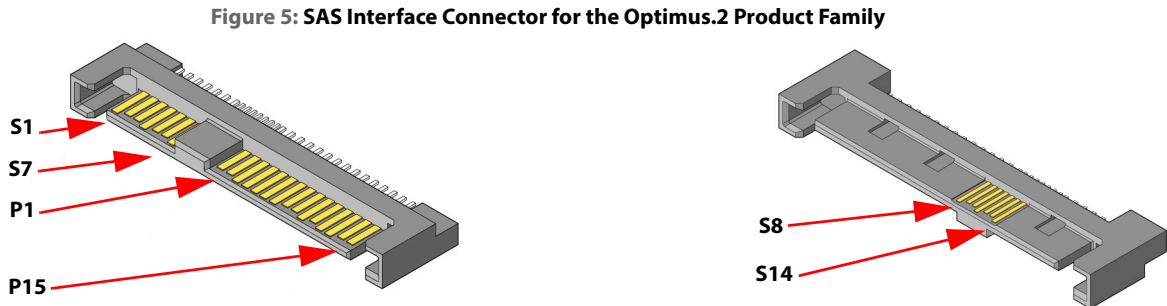
Table 9: Signal Pinout Descriptions

Pin	Backplane	SAS Drive Plug
S1	GND	GND
S2	Transmit primary differential signal out +	Receive primary differential pair signal in +
S3	Transmit primary differential signal out -	Receive primary differential pair signal in -
S4	GND	GND
S5	Receive primary differential pair signal in -	Transmit primary differential pair signal out -
S6	Receive primary differential pair signal in +	Transmit primary differential pair signal out +
S7	GND	GND
S8	GND	GND
S9	Transmit secondary differential signal out +	Receive secondary differential signal in +
S10	Transmit secondary differential signal out -	Receive secondary differential signal in -
S11	GND	GND
S12	Receive secondary differential signal in -	Transmit secondary differential signal out -
S13	Receive secondary differential signal in +	Transmit secondary differential signal out +
S14	GND	GND

Table 10: Power Pinout Descriptions

Pin	Signal Name	In/Out	Signal Description
P1	V3.3	N/A	3.3 V power (not used)
P2	V3.3	N/A	3.3 V power (not used)
P3	V3.3	N/A	3.3 V power (not used)
P4	GND	In	1st mate
P5	GND	In	2nd mate
P6	GND	In	2nd mate
P7	V5	In	5 V power, pre-charged, 2nd mate
P8	V5	In	5 V power
P9	V5	In	5 V power
P10	GND	In	2nd mate
P11	Reserved	In/Out	Ready and fault indicator
P12	GND	In	1st mate
P13	V12	In	12 V power
P14	V12	In	12 V power
P15	V12	In	12 V power

4.1.2 Dual Port

As shown in "SAS Interface Connector for the Optimus.2 Product Family," on page 17, the Optimus.2 product family 2.5" SAS SSDs support dual ports. Although each of these has individual SAS addresses, they can connect to the same or different SCSI domains. In addition, each port is independently clocked with support for 6 Gbits/sec link rates.

4.2 Remote LED

In compliance with the SAS specification, pin P11 on the 15-pin power connector supports a remote LED. Because the signal is not suitable for directly driving an LED, a circuit external to the device first buffers the signal. When connected, the remote LED indicates both ready and fault conditions. See the following table for the blink rates associated with the remote LED when activity is detected.

Table 11: Activity LED Blink Rates

Command	Blink Rate
Read/Write Operations	Proportional to the I/O rate
Format	2 times per second
Send Diagnostics Foreground Self-test	2 times per second
Send Diagnostics Background Self-test	2 times per second

4.3 Thermal Sensor

Optimus.2 product family 2.5" SAS SSDs have a thermal sensor on the printed circuit board (PCB). The drive stores the highest and lowest temperature readings in the drive logs. The reading represents the temperature of the PCB and not the drive case. See "Log Pages," on page 25 for more information about log pages.

4.4   Absolute Maximum Ratings

The listed values apply to all Optimus.2 product family drives.

Table 12: Voltage and Storage Temperature

Symbol	Parameter	Ratings (Max)	Unit
V_{IN}	5.0 +10%,-5%	5.50	V
	12.0 $\pm$ 5%	12.60	
I_{ACTIVE}	Active Current (5 V)[8]	1.20	V
	Active Current (12 V)[8]	0.50	
T_{STG}	Storage Temperature	-40 to +85	°C

4.5   Recommended Operating Conditions

The listed values apply to all Optimus.2 product family drives.

Table 13: Recommended Operating Conditions

Symbol	Parameter	Ratings	Unit
V_{IN}	5 V Supply Voltage	5.0 +10%, -5%	V
	12 V Supply Voltage	12.0 $\pm$ 5%	
T_A	Operating Temperature (Internal)[9]	0 to +70	°C

4.6   DC Characteristics

Table 14: DC Characteristics[10]

Symbol	Parameter	Average	Peak	Unit	Condition
I_{READ}	Current During Read	0.46	0.72	A	V_{IN} = 5 V
		0.19	0.30	A	V_{IN} = 12 V
I_{WRITE}	Current During Write	0.62	1.20	A	V_{IN} = 5 V
		0.26	0.50	A	V_{IN} = 12 V
I_{IDLE}	Idle Current	0.34	0.37	A	V_{IN} = 5 V
		0.14	0.15	A	V_{IN} = 12 V

8. These values represent the maximum current possible drawn on either power rail, independent of the other. In operation, maximum 5 V current draw does not occur synchronously with maximum 12 V current draw. These values are not be summed to estimate a maximum drive power consumption; this value must be determined by direct measurement only.
9. As measured by the thermal sensor.
10. Current values presented for 12 V and 5 V are independent measurements and cannot be combined to compute overall drive power consumption. Peak draw is transient, typically lasting < 100 usec.

5.0   SOFTWARE SPECIFICATIONS

5.1   Supported SCSI Commands

The Optimus.2 product family 2.5" SAS SSDs support the standard commands listed in the following table. For more detailed descriptions of the commands, please refer to the specification defined for the command.

Table 15: Supported SCSI Commands

Command Name	Op Code/Service Action (Hex)	Standard
Format Unit	04	SCSI Block Commands-3
Inquiry	12	SCSI Primary Commands-4
Log Select (10 Bytes)	4C	SCSI Primary Commands-4
Log Sense (10 Bytes)	4D	SCSI Primary Commands-4
Mode Select (6 Bytes)	15	SCSI Primary Commands-4
Mode Select (10 Bytes)	55	SCSI Primary Commands-4
Mode Sense (6 Bytes)	1A	SCSI Primary Commands-4
Mode Sense (10 Bytes)	5A	SCSI Primary Commands-4
Persistent Reserve In	5E	SCSI Block Commands-3
Persistent Reserve Out	5F	SCSI Block Commands-3
Read (6 Bytes)	08	SCSI Block Commands-3
Read (10 Bytes)	28	SCSI Block Commands-3
Read (12 Bytes)	A8	SCSI Block Commands-3
Read (16 Bytes)	88	SCSI Block Commands-3
Read (32 Bytes)	7F/0009	SCSI Block Commands-3
Read Buffer	3C	SCSI Block Commands-3
Read Capacity (10 Bytes)	25	SCSI Block Commands-3
Read Capacity (16 Bytes)	9E /10	SCSI Block Commands-3
Read Defect Data (10 Bytes)	37	SCSI Block Commands-3
Read Defect Data (12 Bytes)	3E	SCSI Block Commands-3
Read Long (10 Bytes)	1B	SCSI Primary Commands-4
Reassign Blocks	07	SCSI Block Commands-3
Receive Diagnostics Results	1C	SCSI Block Commands-3
Report LUNS	A0	SCSI Primary Commands-4
Report Supported Opcodes	A3	SCSI Primary Commands-4
Request Sense	03	SCSI Primary Commands-4
Send Diagnostic	1D	SCSI Primary Commands-4
Start/Stop Unit	1B	SCSI Primary Commands-4
Synchronize Cache (10 Bytes)	35	SCSI Primary Commands-4
Test Unit Ready	00	SCSI Primary Commands-4
Unmap	42	SCSI Primary Commands-4
Verify (10 Bytes)	2F	SCSI Block Commands-3
Verify (12 Bytes)	AF	SCSI Block Commands-3
Verify (16 Bytes)	8F	SCSI Block Commands-3
Verify (32 Bytes)	7F/000A	SCSI Block Commands-3
Write (6 Bytes)	0A	SCSI Block Commands-3
Write (10 Bytes)	2A	SCSI Block Commands-3
Write (12 Bytes)	AA	SCSI Block Commands-3

Table 15: Supported SCSI Commands (Continued)

Command Name	Op Code/Service Action (Hex)	Standard
Write (16 Bytes)	8A	SCSI Block Commands-3
Write (32 Bytes)	7F/000B	SCSI Block Commands-3
Write Buffer	3B	SCSI Primary Commands-4
Write Long (10 Bytes)	3F	SCSI Primary Commands-4
Write Long (16 Bytes)	9F	SCSI Primary Commands-4
Write Same (10 Bytes)	41	SCSI Block Commands-3
Write Same (16 Bytes)	93	SCSI Block Commands-3
Write Same (32 Bytes)	7F/000D	SCSI Block Commands-3
Write and Verify (10 Bytes)	2E	SCSI Block Commands-3
Write and Verify (12 Bytes)	AE	SCSI Block Commands-3
Write and Verify (16 Bytes)	8E	SCSI Block Commands-3
Write and Verify (32 Bytes)	7F/000C	SCSI Block Commands-3

5.2   Supported SMART Operations

Self-Monitoring Analysis and Reporting Technology (SMART) attributes provide diagnostic information about drive operation. SMART alerts the host to potential drive problems, allowing system operators to assess the situation and back up data prior to an operational failure.

The following table describes the supported SMART attributes returned in log page 34h. All attributes have a normalized value range of 0 to 255 percent to failure. If a value is 100 or more, a SMART trip is reported. It is important to note that most SMART values are maintained across power cycles (that is, they are non-volatile).

Table 16: Supported SMART Attributes

Attribute ID (Dec)	Name	Indicates
1	Raw Read Error Rate	The raw error related to ECC errors. Correctable and uncorrectable data- fail–correction errors are included in the error event count.
2	Flash ROM Check	Indicates that the firmware image in flash may have a checksum error. 0 = no errors 1 = at least one image failed the checksum test
5	Retired Block Count	The total number of retired blocks. This attribute is non-volatile.
9	Power-On-Hours (POH)	The total number of hours the drive has been powered on. This attribute is non-volatile.
12	Device Power Cycle Count	The number of full power cycles. This attribute is non-volatile.
13	Soft Read Error Rate	The number of corrected read errors reported. This attribute is non-volatile.
177	Percent of Drive Life Remaining	The percentage of drive life remaining. This attribute is non-volatile.
180	Percent of Unused Spare Blocks Remaining	The number of available spare blocks.
181	Program Fail Count	The number of flash program failures that occurred since the drive was first initialized. This attribute is non-volatile.
182	Erase Fail Count	The number of flash erase failures that occurred since the drive was first initialized. This attribute is non-volatile.
190	Critical Temperature	Internal SSD temperature. If the current temperature exceeds the threshold value, the drive throttles the performance.
194	Temperature	Internal SSD temperature.
195	ECC On-the-Fly Count	The total number of uncorrectable errors. This attribute is non-volatile.
198	Uncorrectable Sector Count	The total number of errors the data fail correction algorithm could not correct when reading/writing a sector. A rise in this value indicates defects in the flash memory. This attribute is non-volatile.
233	Number of Write Counts	The total number of writes performed. This attribute is non-volatile.
245	Percentage of Drive Life Used	The total estimated drive life used as a percentage. This attribute is non-volatile.

6.0   SCSI SENSE CODE KEY

SanDisk Optimus SAS drives use sense data to indicate the type of error that occurred if the drive fails to execute a command. If the drive returns a Check Condition, issue the `Request Sense` command to view the sense data. The drive will respond with bytes of information containing the sense key, additional sense key code (ASC), and additional sense code qualifier (ASCQ).

6.1   Sense Data

See the following table for a list of the supported sense data.

Table 17: Sense Data

Sense Key	ASC	ASCQ	FRU	Condition Description
NO SENSE (00h)				
00	00	00	00	GOOD response
00	00	EB	00	RETRANSMIT response
00	00	EE	00	RETRANSMIT GOOD response
RECOVERED ERROR (01h)				
01	0B	00	00	Failure prediction warning
01	0B	01	BE	Failure prediction threshold exceeded drive temperature warning
01	0C	01	00	Write error recovered with auto reallocation
01	11	14	00	Marked recovered by application client
01	15	01	00	Mechanical positioning error recovered
01	17	00	00	Recovered data with no error correction applied
01	17	01	00	Recovered data with retries
01	1C	00	00	Recovered error defect list not found
01	5D	00	00	Failure prediction threshold exceeded
01	5D	00	01	Failure prediction threshold exceeded Raw Read Error Rate
01	5D	00	02	Failure prediction threshold exceeded Flash ROM Check
01	5D	00	05	Failure prediction threshold exceeded Reallocated Block Count
01	5D	00	09	Failure prediction threshold exceeded Power On Hours Count
01	5D	00	0C	Failure prediction threshold exceeded Power Cycle Count
01	5D	00	0D	Failure prediction threshold exceeded ECC Rate
01	5D	00	20	Failure prediction threshold exceeded Write Amplification
01	5D	00	AA	Failure prediction threshold exceeded Percent Unused Reserved Block
01	5D	00	B1	Failure prediction threshold exceeded Percent Drive Life Remaining
01	5D	00	B3	Failure prediction threshold exceeded Percent Used Reserve Block Count
01	5D	00	B4	Failure prediction threshold exceeded Percent Unused Reserve Block Count
01	5D	00	B5	Failure prediction threshold exceeded Program Fail Count
01	5D	00	B6	Failure prediction threshold exceeded Erase Fail Count
01	5D	00	C2	Failure prediction threshold exceeded Drive Temperature
01	5D	00	C3	Failure prediction threshold exceeded Uncorrectable Error Count
01	5D	00	C6	Failure prediction threshold exceeded Offline Scan Uncorrectable Sector Count
01	5D	00	C7	Failure prediction threshold exceeded CRC Error Count
01	5D	00	C9	Failure prediction threshold exceeded Volatile Memory Backup Source Failure
01	5D	00	CA	Failure prediction threshold exceeded Exception Mode Status
01	5D	00	E9	Failure prediction threshold exceeded Number of Write Count
01	5D	00	F0	Failure prediction threshold exceeded Link Error Event

Table 17: Sense Data (Continued)

Sense Key	ASC	ASCQ	FRU	Condition Description
01	5D	00	F5	Failure prediction threshold exceeded Percent Drive Life Used
NOT READY (02h)				
02	04	00	00	LUN not ready; cause not reportable
02	04	01	00	LUN not ready; becoming ready
02	04	02	00	LUN not ready; initialization command required
02	04	04	00	LUN not ready; format in progress
02	04	09	00	LUN not ready; self-test in progress
02	04	11	00	LUN not ready; notify required
02	04	1B	00	LUN not ready; sanitize in progress
02	04	DB	00	LUN not ready; diagnostics running
MEDIUM ERROR (03h)				
03	0C	00	00	Write error
03	0C	14	00	Write error; RMW marked BAD by application client
03	11	00	00	Unrecovered read error
03	11	14	00	Marked BAD by application client
03	31	00	00	Format corrupt
03	32	00	00	No defect spare location available
03	32	01	00	Defect list update failure
HARDWARE ERROR (04h)				
04	3E	03	00	Logical unit failed self-test
04	3E	04	00	Logical unit unable to update self-test result log
04	42	00	00	Power on or self-test failure
04	44	00	00	Internal target failure
04	BA	DA	00	Degraded media state L2P table CZ1
ILLEGAL REQUEST (05h)				
05	0E	01	00	Information unit too short
05	0E	02	00	Information unit too long
05	1A	00	00	Parameter list length error
05	20	00	00	Invalid command operation code
05	21	00	00	LBA out of range
05	24	00	00	Invalid field in CDB
05	25	00	00	Logical unit not supported
05	26	00	00	Invalid field parameter length
05	26	01	00	Parameter not supported
05	26	02	00	Parameter value invalid
05	26	04	00	Invalid release of persistent reservation
05	26	80	00	Parameters full
05	2C	09	00	Previous reservation conflict status
05	49	00	00	Invalid message error
05	55	02	00	Insufficient reservation resources
05	55	04	00	Insufficient registration resources
05	74	00	00	Security error
05	74	01	00	Unable to decrypt data
05	74	02	00	Unencrypted data encountered while decrypting

Table 17: Sense Data (Continued)

Sense Key	ASC	ASCQ	FRU	Condition Description
05	74	03	00	Incorrect data encryption key
05	74	04	00	Cryptographic integrity validation failed
05	74	05	00	Error decrypting data
05	74	06	00	Unknown signature verification key
05	74	07	00	Encryption parameters not usable
05	74	08	00	Digital signature validation failure
05	74	09	00	Encryption mode mismatch on read
05	74	0A	00	Encrypted block not raw read enabled
05	74	0B	00	Incorrect encryption parameters
05	74	0C	00	Unable to decrypt parameter list
05	74	0D	00	Encryption algorithm disabled
05	74	10	00	SA creation parameter value invalid
05	74	11	00	SA creation parameter value rejected
05	74	12	00	Invalid SA usage
05	74	21	00	Data encryption configuration prevented
05	74	30	00	SA creation parameter not supported
05	74	40	00	Authentication failed
05	74	61	00	External data encryption key manager access error
05	74	62	00	External data encryption key manager error
05	74	63	00	External data encryption key not found
05	74	64	00	External data encryption request not authorized
05	74	6E	00	External data encryption control timeout
05	74	6F	00	External data encryption control error
05	74	71	00	Logical unit access not authorized
05	74	79	00	Security conflict in translated device
UNIT ATTENTION (06h)				
06	00	00	00	Unit attention pending
06	29	00	00	Power on reset or bus device reset occurred
06	29	01	00	Power on reset occurred
06	29	02	00	Hard reset occurred
06	29	03	00	LUN reset occurred
06	29	07	00	IT_Nexus loss
06	2A	00	00	Parameters changed
06	2A	01	00	Mode parameters changed
06	2A	02	00	Log parameters changed
06	2A	03	00	Reservations pre-empted
06	2A	04	00	Reservations released
06	2A	05	00	Registrations pre-empted
06	2F	00	00	Commands cleared by another initiator
06	2F	01	00	Commands cleared by power loss notification
06	3F	00	00	Target operation conditions have changed
06	3F	01	00	Microcode has been changed
06	3F	03	00	Inquiry data has changed
06	4B	04	00	NAK received UA

Table 17: Sense Data (Continued)

Sense Key	ASC	ASCQ	FRU	Condition Description
DATA PROTECT (07h)				
07	27	00	00	Write protected
ABORTED (0Bh)				
0B	00	00	00	Aborted command
0B	10	01	00	Logical block guard check failed
0B	10	02	00	Logical block application tag check failed
0B	10	03	00	Logical block reference tag check failed
0B	3F	01	00	Aborted download in progress
0B	44	00	00	Command time limit exceeded
0B	45	00	00	Select/Reselect failure
0B	47	00	00	SCSI parity error
0B	47	01	00	Data phase CRC error detected
0B	47	80	00	Double guard page allocation detected
0B	47	81	00	Data MPECC error detected
0B	47	82	00	Data BCRC error detected
0B	47	83	00	Data HLBA error detected
0B	47	84	00	Unexpected internal check
0B	4B	02	00	Too much write data
0B	4B	04	00	NAK received
0B	4B	05	00	Data offset error
0B	4B	06	00	Initiator response timeout
0B	4B	07	00	Connection lost
0B	4E	00	00	Overlapped commands attempted
0B	55	03	00	Aborted insufficient resources
MISCOMPARE (0Eh)				
0E	1D	00	00	Miscompare during verify operation
0E	1D	01	00	Miscompare verify of unmapped LBA

6.2   Security Erase Support

Optimus.2 product family 2.5" SAS drives support a normal secure erase function through the `Format Unit` command. To erase the drive, set the Initialization Pattern Type field in the Initialization Pattern Description to 81h, and set the Security Initialize bit to 1. For more information about the `Format Unit` command, see the SCSI Block Commands-3 (SBC-3) specification.

6.3   Log Pages

Optimus.2 product family 2.5" SAS SSDs support the log pages listed in the following table. To retrieve these pages, use the `Log Sense SCSI` command with the appropriate code.

Table 18: Supported Log Pages

Log Page	Page Code (Hex)	Description
Supported Pages	00	Lists the supported log pages.
Write Error Counter	02	Returns the total number of uncorrectable write errors.
Read Error Counter	03	Returns the total number of uncorrectable read errors.
Verify Error Counter	05	Returns the total number of uncorrectable verify errors.
Non-medium Error Counter	06	Indicates the number of non-medium errors that occurred.
Time	07	Provides the lifetime power in hours/seconds and the number of power cycles.

Table 18: Supported Log Pages (Continued)

Log Page	Page Code (Hex)	Description
Temperature	0D	Specifies the highest temperature logged from the on-board sensor.
Start/Stop Cycle Counter	0E	Indicates the number of start/stop cycles that occurred.
Application Client	0F	Provides a location for application clients to store information.
Self-test Results	10	Returns the results of the drive self-tests.
Solid State Media	11	Indicates parameters that are specific to SCSI target devices that contain solid state media.
Background Scan Results	15	Returns the results of a background scan, which includes power-on minutes, number of scans performed, etc.
Non-volatile Cache	17	Reports that non-volatile cache is present and for how long the data remains non-volatile.
Protocol-specific Port	18	Returns PHY-specific data for each of the two SAS ports.
General Statistics and Performance	19	Provides performance and general statistical data, such as the number of read commands received, number of blocks transmitted, etc.
Critical Failure	28	Returns a log of critical events, including the time the event occurred and the type of event.
Informational Exceptions	2F	Returns information on specific exceptions related to predictive failure conditions (SMART).
Erase Counts	31	Returns the highest number of erase cycles on a single flash channel.
Erase Errors	33	Returns the total number of uncorrectable errors and defects (both manufacturer-detected and grown).
SMART Data	34	Returns the supported attributes and their respective minimum, maximum, current, and threshold values.
SAS Error Statistics	36	Returns the total number of low-level SAS port errors.
SSD Event	3C	Provides a log of critical and informational events to identify and diagnose problems encountered by the drive.

7.0   Warranty and Part Numbers

7.1   Warranty

The Optimus.2 product family SSD is designed for high performance computing environments and does not implement features to limit the performance. The Optimus.2 product family SSD is warranted for five years for defects in material and workmanship and for its rated endurance specified in DWPD. The drive makes no attempt to limit application performance to meet the DWPD constraint. Configurable SMART warnings are provided to help the application designer manage drive wear-out, including the Percentage of Drive Life Used, Lifetime Remaining, and Write Amplification SMART attributes.

7.2   Part Numbering Information

Table 19: Part Numbering Information

Optimus.2 Product	SanDisk Part Number	Drive Capacity	Form Factor	LBA Count
Optimus.2 Ascend	SDLKOEDM-200G-5CA1	200 GBytes	9.5 mm	390,721,968
	SDLKODDM-400G-5CA1	400 GBytes		781,422,768
	SDLKOCDM-800G-5CA1	800 GBytes		1,562,824,368
	SDLLOCDM-016T-5CA1	1600 GBytes	15 mm	3,125,627,568
Optimus.2 Ultra	SDLKOEGW-150G-5CA1	150 GBytes	9.5 mm	293,046,768
	SDLKODGW-300G-5CA1	300 GBytes		586,072,368
	SDLKOCGW-600G-5CA1	600 GBytes		1,172,123,568
	SDLLOCGW-012T-5CA1	1200 GBytes		2,344,225,968
Optimus.2 Extreme	SDLKOE9W-100G-5CA1	100 GBytes		195,371,568
	SDLKOD9W-200G-5CA1	200 GBytes		390,721,968
	SDLKOC9W-400G-5CA1	400 GBytes		781,422,768
	SDLLOC9W-800G-5CA1	800 GBytes		1,562,824,368