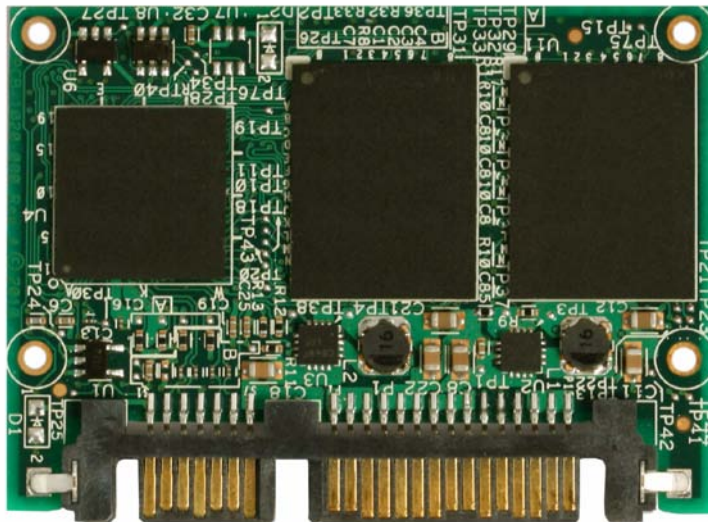


SATA 6Gb/s Industrial Slim SATA Manual



Slim SATA is a non-volatile, solid-state storage device. With its Serial ATA interface and Slim SATA (MO-297) form factor, it is a drop in replacement for hard disk drives. Slim SATA delivers extremely high levels of performance, reliability and ruggedness for I/O intensive or environmentally challenging applications.

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Revision History

| Date | Revision | Description |
|----------|----------|--|
| 1/14/13 | A | Initial release of product datasheet where first generation products were removed. |
| 6/14/13 | B1 | Update SMART attribute to Worst=1 |
| 9/14/13 | B2 | Revised PN table |
| 10/30/13 | B3 | Added notes on Operating Temperature (TOPER). |
| 1/2/14 | B4 | Update datasheet format |
| 6/12/14 | B4 | Rename file from PSFEM1XXXGXXXX to PSFEM1XXXGPXXX |
| | | |
| | | |

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Legal Information

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Ordering Information: Slim SATA SSD Solid-State Drive

| Part Number | SATA Interface | Application | Raw Capacity (GB) | Useable Capacity (GB) ¹ | Minimum Total User Addressable Sectors in LBA Mode | NAND Technology | Temperature Range |
|------------------|----------------|-------------|-------------------|------------------------------------|--|-----------------|-------------------|
| VRFEM1008GPCxMyz | 6Gbps | Industrial | 16 | 8 | 15,649,200 | MLC | 0 to 70°C |
| VRFEM1012GPCxMyz | 6Gbps | Industrial | 16 | 12 | 31,277,232 | MLC | 0 to 70°C |
| VRFEM1025GPCxMyz | 6Gbps | Industrial | 32 | 25 | 48,858,768 | MLC | 0 to 70°C |
| VRFEM1032GPCxMyz | 6Gbps | Industrial | 48 | 32 | 62,533,296 | MLC | 0 to 70°C |
| VRFEM1055GPCxMyz | 6Gbps | Industrial | 64 | 55 | 107,463,888 | MLC | 0 to 70°C |
| VRFEM1080GPCxMyz | 6Gbps | Industrial | 128 | 80 | 156,301,488 | MLC | 0 to 70°C |
| VRFEM1120GPCxMyz | 6Gbps | Industrial | 128 | 120 | 234,441,648 | MLC | 0 to 70°C |

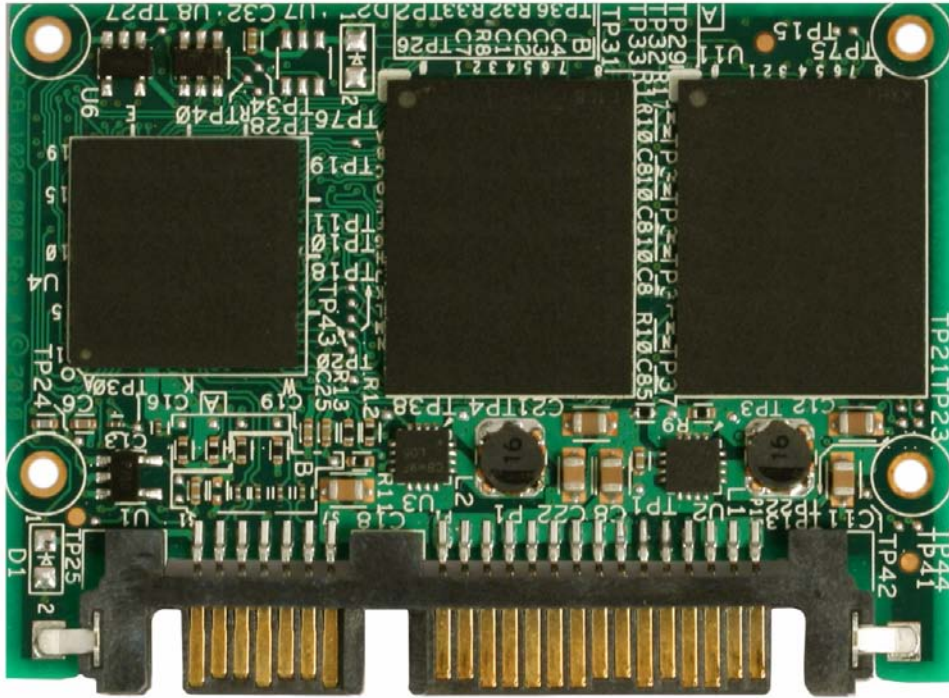
Notes:

- 1) Usable capacity based on a level of over-provisioning applied to wear leveling, bad sectors, index tables etc.
- 2) Higher capacity points may be available based on customer application. Consult your local Viking FAE.
- 3) SSD's ship unformatted from the factory unless otherwise requested.
- 4) x = Lowercase character(s) for device density. Contact Viking for the character that "x" represents in the part number.
- 5) y and z = Lowercase character(s) for NAND vendor and die revisions and/or for customer specific locked BOM's
- 6) 1 GB = 1,000,000,000 Byte and not all of the memory can be used for data storage. Usable capacity based on over-provisioning applied to wear leveling, bad sectors, index tables etc.
- 7) 1 Sector = 512 Byte.

Industrial SSD – Viking’s Industrial SSD contains sophisticated provisions to protect firmware and data from corruption due to unexpected power loss. However, a Industrial SSD by industry definition does not contain on-board capacitance. Should power fail unexpectedly, “in-flight” write data may be lost. Industrial SSD’s are best used in designs that manage power fail events at the system level.

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Product Picture(s)



Slim SATA Top View

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1 Introduction

Viking’s rugged designed SSD’s offer the highest flash storage reliability and performance in harsh environments such as shock, vibration, humidity, altitude, ESD, and extreme temperatures. Viking SSD’s meet JEDEC JESD22 standards and pass numerous qualifications including MIL-STDs and NEBS.

Viking can also provide specialized services to OEMs designing customized hardware and systems by offering:

- Locked BOM control with customer product change notification (PCN)
- Pre-installed software, custom software imaging and ID strings
- Custom packaging and labeling
- Comprehensive supply-chain management
- Customer specified testing
- 30K volt ESD protection
- Conformal coating
- Localized Field Application Engineering for complete pre and post sale technical support

1.1 Features

Table 1-1: Slim SATA SSD Features

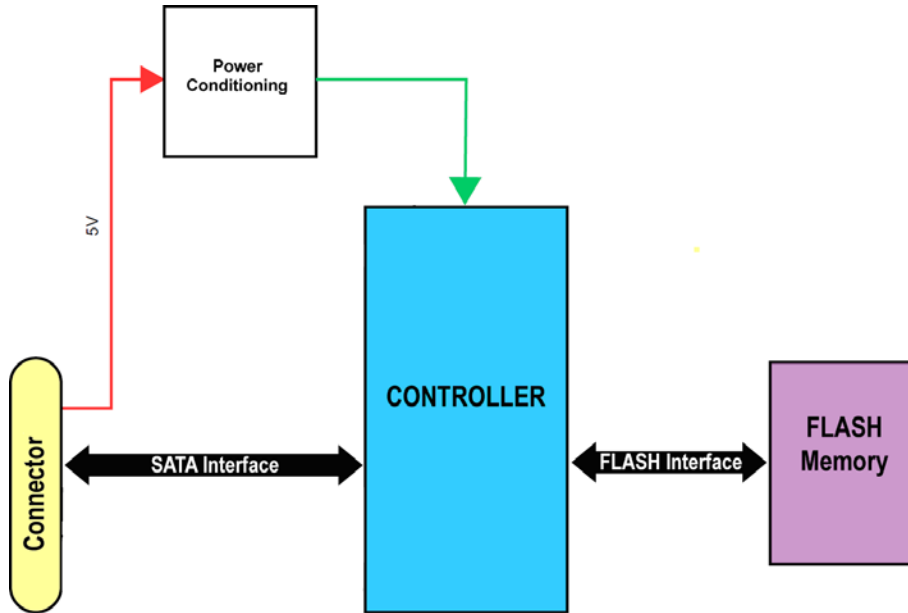
The Slim SATA SSD delivers the following features:

| Feature | VRFEM1xxxGP |
|---|-------------|
| Best in class sequential and random Read/Write performance | • |
| Seamless SATA Revision 2.x interface support for SATA up to 3Gbps) | • |
| Seamless SATA Revision 3.x interface support for SATA up to 6Gbps) | • |
| Power hold-up circuit technology ensures no data loss resulting from an unexpected power loss and is supported for industrial temperatures (requires host provisions) | |
| PFAIL/DHARD signaling with the host | |
| Support for ONFi and Toggle Mode NAND | • |
| Patented architecture for SSD longevity, reliability and data integrity | • |
| Supports Native Command Queuing (NCQ) to 32 commands | • |
| Native support for 512 and non-512 host LBA sizes | • |
| Automatic Trim Command support | • |
| Compatible with all major SLC and MLC NAND flash technologies | • |
| Protection against catastrophic flash page and block failures | • |

| Feature | VRFEM1xxxGP |
|---|-------------|
| AES-128 encryption in CTR mode | • |
| S.M.A.R.T. command transport (SCT) technology | • |
| Superior wear-leveling algorithm | • |
| Intelligent flash memory block management and read disturb management | • |
| Efficient error recovery | • |
| Power-throttling support | • |
| Thermal sensing energy management | • |
| RoHS and WEEE compliant | • |

1.2 Block Diagram

Figure 1-1: High-Level Block Diagram for VRFEM1xxP



1.3 SATA Interface for VRFEM1xxxGP

- The Serial ATA (SATA) interface is compliant with the SATA IO Serial ATA specification, revision 3.x that supports SATA up to 6Gbps.
- The SATA interface connects the host computer to the SSD subsystem.
- The SATA interface runs at a maximum speed of 6.0Gbps (Gigabits per second). If the host computer is unable to negotiate a speed of 6.0Gbps, the SATA interface automatically renegotiates to a speed of 3.0 or 1.5 Gbps.

For a list of supported commands and other specifics, please see Chapter 5.

1.4 Indicator LEDs

There is an optional LED indicator on the Slim SATA module that will flash to indicate an SATA activity condition. There is also a remote LED indicator at Pin 11 of the Power Segment Connector, called “Device Activity Signal”. For a remote LED application, an LED should be tied high through a current limiting resistor on the host side. The Slim SATA will sink current on the module to allow the LED to flash to indicate an ACTIVITY. If a remote LED is not implemented, pin 11 may be connected to GND to allow the ACTIVITY LED to remain on and indicate a Power On condition when using a standard ATX type power supply.

2 Product Specifications

2.1 Performance

Maximum SSD performance can be achieved for certain workloads by:

- Initiating read and write transfers for random accesses with small block sizes of 4K bytes to optimize IOPs performance for applications such as databases, OLTP etc.
- Initiating read and write transfers for sequential accesses with large blocks (128K or larger) to optimize performance toward throughput (MBps) for applications such as video streaming, data acquisition etc.
- Issuing transfers at starting LBA’s which align the access on 4K boundaries:
 - Minimizes or eliminates internal Read-Modify-Write operations
 - Align on 4K boundaries is optimal for SSD capacities up to 256 GB
 - For SSD capacities greater than 256 GB, aligning on 8K boundaries is optimal
- Avoid mixing NCQ and non-NCQ commands

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Table 2-1: Maximum Sustained Read and Write: MB/sec and IOPS

| Access Type | VRFEM1xxxGP | Units |
|-----------------------------------|--------------|-------|
| Sequential Read, 128K block size | Up to 500 | MB/s |
| Sequential Write, 128K block size | Up to 500 | MB/s |
| Random Read, 4K block size | Up to 60,000 | IOPS |
| Random Write, 4K block size | Up to 20,000 | IOPS |

Notes:

1. Performance measured using IOmeter 08 with queue depth set to 32.
2. Write Cache enabled.
3. Random IOPS cover the entire range of legal logical block addresses (LBA's). Measurements are performed on a full drive (all LBA's have valid content).
4. Performance may vary by NAND type and host.
5. Refer to Application Note AN0006 for Viking SSD Benchmarking Methodology.

2.2 Timing

Table 2-2: Timing Specifications

| Type | Average Latency or Timing |
|---|---------------------------|
| Power-On-to-Ready (POR) | 115 ms |
| Reset to Ready | 115 ms |
| Sleep to Ready | <1000 μ s |
| Command to DRQ | <1000 μ s |
| Time to Erase (ATA Secure Erase) | 4 seconds |
| Time to Erase (ATA Secure Erase with flash erase) | ~ 1 GB/second |

Notes:

1. Based on MLC
2. Device measured using Drivemaster.
3. Sector Read/Write latency measured up to 2048 block transfers (512B/sector = 1 Block)
4. Queue depth set to 32 for NCQ
5. Sequential IOPS cover the entire range of legal logical block addresses (LBA's). Measurements are performed on a full drive (all LBA's have valid content)

2.2.1 STANDBY IMMEDIATE Command

The Power On to Ready time assumes a proper shutdown (power removal preceded by STANDBY IMMEDIATE command. A STANDBY IMMEDIATE before power down always performs a graceful shutdown and does not require the use of the hold-up circuit. Note that SMART attribute 174 "Unexpected Power Loss" records the number of non-graceful power cycle events.

Table 2-3: STANDBY IMMEDIATE Timings

| Power Cycle Endurance | Min | Max | Unit |
|-----------------------------------|-----|-----|------|
| STANDBY IMMEDIATE to WE completed | 15 | 25 | ms |

2.3 Electrical Characteristics

2.3.1 Absolute Maximum Ratings

Values shown are stress ratings only. Functional operation outside normal operating values is not implied. Extended exposure to absolute maximum ratings may affect reliability.

Table 2-4: Absolute Maximum Ratings

| Description | Min | Max | Unit |
|-------------------------------|------|-----|------|
| Maximum Voltage Range for Vin | -0.2 | 6 | V |
| Maximum Temperature Range | -40 | 85 | c |

2.3.2 Supply Voltage

The operating voltage is 5.0V.

Table 2-5: Operating Voltage

| Description | Min | Max | Unit |
|---------------------------------------|-----|-----|------|
| Operating Voltage for 5.0 V (+/- 10%) | 4.5 | 5.5 | V |

2.3.3 Supply Current

Table 2-6: Current Draw

| Mode | VRFEM1xxxGPxx ¹ | Unit |
|-------------|----------------------------|------|
| Read/Writes | 400 | mA |
| Peak | 600 | mA |
| Idle | <80 | mA |

Notes:

1. Typical power workload: 16K block size, 50% read, 50% sequential write. Maximum power workload: 256K block size, 0% read, 100% sequential write.
2. Table values based on 100GB drive.

2.3.4 Power Consumption

All onboard power requirements of the Slim SATA are derived from the SATA 5.0V input rail.

Table 2-7: Typical Power Consumption

| Mode | VRFEM1xxxGPxx ¹ | Unit |
|-------------|----------------------------|------|
| Read/Writes | 2.0 | W |
| Idle | <0.4 | W |

Notes:

1. Typical power workload: 16K block size, 50% read, 50% sequential write. Maximum power workload: 256K block size, 0% read, 100% sequential write.
2. Typical power consumption is that of a device with 64GB of physical capacity.

2.4 Environmental Conditions

2.4.1 Temperature and Altitude

Table 2-8: Temperature and Altitude Related Specifications

| Conditions | Operating | Shipping | Storage |
|--|---|---|---|
| Commercial Temperature ^{2,3} | 0 to 70°C (32 to 158° F) | -40 to 85°C (-40 to 185° F) | -40 to 85°C (-40 to 185° F) |
| Humidity (non-condensing) | 10% to 80% | 5% to 95% | 5% to 95% |
| Max Temperature Gradient | 20°C/Hour (36°F/Hour) | n/a | n/a |
| Altitude ² | -304.8 to 24,384 m (-1,000 to 80,000 ft) | -304.8 to 24,384 m (-1,000 to 80,000 ft) | -304.8 to 24,384 m (-1,000 to 80,000 ft) |
| Storage Time Duration | n/a | n/a | 1 year |

Notes:

1. Flash based products are available in the following temperature ranges:
 - a) Commercial temperature range of 0 to 70°C (32 to 158° F)
 - b) Storage temperature range of -40 to 85°C is limited by LED and ferrite bead
2. Operating Temperature (TOPER) is the case surface temperature on the center/top side of the NAND.
3. Operating Temperature Range specifies the temperatures where all NAND specifications will be supported. During operation, the NAND case temperature must be maintained between the range specified in the table under all operating conditions.

2.4.2 Shock and Vibration

Slim SATA products are tested in accordance with environmental specification MIL-STD-810F.

Table 2-9: Shock and Vibration Specifications

| | Description |
|-----------|--|
| Shock | 50g, 11ms, 3 shocks applied in each direction on 3 mutually perpendicular axes X, Y, Z |
| Vibration | 16.4g rms 10-2,000 Hz, 3 axes |

2.4.3 Electromagnetic Immunity

Slim SATA is an embedded product for host systems and is designed not to impair with system functionality or hinder system EMI/FCC compliance.

2.5 Reliability

Table 2-10: Reliability Specifications

| Parameter | Value |
|--|--|
| Nonrecoverable read errors (BER) ¹ | <1 sector in 10 ¹⁷ bits read, max |
| Mean Time Between Failures (MTBF) ² | 3,000,000 hours |
| Power On/Off Cycles ³ | 50,000 cycles |
| Read Endurance | Unlimited |
| Write or Erase Endurance ⁴ | (specified by the flash component) |
| Global wear-leveling | ~ 2% between least worn and most worn |
| Data retention | >10 years when new, 90 days at drive EOL |

Notes:

1. BER will not exceed one sector in the specified number of bits read. In the extremely unlikely event of a non-recoverable read error, the drive will report it as a read failure to the host; the sector in error is considered corrupt and is not returned to the host.
2. MTBF is calculated based on a Part Stress Analysis. It assumes nominal voltage, with all other parameters within specified range. Telcordia method SR-332, component FIT rate at 55°C.
3. Power On/Off Cycles defined as power being removed from the drive, and then restored. Note that host systems and drive enclosures may remove power from the drive for reasons other than a system shutdown.
4. SLC NAND has a higher endurance than MLC NAND

2.5.1 Data, MetaData, and Firmware Code Protection

Slim SATA implements data protection throughout its data path. Protection techniques include:

- Data ECC Algorithms
- Datapath CRC Error Detection
- RAISE™ Data Protection Against Catastrophic Flash Page/Block Failure

2.5.1.1 DATA ECC Algorithms

The following data error correction is provided:

- Up to 55 bytes of redundancy applied to 512 bytes of data

2.5.1.2 Data Path CRC Error Detection

CRC error detection is applied against data along internal data paths. CRC detection uses a 32-bit checksum (CRC32) to protect data along all internal data paths.

2.5.1.3 RAISE™ Data Protection Against Catastrophic Flash Page/Block Failure

R.A.I.S.E.™ (Redundant Array of Independent Silicon Elements) provides data protection to overcome the probabilistic risk of page or block failure inherent in all Flash memory technology. In a tiered approach to detecting and correcting NAND errors, RAISE™ takes over where ECC leaves off.

Flash technology can exhibit a finite probability that a block or page will fail within the rated Program-Erase (P-E) cycle count lifetime of the Flash device. While this probability may appear tolerable for a given application, note that it is for a particular Flash die. For an SSD incorporating up to 128 Flash die, the additive probability of this phenomenon can reveal measurable risk to the SSD over its multi-year lifetime.

RAISE™ technology addresses this risk. In the event of a catastrophic failure of an entire Flash page or Flash block, RAISE™ off-line protection rebuilds the data in the failed page or block and relocates it elsewhere in the Flash array. Performance during recovery is minimally impacted, but after recovery is complete, Slim SATA returns to full performance and full functionality. The performance impact period is only the amount of time required to rebuild and relocate the page or block data, and to map out the problematic Flash block.

In contrast to other SSD Flash controllers, Slim SATA with RAISE™ technology uniquely, reliably and seamlessly overcomes these catastrophic data loss risks with only temporary impact to throughput and latency and no impact to power consumption. In a RAID drive array application, Slim SATA can auto-rebuild data locally, without passing the problem upstream to the system level and without incurring the associated significant system rebuild hit. The difference in impact between a standard approach and Slim SATA with RAISE™ approach is significant. Additionally, following recovery from a page failure or block failure, Slim SATA is fully functional and fully reliable, whereas a page-failed or block-failed drive recovered by system RAID must be immediately replaced.

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2.5.1.4 Firmware Code Protection

Firmware requires special attention to ensure the code is execution-worthy. For this reason, firmware is stored in multiple redundant images in the Flash array. Image checksums are compared between all stored copies to ensure identical code. Any image not corroborated by at least one other image is discarded. In this way a reliable firmware image is always chosen on boot-up for execution.

If a firmware image is discarded, a new redundant image is created from the good images to ensure original levels of protection.

Firmware images are also protected in Flash memory and during fetch by the maximum ECC correction power, and by RAISE™ correction technology.

2.5.2 Intelligent Read Disturb Management

Flash memory is primarily at risk from writes and erasures. However, reads also affect data longevity. Excessive reads of Flash memory cells induce inter-cell voltage shift, although the effect not as accelerated as write-induced cell damage. The degradation occurs in data stored in nearby cells, rather than in the cell being read. Read-induced data degradation is called “Read Disturb.”

The controller provides read operation management to overcome Flash Memory “Read Disturb” concerns by ensuring that data integrity is not impacted by multiple reads of the same Flash Memory address. It tracks reads and automatically and seamlessly recovers and refreshes data in proximity before that data is negatively impacted. Its superior throughput and latency performance, delivered over the life of the drive, is not diminished by this process and the expected data retention capability is assured throughout the warranted life of the SSD.

2.5.3 Intelligent Write Operation Management

The controller makes data location/relocation decisions which greatly increase the life of the SSD.

2.5.3.1 Sophisticated Wear-Leveling

Wear leveling refers to the practice of equalizing the impact of write and erase operations over the larger pool of Flash memory blocks. Industry-standard wear leveling techniques focus on conventional schemes that attempt to equalize writes and erases across blocks. While on the surface this appears to be a reasonable approach, it is clear that it assumes all blocks will “wear” equally when written or erased. This is far from the truth. The NAND processor takes much more into account. It measures a variety of parameters to determine the actual wear of blocks during P-E cycles, to determine which blocks are impacted

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more by erasures and writes over time. That is, it determines actual cell wear, not simply assumed wear normalized to write/erase events. The controller employs this information in its superior wear-leveling algorithm along with its ongoing record of writes and erasures, to ensure each block is impacted by P-E cycles no more than the average. The result is an SSD that is far more reliable across its full capacity and over a far greater length of time. The controller uses both static and dynamic wear-leveling algorithms to globally manage cell degradation to approximately 2% between least worn and most worn cells or to the value specified in the S.M.A.R.T Wear Range Delta command (ID=177, Opcode=0xB1)

2.5.3.2 Write Operation Reduction

The controller uses intelligent algorithms to minimize P-E cycles through aggregation, virtualization, and difference processing. It is uniquely effective in reducing the wear and maintaining the reliability of the overall pool of Flash memory blocks by intelligently minimizing re-writes of identical data, to maximize the effectiveness of the wear-leveling process.

2.6 Data Security

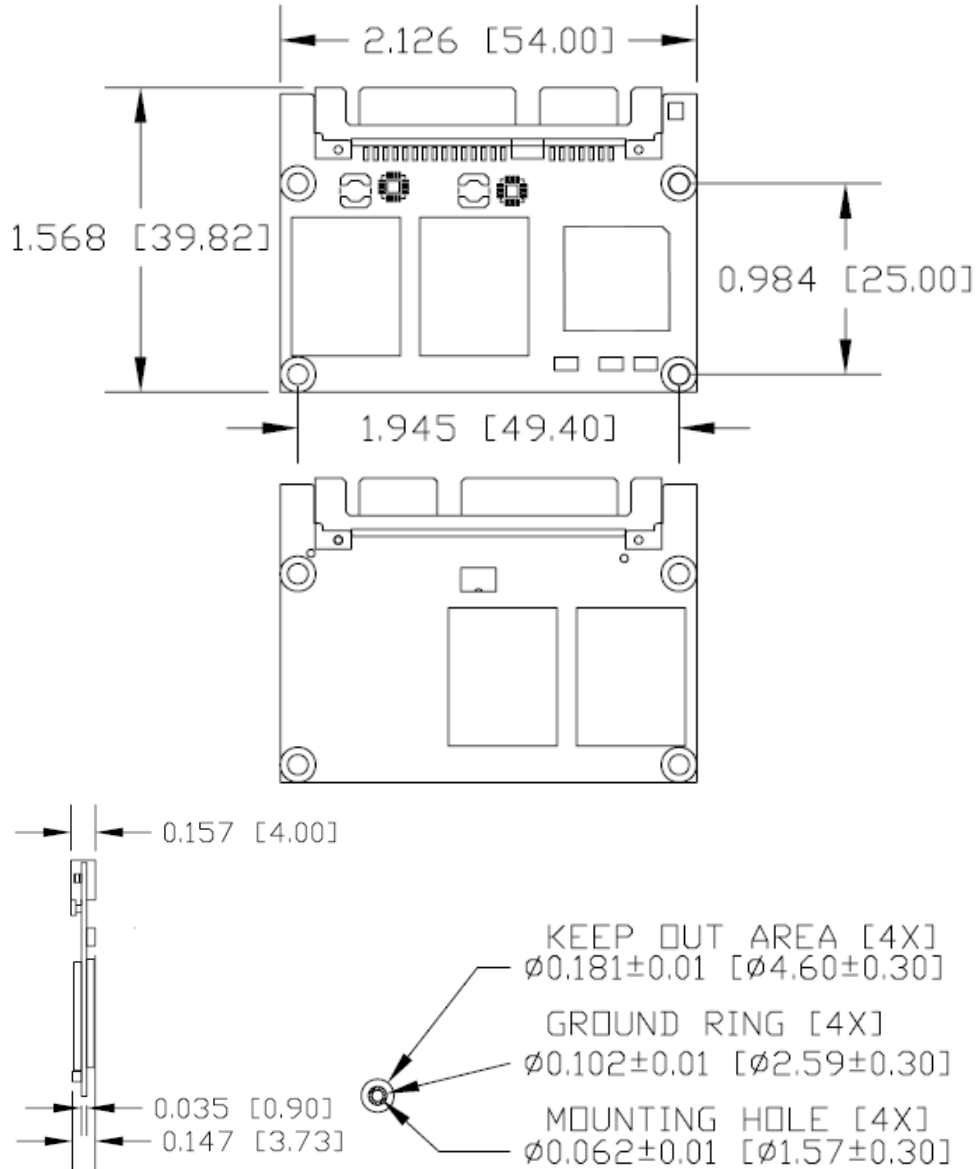
Element SSD supports AES-128 encryption and ATA Secure Erase features to protect sensitive data.

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3 Mechanical Information

| Capacity (GB) | Height (mm) | Width (mm) | Length (mm) |
|---------------|-------------|------------|-------------|
| 8 to 120 | 4.00 max | 54 max | 39.82 max |

Figure 3-1: Dimensions



Notes:

- All dimensions are in inches [millimeters].

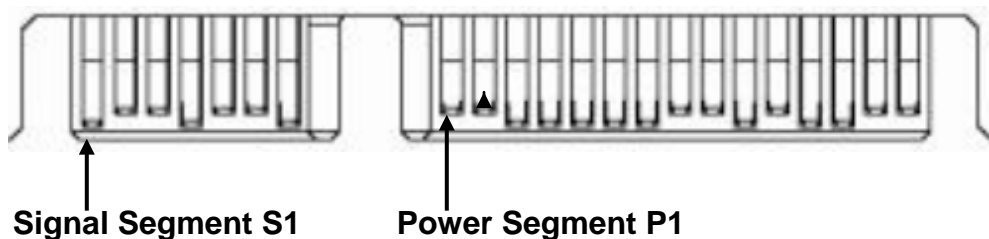
3.1 Slim SATA SSD Weight

The weight of a Slim SATA (MO-297) is approximately 8.0 grams.

4 Pin and Signal Descriptions

4.1 Pin Locations

Figure 4-1: Layout of Signal and Power Segment Pins



4.2 Signal and Power Description Tables

Table 4-1: Serial ATA Connector Pin Signal Definitions

| Pin | Function | Definition | Mating Order |
|-----|-------------------------|---------------------|--------------|
| S1 | SGND_1 | Signal Ground | 1st |
| S2 | RX+ on SSD, TX+ on Host | Differential Signal | 2nd |
| S3 | RX- on SSD, TX- on Host | Differential Signal | 2nd |
| S4 | SGND_2 | Signal Ground | 1st |
| S5 | TX- on SSD, RX- on Host | Differential Signal | 2nd |
| S6 | TX+ on SSD, RX+ on Host | Differential Signal | 2nd |
| S7 | SGND_3 | Signal Ground | 1st |

Notes:

Key and spacing separate signal and power segments. Pin locations and layout are consistent with SATA specification.

Table 4-2: Serial ATA Power Pin Definitions

| Pin | Function | Definition | Mating Order |
|-----|----------|------------------------------------|--------------|
| P1 | 3.3V_1 | No connection | 2nd |
| P2 | 3.3V_2 | No connection | 2nd |
| P3 | 3.3V_3 | No connection | 1st |
| P4 | GND_1 | Ground | 1st |
| P5 | GND_2 | Ground | 1st |
| P6 | GND_3 | Ground | 1st |
| P7 | 5V_1 | 5VDC Power (pre-charge) | 1st |
| P8 | 5V_2 | 5VDC Power | 2nd |
| P9 | 5V_3 | 5VDC Power | 2nd |
| P10 | GND_4 | Ground | 1st |
| P11 | Activity | Device Activity Signal (See note1) | 2nd |
| P12 | GND_5 | Ground | 1st |
| P13 | 12V_1 | No connection | 1st |
| P14 | 12V_2 | No connection | 2nd |
| P15 | 12V_3 | No connection | 2nd |

Notes:

For Remote LED application, an LED should be tied high thru a current limiting resistor on the host side. If a Remote LED is not implemented, pin 11 may be connected to GND to allow the ACTIVITY LED to remain on to indicate a Power On condition when using a standard ATX type power supply.

4.3 Hot Plug Support

Hot Plug insertion and removal are supported in the presence of a proper connector and appropriate operating system (OS) support as described in the SATA 2.6 specification. This product supports Asynchronous Signal Recovery and will issue an unsolicited COMINIT when first mated with a powered connector to guarantee reliable detection by a host system without hardware device detection.

5 Command Sets

The Element SSD complies with ATA-8. All mandatory and many optional commands and features are supported. The tables below summarize the supported ATA feature set and commands.

Table 5-1: ATA Feature Set

| Feature Set | ATA-8 REF | Support | |
|---|-----------|------------|-------------|
| | | ATA Device | Element SSD |
| General feature set | 4.2 | M | YES |
| PACKET feature set | 4.3 | P | NO |
| 48-Bit Address feature set | 4.4 | O | YES |
| Advanced Power Management (APM) feature set | 4.5 | O | NO |
| Automatic Acoustic Management (AAM) feature set | 4.6 | O | NO |
| CompactFlash Association (CFA) feature set | 4.7 | N | NO |
| Device Configuration Overlay (DCO) feature set | 4.8 | O | YES |
| Free-fall Control feature set | 4.9 | O | NO |
| General Purpose Logging (GPL) feature set | 4.10 | O | YES |
| Host Protected Area (HPA) feature set | 4.11 | O | YES |
| Long Logical Sector (LLS) feature set | 4.12 | O | NO |
| Long Physical Sector (LPS) feature set | 4.13 | O | NO |
| Media Card Pass Through Command feature set | 4.14 | N | NO |
| Native Command Queuing (NCQ) feature set | 4.15 | O | YES |
| NV Cache feature set | 4.16 | O | NO |
| NV Cache Power Management feature set | 4.17 | O | NO |
| Power Management feature set | 4.18 | M | YES |
| Power-Up In Standby (PUIS) feature set | 4.19 | O | YES |
| Security feature set | 4.20 | O | YES |
| S.M.A.R.T. feature set | 4.21 | O | YES |
| Software Settings Preservation (SSP) feature set | 4.22 | O | YES |
| Streaming feature set | 4.23 | O | NO |
| Tagged Command Queuing (TCQ) feature set | 4.24 | O | NO |
| Trusted Computing feature set | 4.25 | O | NO |
| Write-Read-Verify feature set | 4.26 | O | NO |
| Key: M – Mandatory, O – Optional, P – Prohibited, N – Not defined, YES – Supported, NO – Not Supported | | | |

| | |
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5.1 ATA Commands

Table 5-2: ATA Commands

| ATA-8 REF | Commands | ATA-8 | Sup p | Key Word Option | Feature Set | OP |
|-----------|-----------------------------------|-------|-------|---------------------------|----------------|---------|
| 7.2 | CFA ERASE SECTORS | N | NO | CfaEraseSec, CFES | CFA | C0h |
| 7.3 | CFA REQUEST EXTENDED ERROR CODE | O | NO | CfaReqErr, CFRE | CFA | 03h |
| 7.4 | CFA TRANSLATE SECTOR | O | NO | CfaTransSec, CFTS | CFA | 87h |
| 7.5 | CFA WRITE MULTIPLE WITHOUT ERASE | O | NO | CfaWrMul, CFWM | CFA | CDh |
| 7.6 | CFA WRITE SECTOR(S) WITHOUT ERASE | O | NO | CfaWrSec, CFWS | CFA | 38h |
| 7.7 | CHECK MEDIA CARD TYPE | O | NO | ChkMedType, CHMT | Media Card | D1h |
| 7.8 | CHECK POWER MODE | M | YES | ChkPwrMode, CKPW, CHPW | Power Manage | E5h |
| 7.9 | CONFIGURE STREAM | O | NO | CfgStr, CFST | Streaming | 51h |
| 7.10.2 | DEVICE CONFIGURATION FREEZE LOCK | O | YES | DevCfgFrzLock, DCOF, DCFL | DCO | B1h/C1h |
| 7.10.3 | DEVICE CONFIGURATION IDENTIFY | O | YES | DevCgldfy, DCOI, DCFI | DCO | B1h/C2h |
| 7.10.4 | DEVICE CONFIGURATION RESTORE | O | YES | DevCfgRestore, DCOR, DEFR | DCO | B1h/C0h |
| 7.10.5 | DEVICE CONFIGURATION SET | O | YES | DevCfgSet, DCOS, DCFS | DCO | B1h/C3h |
| 7.11 | DEVICE RESET | N | NO | DevRst, DRST | Packet | 08h |
| 7.12 | DOWNLOAD MICROCODE | O | YES | Download, DNLD | General | 92h |
| 7.13 | EXECUTE DEVICE DIAGNOSTIC | M | YES | Diagnose, DIAG | General | 90h |
| 7.14 | FLUSH CACHE | M | YES | FlushCache, FLSH | General | E7h |
| 7.15 | FLUSH CACHE EXT | M | YES | FlushCacheEx, FLSE, FLEX | 48-bit Address | EAh |
| 7.16 | IDENTIFY DEVICE | M | YES | Identify, IDFY | General | ECh |
| 7.17 | IDENTIFY PACKET DEVICE | N | NO | IdfyPktDev, IDPD | Packet | A1h |
| 7.18 | IDLE | M | YES | IDLE | Power Manage | E3h |
| 7.19 | IDLE IMMEDIATE | M | YES | IDLI | Power Manage | E1h |
| - | IDLE/UNLOAD IMMEDIATE | O | YES | | | E1h-41h |
| - | INITIALIZE DRIVE PARAMETERS | M | YES | | | 91h |
| 7.20.3 | ADD LBA(S) TO NV CACHE PINNED SET | O | NO | | NV Cache | B6h/10h |
| 7.20.4 | FLUSH NV CACHE | O | NO | | NV Cache | B6h/14h |
| 7.20.5 | NV CACHE DISABLE | O | NO | | NV Cache | B6h/16h |
| 7.20.6 | NV CACHE ENABLE | O | NO | | NV Cache | B6h/15h |
| 7.20.7 | QUERY NV CACHE MISSES | O | NO | | NV Cache | BRh/13h |
| 7.20.8 | QUERY NV CACHED PINNED SET | O | NO | | NV Cache | B6h/12h |

| ATA-8 REF | Commands | ATA-8 | Sup p | Key Word Option | Feature Set | OP |
|-----------|--------------------------------------|-------|-------|---------------------|----------------|---------|
| 7.20.9 | REMOVE LBA(S) FROM CACHED PINNED SET | O | NO | | NV Cache | B6h/11h |
| 7.20.10 | RETURN FROM NV CACHE POWER MODE | O | NO | | NV Cache | B6h/01h |
| 7.20.11 | SET NV CACHE POWER MODE | O | NO | | NV Cache | B6h/00h |
| 7.21 | NOP | O | YES | NOP | General | 00h |
| 7.22 | PACKET | O | NO | Packet, PAKT | Packet | A0h |
| 7.23 | READ BUFFER | O | YES | RdBuf, RBUF | General | E4H |
| 7.24 | READ DMA | M | YES | RdDma, RDMA | General | C8h |
| 7.25 | READ DMA EXT | M | YES | RdDmaEx, RDMX | 48-bit Address | 25h |
| 7.26 | READ DMA QUEUED | O | NO | RdDmaQ, RDMQ | TCQ | C7h |
| 7.27 | READ DMA QUEUED EXT | O | NO | RdDmaQEx, RDQX | TCQ | 26h |
| - | READ DMA (w/o retry) | Obs | YES | | | C9h |
| 7.28 | READ FPDMA QUEUED | M | YES | RFPDMAQ, RDMA_NCQ | NCQ | 60h |
| 7.29 | READ LOG EXT | M | YES | RdLogEx, RLEX | GPL | 2Fh |
| 7.30 | READ LOG DMA EXT | O | YES | | 48-bit Address | 47h |
| 7.31 | READ MULTIPLE | M | YES | RdMul, RMUL | General | C4h |
| 7.32 | READ MULTIPLE EXT | M | YES | RdMulEx, RDME, RMEX | 48-bit Address | 29h |
| 7.33 | READ NATIVE MAX ADDRESS | M | YES | RdNativeMax, RNMA | HPA | F8h |
| 7.34 | READ NATIVE MAX ADDRESS EXT | M | YES | RdNativeMaxEx, RNME | HPA | 27h |
| 7.35 | READ SECTOR(S) | M | YES | RdSec, RDSK, REC | General | 20h |
| 7.36 | READ SECTOR(S) EXT | M | YES | RdSecEx, RDSE, RSEX | 48-bit Address | 24h |
| 7.37 | READ STREAM DMA EXT | O | NO | RdStrDma, RSTD | Streaming | 2Ah |
| 7.38 | READ STREAM EXT | O | NO | RdStrPio, RSTP | Streaming | 2Bh |
| 7.39 | READ VERIFY SECTOR(S) | M | YES | RdVfy, RVFE | General | 40h |
| 7.40 | READ VERIFY SECTOR(S) EXT | M | YES | RdVfyEx, RVFE | 48-bit Address | 42h |
| - | READ VERIFY SECTORS(S) (w/o retry) | Obs | YES | | | 41h |
| - | RECALIBRATE | Obs | YES | | | 10h |
| 7.41 | SECURITY DISABLE PASSWORD | M | YES | SecuDisPsw, SEDP | Security | F6h |
| 7.42 | SECURITY ERASE PREPARE | M | YES | SecuErasePrep, SERP | Security | F3h |
| 7.43 | SECURITY ERASE UNIT | M | YES | SecuEraseUnit, SEEU | Security | F4h |
| 7.44 | SECURITY FREEZE LOCK | O | YES | SecuFrzLock, SFZL | Security | F5h |
| 7.45 | SECURITY SET PASSWORD | M | YES | SecuSetPsw, SESP | Security | F1h |
| 7.46 | SECURITY UNLOCK | M | YES | SecuUnlock, SEUL | Security | F2h |

| ATA-8 REF | Commands | ATA-8 | Sup p | Key Word Option | Feature Set | OP |
|-----------|------------------------------------|-------|-------|------------------------|--------------|---------|
| - | SEEK | M | YES | | | 70h-7Fh |
| 7.47 | SERVICE | O | NO | Service, SRVC | TCQ | A2h |
| 7.48 | SET FEATURES | M | YES | SetFeature, SETF | General | EFh |
| 7.49.2 | SET MAX ADDRESS | M | YES | SetMaxAddr, SMXA, SMAX | HPA | F9h |
| 7.49.3 | SET MAX FREEZE LOCK | O | YES | SetMaxFrzLock, SMFL | HPA | F9h/04h |
| 7.49.4 | SET MAX LOCK | O | YES | SetMaxLock, SMLK | HPA | F9h/02h |
| 7.49.5 | SET MAX SET PASSWORD | O | YES | SetMaxSetPswd, SMSP | HPA | F9h/01h |
| 7.49.6 | SET MAX UNLOCK | O | YES | SetMaxUnlock, SMUN | HPA | F9h/03h |
| 7.50 | SET MAX ADDRESS EXT | M | YES | SetMaxEx, SAME | HPA | 37h |
| 7.51 | SET MULTIPLE MODE | M | YES | SetMul, SMUL | General | C6h |
| 7.52 | SLEEP | M | YES | Sleep, SLEP | Power Manage | E6h |
| 7.53.2 | SMART DISABLE OPERATION | M | YES | SmDisable, SDSO, SMDI | SMART | B0h/D9h |
| - | SMART ENABLE/DISABLE AUTO OFF-LINE | Obs | YES | | SMART | B0h-DBh |
| 7.53.3 | SMART ENABLE/DISABLE AUTOSAVE | M | YES | SmAutoSv, SAAS, SMAS | SMART | B0h/D2h |
| 7.53.4 | SMART ENABLE OPERATION | M | YES | SmEnable, SESO, SMEN | SMART | B0h/D8h |
| 7.53.5 | SMART EXECUTE OFFLINE IMMEDIATE | O | YES | ExeSmOL, SEOI, SMOI | SMART | B0h/D4h |
| 7.53.6 | SMART READ DATA | O | YES | SmRdData, SRLS, SMRD | SMART | B0h/D0h |
| 7.53.7 | SMART READ LOG | O | YES | SmRdLog, SRLS, SMRL | SMART | B0h/D5h |
| - | SMART READ THRESHOLD | Obs | YES | | SMART | B0h-D1h |
| 7.53.8 | SMART RETURN STATUS | O | YES | SmStatus, SRSS | SMART | B0h/DAh |
| - | SMART SAVE ATB VALUES | Obs | YES | | SMART | B0h-D3h |
| 7.53.9 | SMART WRITE LOG | O | YES | SmWrLog, SWLS, SMWL | SMART | B0h/D6h |
| 7.54 | STANDBY | M | YES | Standby, STBY | Power Manage | E2h |
| 7.55 | STANDBY IMMEDIATE | M | YES | StandbyIm, STBI | Power Manage | E0h |
| 7.56 | TRUSTED NON-DATA | O | NO | | Trusted | 5Bh |
| 7.57 | TRUSTED RECEIVE | O | NO | | Trusted | 5Ch |
| 7.58 | TRUSTED RECEIVE DMA | O | NO | | Trusted | 5Dh |
| 7.59 | TRUSTED SEND | O | NO | | Trusted | 5Eh |
| 7.60 | TRUSTED SEND DMA | O | NO | | Trusted | 5Fh |
| 7.61 | WRITE BUFFER | O | YES | WrBuf, WBUF | General | E8h |
| 7.62 | WRITE DMA | M | YES | WdDma, WDMA | General | CAh |

| ATA-8 REF | Commands | ATA-8 | Sup p | Key Word Option | Feature Set | OP |
|-----------|-------------------------------------|-------|-------|---------------------|----------------|-----|
| 7.63 | WRITE DMA EXT | M | YES | WrDmaEx, WDMX | 48-bit Address | 35h |
| 7.64 | WRITE DMA FUA EXT | M | YES | WrDmaFuaEx, WDFE | 48-bit Address | 3Dh |
| 7.65 | WRITE DMA QUEUED | O | NO | WrDmaQ, WDMQ | TCQ | CCh |
| 7.66 | WRITE DMA QUEUED EXT | O | NO | WrDmaQEx, WDQX | TCQ | 36h |
| 7.67 | WRITE DMA QUEUE FUA EXT | O | NO | WrDmaQFuaEx, WDQF | TCQ | 3Eh |
| - | WRITE DMA (w/o retry) | Obs | YES | | | CBh |
| 7.68 | WRITE FPDMA QUEUED | M | YES | WFPDMAQ, WDMA_NCQ | NCQ | 61h |
| 7.69 | WRITE LOG EXT | M | YES | WrLogEx, WRLE | GPL | 3Fh |
| 7.70 | WRITE LOG DMA EXT | O | YES | | | 57h |
| 7.71 | WRITE MULTIPLE | M | YES | WrMul, WMUL | General | C5h |
| 7.72 | WRITE MULTIPLE EXT | M | YES | WrMulEx, WDME, WMEX | 48-bit Address | 39h |
| 7.73 | WRITE MULTIPLE FUA EXT | M | YES | WrMulFuaEx, WMFE | 48-bit Address | CEh |
| 7.74 | WRITE SECTOR(S) | M | YES | WrSec, WDSK, WSEC | General | 30h |
| 7.75 | WRITE SECTOR(S) EXT | M | YES | WrSecEx, WDSE, WSEX | 48-bit Address | 34h |
| - | WRITE SECTOR(S) (w/o retry) | Obs | YES | | | 31h |
| 7.76 | WRITE STREAM DMA EXT | O | NO | WrStrDma, WSTD | Streaming | 3Ah |
| 7.77 | WRITE STREAM EXT | O | NO | WrStrPio, WSTP | Streaming | 3Bh |
| 7.78 | WRITE UNCORRECTABLE EXT | O | YES | | | 45h |
| - | DATA SET MANAGEMENT EXT (I.E. TRIM) | O | YES | | | 06h |

Key: M – Mandatory, O – Optional, Obs – Obsolete, P – Prohibited, N – Not defined, YES – Supported, NO – Not Supported

5.1.1 48-Bit Address Command Set

Slim SATA supports the 48-Bit Address command set consisting of:

- Flush Cache Ext
- Read DMA Ext
- Read native Max Address Ext
- Read Sector(s) Ext
- Set Max Address Ext
- Write DMA Ext
- Write Multiple Ext
- Write Sector(s) Ext

5.1.2 ATA General Feature Command Set

Slim SATA supports the ATA General Feature command set consisting of:

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- Download Microcode
- Executive Device Diagnostics
- Flush Cache
- Identify Device
- NOP (optional)
- Read Buffer (optional)
- Read DMA
- Read Multiple
- Read Sector(s)
- Read Verify Sector(s)
- Seek
- Set Features
- Set Multiple Mode
- Write Buffer (optional)
- Write DMA
- Write Multiple
- Write Sector(s)

5.1.3 Device Configuration Overlay Command Set

Slim SATA supports the Device Configuration Overlay command set consisting of:

- Device Configuration Freeze Lock
- Device Configuration Identity
- Device Configuration Restore
- Device Configuration Set

5.1.4 General Purpose Log Command Set

Slim SATA supports the General Purpose Log command set consisting of:

- Read Log Ext
- Write Log Ext

5.1.5 Host Protected Area Command Set

Slim SATA supports the Host Protected Area command set consisting of:

- Read Native Max Address
- Read Native Max Address Ext
- Set Max Address
- Set Max Address Ext
- Set Max Freeze Lock (optional)
- Set Max Lock (optional)
- Set Max Set Password (optional)

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- Set Max Unlock (optional)

5.1.6 Power Management Command Set

Slim SATA supports the Power Management command set consisting of:

- Check Power Mode
- Idle
- Idle Immediate
- Sleep
- Standby
- Standby Immediate

5.1.7 Security Mode Feature Set

Slim SATA supports the Security Mode command set consisting of:

- Security Set Password (OPCODE: F1h)
- Security Unlock (OPCODE: F2h)
- Security Erase Prepare (OPCODE: F3h)
- Security Erase Unit (OPCODE: F4h)
- Security Freeze Lock (OPCODE: F5h)
- Security Disable Password (OPCODE: F6h)

5.1.1 S.M.A.R.T. Support

Data storage drives capture a variety of information during operation that may be used to analyze drive —health. SATA drives provide Self-Monitoring, Analysis and Reporting Technology (SMART) features that include monitoring and storing critical performance and calibration parameters to attempt to predict the likelihood of near-term degradation or fault conditions. Drive manufacturers have adopted S.M.A.R.T. to help warn system software, a system administrator, or a user of impending drive failure, while time remains to take preventive action. It provides the host system with the knowledge of a negative reliability condition to allow the host system to warn the user of the impending risk of data loss and advise the user of the appropriate action.

The technical documentation for S.M.A.R.T. is captured in the AT Attachment (ATA) standard. The standard defines the protocols for reporting errors and for invoking self-tests to collect and analyze data on demand. The ATA specification is flexible and provides for individual manufacturers to define their own unique vendor specific information. This section describes the baseline supported S.M.A.R.T. command attributes. The information herein should be used in conjunction with the ATA standard and related documents, which may serve as references for topics and details not addressed here. Further, it is recommended to consult the list of public S.M.A.R.T. attributes.

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The supported S.M.A.R.T. command set is listed in the table below. See the AT Attachment standard for implementation details.

5.1.2 S.M.A.R.T. Command Set

The supported S.M.A.R.T. command set is listed in the table below. See the AT Attachment standard for implementation details.

Table 5-3: S.M.A.R.T. Command Set

| Value (hex) | Command |
|--|--|
| 00-CF | Reserved |
| D0 | S.M.A.R.T. read attributes |
| D1* | S.M.A.R.T. read threshold |
| D2 | S.M.A.R.T. enable/disable attribute autosave |
| D3* | S.M.A.R.T. save attribute values |
| D4 | S.M.A.R.T. execute off-line immediate |
| D5 | S.M.A.R.T. read log sector |
| D6 | S.M.A.R.T. write log sector |
| D7* | S.M.A.R.T. write attribute threshold |
| D8 | S.M.A.R.T. enable operations |
| D9 | S.M.A.R.T. disable operations |
| DA | S.M.A.R.T. return status |
| DB | S.M.A.R.T. enable/disable automatic off-line |
| DC-FF | Reserved (Vendor Specific) |
| * Note that D1, D3, and D7 have been made obsolete in the ATA-8 specification. | |

5.1.2.1 Off-line Mode

The Element SSD supports the optional 28-bit S.M.A.R.T. EXECUTION OFF-LINE IMMEDIATE (B0h/D4h) command per the ATA-8 specification. This command causes the Element SSD to initiate the collection of S.M.A.R.T. data in an off-line mode and then preserves this data across power and reset events. Supported subcommands include those shown in the table below. Reference the ATA-8 specification for subcommand detail.

Table 5-4: Supported S.M.A.R.T. EXECUTE OFF-LINE IMMEDIATE Subcommands

| Value | Description |
|-------|-------------|
|-------|-------------|

| | |
|-----|---|
| 00h | Execute S.M.A.R.T. off-line routine immediately in off-line mode |
| 01h | Execute S.M.A.R.T. Short self-test routine immediately in off-line mode |
| 02h | Execute S.M.A.R.T. Extended self-test routine immediately in off-line mode |
| 04h | Execute S.M.A.R.T. Selective self-test routine immediately in off-line mode |
| 7Fh | Abort off-line mode self-test routine |
| 81h | Execute S.M.A.R.T. Short self-test routine immediately in captive mode |
| 82h | Execute S.M.A.R.T. Extended self-test routine immediately in captive mode |
| 84h | Execute S.M.A.R.T. Selective self-test routine immediately in captive mode |

5.1.2.2 Captive Mode

When executing a self-test in captive mode, the Element SSD executes the self-test routine after receipt of the command. At the end of the routine the Element SSD places the results of this routine in the self-test execution status byte and reports command completion. If an error occurs while the Element SSD is performing the routine it discontinues its testing, place the results of this routine in the self-test execution status byte and the DST log page, and complete the command.

5.1.2.3 S.M.A.R.T. Logs

S.M.A.R.T. logs are intended to enhance S.M.A.R.T. Attribute information by capturing additional drive details at appropriate times. This information may lead to improved error detection and reporting capability. The controller supports S.M.A.R.T. logs, and relevant tests, events, and conditions each have an associated log. S.M.A.R.T. logs conform to industry-standard structures.

The reported size of each log is reported by the Log Directory (Log 0). Note that the information returned via S.M.A.R.T. Read Log access to Log 0 is more limited than that via GP Read Log. Log size is only reported the LSB (max 255 blocks) when access via S.M.A.R.T. Read Log command; and full 2 bytes (max 65535 blocks) when access via Read Log EXT command.

The frequency at which S.M.A.R.T. logs are updated is the frequency at which checkpoint information is saved. That frequency is related to data volume, and can range between approximately 2 seconds and 2 minutes, depending on how much data is being transferred. Therefore, constant host system IOs cause check-pointing and S.M.A.R.T. log update relatively frequently (approximately every 2 seconds); very slow or idle host transaction rates result in check-pointing and S.M.A.R.T. log update less frequently (worst-case around every 2 minutes).

All logs are non-volatile except as within each of the log description.

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Handling and reporting error conditions relating to the updating of S.M.A.R.T. logs and S.M.A.R.T. Attributes is accomplished the same as handling error conditions experienced while saving user data. Likewise, handling and reporting error conditions relating to other processes (including background processes) that occur while updating S.M.A.R.T. logs and S.M.A.R.T. Attributes is accomplished the same as handling such error conditions while saving user data. S.M.A.R.T. logs are validated by affecting the events being detected and logged; the S.M.A.R.T. log always reflects the event that occurred, whether that event is injected artificially or occurs independently.

5.1.3 S.M.A.R.T. Attributes

5.1.3.1 Supported (Baseline) Attributes

The following table shows the supported S.M.A.R.T. attributes.

Table 5-5: Baseline S.M.A.R.T. Attribute Summary

| ID | Hex | Attribute Name | Description |
|-----|------|-------------------------------|---|
| 1 | 0x01 | Raw Read Error Rate | Raw error rate related to ECC errors. Correctable and uncorrectable RAISE errors are included in the error event count. (UECC + URAISE) |
| 5 | 0x05 | Retired Block Count | Tracks the total number of retired blocks. |
| 9 | 0x09 | Power-On Hours (POH) | Count of hours in power-on state. The raw value of this attribute shows total count of hours in power-on state. |
| 12 | 0x0C | Device Power Cycle Count | This attribute indicates the count of full hard disk power on/off cycles. |
| 171 | 0xAB | Program Fail Count | Counts the number of flash program failures |
| 172 | 0xAC | Erase Fail Count | Counts the number of flash erase failures |
| 174 | 0xAE | Unexpected Power Loss Count | Counts the number of unexpected power loss events since the drive was deployed. |
| 177 | 0xB1 | Wear Range Delta | Returns the percentage difference in wear between the most worn block and the least worn block. |
| 181 | 0XB5 | Program Fail Count | (Identical to Attribute 171) |
| 182 | 0XB6 | Erase Fail Count | (Identical to Attribute 172) |
| 187 | 0xBB | Reported Uncorrectable Errors | This attribute tracks the number of uncorrectable RAISE (URAISE) errors reported back to the host for all data access commands. |
| 194 | 0xC2 | Temperature | Temperature assuming an on-board sensor connected via Industry Standard Two Wire Interface (ISTW) interface to the controller. |
| 195 | 0xC3 | ECC On the Fly Count | This attribute tracks the number of uncorrectable errors (UECC). |
| 196 | 0xC4 | Reallocation Count | This attribute tracks the # of blocks failing programming which are reallocated. |

| ID | Hex | Attribute Name | Description |
|-----|------|------------------------------------|---|
| 201 | 0xC9 | Uncorrectable Soft Read Error Rate | Number of soft read errors that cannot be fixed on-the-fly and requires deep recovery via RAISE. (ie UECC) |
| 204 | 0xCC | Soft ECC Correction Rate | Number of errors corrected by RAISE that cannot be fixed on-the-fly and requires ECC (multilevel) to correct. (ie UECC) |
| 231 | 0xE7 | SSD Life Left | Indicates the approximate percentage of SSD life left. |
| 241 | 0xF1 | Lifetime Writes from Host | Indicates the total amount of data written from hosts since the drive was deployed. |
| 242 | 0xF2 | Lifetime Reads to Host | Indicates the total amount of data read to hosts since the drive was deployed. |

Notes:

1. SMART ID# 233 and 234 are for Internal Use only.

5.1.3.2 Supported Baseline Attribute Details

The table below provides a detailed description of supported S.M.A.R.T. attributes and how they may be used.

Table 5-6: Baseline S.M.A.R.T. Attribute Details

| ID | Attribute Name | Description | Rational |
|----|---------------------|--|--|
| 1 | Raw Read Error Rate | <p>Raw error rate related to ECC errors. Errors are counted as ECC errors above a threshold. For the controller, this attribute includes Uncorrectable ECC (UECC) errors, and Uncorrectable RAISE (URAISE) errors.</p> <p><u>Normalized Equation:</u> $10\log_{10}(\text{BitsRead}/\text{ReadErrors} + 1)$ SectorsRead= Number of sectors read SectorsToBits= 512*8 BitsRead= SectorsRead*SectorsToBits</p> <p><u>Normalized Value Range:</u> Best = 130 Worst = 38 Invalid = 0</p> <p><u>Raw Usage:</u> [3-0] : Number of sectors read [6-4]: Read errors (UECC+URAISE)</p> | <p>The Raw Read error rate includes two types of ECC errors that are tracked by the controller: UECC and URAISE. The normalized equation for Raw read error rate is logarithmic since the valid BER range of the attribute spans from 1.00E-10 to 1.00E-12. To force positive numbers, the numerator and denominator are flipped. One is then added to the number of errors in the denominator to avoid a divide-by-0 condition if no errors are encountered. By taking the log of the inverted BER and multiplying by ten a reasonable range of normalized values from 130 to 38 (representing a BER range of 1.00E-13 to 1.68E-04) are presented.</p> <p>This Attribute reads '0' until a sample size between 10E10 and 10E12 is available to be tracked by this Attribute.</p> |

| ID | Attribute Name | Description | Rational |
|----|--------------------------|---|---|
| 5 | Retired Block Count | <p>Tracks the total number of retired blocks.</p> <p><u>Normalized Equation:</u></p> $\text{Count} = 100 - (100 * \text{RBC} / \text{MRB})$ <p>RBC = RetiredBlockCount = Number of retired blocks.</p> <p>MRB = MinimumReqBlocks = Minimum number of reserve blocks available for controller use. This value is set at factory configuration time.</p> <p><u>Normalized Value Range:</u> Best = 100 Worst = 1</p> <p><u>Raw Usage:</u> [3-0] : Retired block count</p> <p>[6-4] : None (0x00)</p> | <p>The normalized equation for this attribute decrements as blocks are retired and the reserve (over-provisioned) block count is decremented. (Note that all blocks, including reserve blocks, are in service at all times; reserve blocks constitute Flash memory space over and above the drive's logical capacity.)</p> <p>As defined, this attribute is identical to the Reallocation Event Count attribute (#196).</p> |
| 9 | Power-On Hours (POH) | <p>Count of hours in power-on state. The raw value of this attribute shows total count of hours in the power-on state.</p> <p><u>Normalized Equation:</u> $100 - (\text{POH} / \text{HPY} * 10)$</p> <p><u>Normalized Value Range:</u> Best = 100 Worst = 1</p> <p><u>Raw Usage:</u> [3-0] : Total number of power-on hours</p> <p>[6-4]: total number of milliseconds since last hour update</p> | <p>The normalized equation for Power-On hours decrements by 1 each 1/10 year. Note that some manufacturers elect to decrement by 1 for each 1/12 year of POH.</p> |
| 12 | Device Power Cycle Count | <p>This attribute indicates the count of full hard disk power on/off cycles.</p> <p><u>Normalized Equation:</u> $100 - (\text{PCC} / 1024)$</p> <p><u>Normalized Value Range:</u> Best = 100 Worst = 1</p> <p><u>Raw Usage:</u> [3-0] : Cumulative lifetime power cycle count (PCC)</p> | <p>The normalized equation for Power Cycle Count decrements by 1 for each 1024 power cycle.</p> |

| ID | Attribute Name | Description | Rational |
|-----|-----------------------|--|--|
| | | [6-4] : None (0x00) | |
| 171 | Program Fail Count | Counts the number of flash program failures. <u>Usage:</u> [3-0] : Program Error Count [6-4] : None (0x00) | This Attribute returns the total number of Flash program operation failures since the drive was deployed. This Attribute is identical to Attribute 181. |
| 172 | Erase Fail Count | Counts the number of flash erase failures. <u>Usage:</u> [3-0] : Erase Error Count [6-4] : None (0x00) | This Attribute returns the total number of Flash erase operation failures since the drive was deployed. This Attribute is identical to Attribute 182. |
| 174 | Unexpected Power Loss | Counts the number of unexpected power loss events, as determined by the number of times PFAIL has been asserted (or other criteria?). <u>Usage:</u> [3-0] : Unexpected Power Loss Event Count [6-4] : None (0x00) | This Attribute returns the total number of unexpected power loss events over the life of the drive. |

| ID | Attribute Name | Description | Rational |
|-----|--------------------|---|--|
| 177 | Wear Range Delta | <p>Provides a value equal to the delta between the max worn Flash block and the least worn Flash block, as a percentage of the max rated wear of the SSD.</p> <p><u>Equation:</u> $\text{Wear Range Delta} = \frac{(\text{MW} - \text{LW})}{\text{MRW}} \times 100$ </p> <p>MW = P-E Cycles experienced by Most Worn block LW = P-E Cycles experienced by Least Worn block MRW = Max Rated Wear = P-E Cycle rating for the Flash memory</p> <p><u>Usage:</u> [3-0] : Wear Range delta [6-4] : None (0x00)</p> | <p>This Attribute identifies the “delta” between most-worn and least-worn Flash blocks, as a percentage of the max rated wear of the Flash memory on the SSD.</p> <p>For 10,000-cycle Flash, where 1% of rated cycles is 100 cycles, a value of 1.5 for this Attribute means the difference in wear between the least worn block and the most-worn block is 150 Erase cycles.</p> <p>This attribute may not be accurate until approximately 10% of drive life has been used.</p> |
| 181 | Program Fail Count | <p>Counts the number of flash program failures.</p> <p><u>Usage:</u> [3-0] : Program Error Count [6-4] : None (0x00)</p> | <p>This Attribute returns the total number of Flash program operation failures since the drive was deployed.</p> <p>This Attribute is identical to Attribute 171.</p> |
| 182 | Erase Fail Count | <p>Counts the number of flash erase failures.</p> <p><u>Usage:</u> [3-0] : Erase Error Count [6-4] : None (0x00)</p> | <p>This Attribute returns the total number of Flash erase operation failures since the drive was deployed.</p> <p>This Attribute is identical to Attribute 172.</p> |

| ID | Attribute Name | Description | Rational |
|-----|--|---|--|
| 187 | Reported Uncorrectable Errors (URAISE) | <p>Uncorrectable Errors (URAISE)</p> <p>This attribute tracks the number of uncorrectable RAISE (URAISE) errors reported back to the host for all data access commands.</p> <p><u>Normalized Equation:</u> $100 - (\text{URAISE})$ <u>Normalized Value Range:</u> Best = 100 Worst = 1</p> <p><u>Raw Usage:</u> [1-0] : Cumulative lifetime URAISE errors [6-2] : None (0x00)</p> | <p>The uncorrectable ECC error rate tracks the controller Uncorrectable RAISE (URAISE) errors. The normalized equation for Uncorrectable Error Count decrements by 1 for each URAISE error. Uncorrectable errors reported in this field are uncorrectable by any level of ECC protection including RAISE.</p> |
| 194 | Temperature | <p>Temperature of the SSD assembly. That is, the temperature inside the SSD housing.</p> <p><u>Normalized Equation:</u></p> <p>Temperature = Temperature (Celsius)</p> <p><u>Normalized Value Range:</u> Lowest = -127 Highest = 127</p> <p><u>Raw Usage:</u> [1-0] : Current temperature (C; from sensor) [3-2]: Highest temperature (C; since power-on) [5-4]: Lowest temperature (C; since power-on) [6] : None (0x00)</p> | <p>The normalized temperature is a straight Celsius value as obtained from the primary SSD temperature sensor.</p> <p>The raw values represent current and historical Celsius temperature values from the primary SSD temperature sensor.</p> <p>For SSD designs incorporating multiple temperature sensors, current temperature is taken from the sensor with the highest reading; historical values are highest or lowest of all sensors polled.</p> |

| ID | Attribute Name | Description | Rational |
|-----|----------------------------|--|---|
| 195 | ECC On-the-Fly Error Count | <p>This attribute tracks the number of uncorrectable ECC errors (UECC). The normalized value is only computed when the number of bits in the "BitsRead" count is in the range of 10¹⁰ to 10¹². The count is cleared at power on reset and when >10¹² bits have been read.</p> <p><u>Normalized Equation:</u> $10 \log_{10}(\text{BitsRead} / (\text{ECCOnTheFlyErrors} + 1))$</p> <p>SectorsRead= Number of sectors read SectorsToBits= 512*8 BitsRead= SectorsRead*SectorsToBits</p> <p><u>Normalized Value Range:</u> Best = 130 Worst = 38 Invalid = 0</p> <p><u>Raw Usage:</u> [3-0] : Number of sectors read [6-4]: ECCOnTheFlyErrors (UECC) count</p> | <p>The ECC On The Fly error rate includes all uncorrectable ECC errors (UECC) tracked by the controller. The normalized equation for ECC On The Fly error rate is logarithmic since the valid BER range of the attribute spans from 1.00E-10 to 1.00E-12. To force positive numbers, the numerator and denominator are flipped. One is then added to the number of errors in the denominator to avoid a divide-by-0 condition if no errors are encountered. By taking the log of the inverted BER and multiplying by ten a reasonable range of normalized values from 130 to 38 (representing a BER range of 1.00E-13 to 1.68E-04) are presented. As defined, this Attribute is identical to Attribute 201 and Attribute 204.</p> <p>This Attribute reads '0' until a sample size between 10E10 and 10E12 is available to be tracked by this Attribute.</p> <p>Note that many UECC errors counted by this Attribute are corrected by RAISE correction.</p> |

| ID | Attribute Name | Description | Rational |
|-----|--------------------------------------|--|---|
| 196 | Reallocation Event Count | <p>Tracks the total number of reallocated Flash blocks.</p> <p><u>Normalized Equation:</u></p> $\text{Count} = 100 - (100 * \text{RBC} / \text{MRB})$ <p>RBC = RetiredBlockCount = Number of retired blocks.</p> <p>MRB = MinimumReqBlocks = Minimum number of reserve blocks available for controller use. This value is set at factory configuration time.</p> <p><u>Normalized Value Range:</u> Best = 100 Worst = 1</p> <p><u>Raw Usage:</u> [3-0] : Retired block count [6-4] : None (0x00)</p> | <p>The normalized equation for this attribute decrements as blocks are retired and the reserve (over-provisioned) block count is decremented. (Note that all blocks, including reserve blocks, are in service at all times; reserve blocks constitute Flash memory space over and above the drive's logical capacity.)</p> <p>As defined, this attribute is identical to the Retired Block Count attribute (#5).</p> |
| 201 | Uncorrectable Soft Read Error (UECC) | <p>Number of soft read errors that cannot be fixed on-the-fly and requires deep recovery provided by RAISE. The normalized value is only computed when the number of bits in the "BitsRead" count is in the range of 10^{10} to 10^{12}. The count is cleared at power on reset and when $>10^{12}$ bits have been read.</p> <p><u>Normalized Equation:</u> $10 \log_{10}(\text{BitsRead} / \text{UECC} + 1)$</p> <p>SectorsRead= Number of sectors read SectorsToBits= $512 * 8$ BitsRead= SectorsRead*SectorsToBits</p> <p><u>Normalized Value Range:</u> Best = 130 Worst = 38 Invalid = 0</p> <p><u>Raw Usage:</u> [3-0] : Number of sectors read [6-4]: Uncorrectable Soft error count (UECC)</p> | <p>The Uncorrectable Soft Read Error Rate includes all uncorrectable ECC (UECC) errors tracked by the CONTROLLER. The normalized equation for Uncorrectable Soft Read Error Rate is logarithmic since the valid BER range of the attribute spans from $1.00E-10$ to $1.00E-12$. To force positive numbers, the numerator and denominator are flipped. One is then added to the number of errors in the denominator to avoid a divide-by-0 condition if no errors are encountered. By taking the log of the inverted BER and multiplying by ten a reasonable range of normalized values from 130 to 38 (representing a BER range of $1.00E-13$ to $1.68E-04$) are presented. As defined this attribute is identical to 195 and 204.</p> <p>This Attribute reads '0' until a sample size between $10E10$ and $10E12$ is available to be tracked</p> |

| ID | Attribute Name | Description | Rational |
|-----|---------------------------------|---|---|
| | | | by this Attribute. |
| 204 | Soft ECC Correction Rate (UECC) | <p>Number of errors corrected by RAISE that cannot be fixed on-the-fly and requires RAISE to correct. The normalized value is only computed when the number of bits in the "BitsRead" count is in the range of 10¹⁰ to 10¹². The count is cleared at power on reset and when >10¹² bits have been read.</p> <p>Normalized Equation: $10\log_{10}(\text{BitsRead}/\text{UECC} + 1)$</p> <p>SectorsRead= Number of sectors read SectorsToBits= 512*8 BitsRead= SectorsRead*SectorsToBits</p> <p>Normalized Value Range: Best = 130 Worst = 38 Invalid = 0</p> <p>Raw Usage: [3-0] : Number of sectors read [6-4]: Soft ECC correction count (UECC)</p> | <p>The Soft ECC Correction Rate includes all uncorrectable ECC (UECC) errors tracked by the CONTROLLER. The normalized equation for Soft ECC Correction Rate is logarithmic since the valid BER range of the attribute spans from 1.00E-10 to 1.00E-12. To force positive numbers, the numerator and denominator are flipped. One is then added to the number of errors in the denominator to avoid a divide-by-0 condition if no errors are encountered. By taking the log of the inverted BER and multiplying by ten a reasonable range of normalized values from 130 to 38 (representing a BER range of 1.00E-13 to 1.68E-04) are presented. As defined this attribute is identical to 195 and 201.</p> <p>This Attribute reads '0' until a sample size between 10E10 and 10E12 is available to be tracked by this Attribute.</p> |
| 231 | SSD Life Left | <p>Indicates the approximate SSD life left, in terms of PE cycles and Flash blocks currently available for use.</p> <p>Normalized Equation: SSD Life Left = MIN[MAX(termA, 10), termB] termA = (Unused)/(Rated) x 100 Unused = (unused PE cycles) Rated = (rated PE cycles) termB = (AvailExcess)/(OrigExcess) AvailX = (Blocks above min req'd) OrigX = (Original blks above min req'd)</p> | <p>SSD life left is based on actual usage and takes into account PE cycle consumption and Flash block retirement.</p> <p>PE cycle usage at a rate less than the rate used for performance throttling will result in extending drive life. Actual Flash endurance remaining is normally greater than the unused rated PE cycles.</p> <p>Note that block retirement rate also affects SSD life and this</p> |

| ID | Attribute Name | Description | Rational |
|-----|----------------------------------|--|---|
| | | Normalized Value Range: 100 = Best = Full SSD life remains 10 = Replace = Sufficient Flash blocks still in service, but rated PE Cycles consumed 1 = Worst = Insufficient Flash blocks remain in service; EOL; drive is read-only | Attribute value. |
| 241 | Lifetime Writes from Host System | Indicates the number of bytes (in 64GB resolution) written to the drive by a host system, over the life of the drive. <u>Usage:</u> [3-0]: Count of 64GB units written [6-4] : None (0x00) | This Attribute returns a byte count, in units of Gigabytes at an update resolution of 64 GBytes. The count represents the number of bytes written. The Attribute reads '0' until the number of bytes written reaches 64GB; at 64GB the Attribute increments to a value of '64' (decimal). |
| 242 | Lifetime Reads from Host System | Indicates the number of bytes (in 64GB resolution) read from the drive by a host system, over the life of the drive. <u>Usage:</u> [3-0]: Count of 64GB units read [6-4] : None (0x00) | This Attribute returns a byte count, in units of Gigabytes at an update resolution of 64 GB. The count represents the number of bytes read. The Attribute reads '0' until the number of bytes read reaches 64GB; at 64GB the count increments to a value of '64' (decimal). |

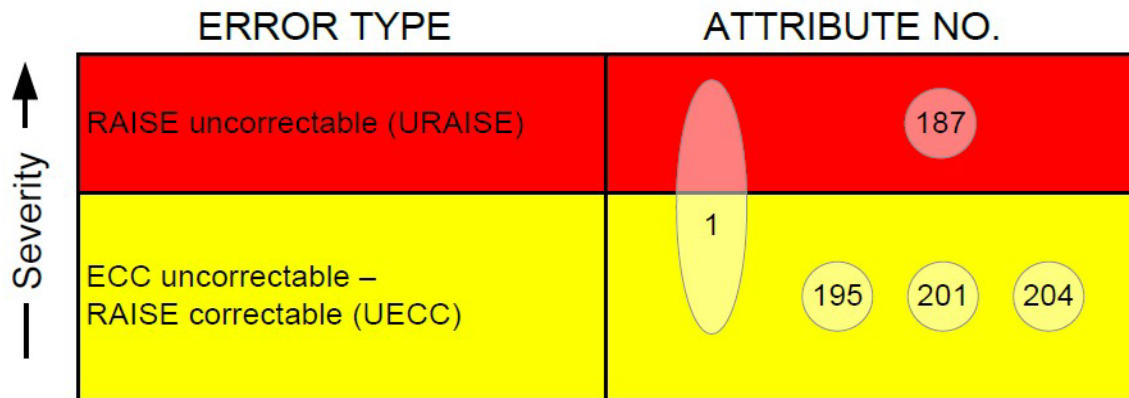


Figure 5-1: S.M.A.R.T. ECC and RAISE Error Summary

Attribute Sector

The S.M.A.R.T. Attribute Sector defines attribute format and the data structure is defined in the following table.

Table 5-7: S.M.A.R.T. Attribute Data Structure

| Byte | Description |
|---------|--|
| 0:1 | S.M.A.R.T. structure version number |
| 2 | First Stored Attribute Number (i.e. "1" for RawErrorRate) |
| 3:4 | Status |
| 5 | Nominal value |
| 6 | Worst value since SSD was deployed |
| 7:12 | Raw Data |
| 13 | Reserved |
| 14:25 | Next Stored Attribute Number (ie "3" for "Retired Block Count") |
| 26:361 | Next Stored Attribute Numbers (max 30 collected Attributes, including above) |
| 362 | Off-line data collection status |
| 363 | Self-test execution status byte |
| 364:365 | Total time to complete off-line data collection (in seconds) |
| 366 | Reserved |
| 367 | Off-line Data Collection capability |
| 368:369 | S.M.A.R.T. capability |
| 370 | Error Logging Capability (bit 0 set = device error logging supported) |
| 371 | Next Self Test Step |
| 372 | Short Self Test routine recommended polling time (in minutes) |
| 373 | Extended Self Test routine recommended polling time (in minutes) |
| 374 | Recommended polling time for Conveyance Self Test |
| 375:376 | Time for Extended Self Test if > 255 (ie, 373 to FFh) |
| 377:385 | Reserved |
| 386:510 | Vendor Information |
| 511 | Checksum of data structure (generated on retrieval of stored data) |

Notes: Bytes 2:361 are vendor unique

5.1.4 Threshold Sector

The S.M.A.R.T. Threshold Sector defines attribute trip thresholds. Attributes are compared to the thresholds when the S.M.A.R.T. Return Status Command (DA) retrieves drive reliability Status. The S.M.A.R.T. Read Threshold Sector Command (DI) then used to read this information. Threshold information may be modified or written via the S.M.A.R.T. Write Threshold Value Command (D7). Threshold values are obtained from the Saved Configuration Page.

Table 5-8: S.M.A.R.T. Threshold Data Structure

| Byte | Description |
|---------|--|
| 0:1 | S.M.A.R.T. structure version number |
| 2 | First Stored Attribute Number (i.e. "1" for RawErrorRate) |
| 3 | Threshold Value for first attribute |
| 4:13 | Reserved |
| 14 | Next Stored Attribute Number |
| 15 | Threshold Value for next attribute |
| 16:25 | Reserved |
| 26:361 | Attribute Number, Threshold and 10 reserved bytes for supported attributes, (max 30 collected Attributes, including above) |
| 362:379 | Reserved |
| 380:510 | Vendor Unique |
| 511 | Checksum |

5.1.5 S.M.A.R.T. Command Transport (SCT)

The Element SSD supports the S.M.A.R.T. Command Transport (SCT). SCT allows the host to send commands, send and receive data, and receive status to and from the Element SSD using log page 0xE0 and log page 0xE1. SCT uses S.M.A.R.T. READ/WRITE LOG commands, READ/WRITE LOG EXT commands, or READ/WRITE LOG DMA EXT commands to access the log pages. For additional SCT information please reference ATA8-ACS.

5.2 SATA Commands

The SATA 2.6 specification is a super set of the ATA/ATAPI-7 specification with regard to supported commands. The Element SATA SSD supports the following features that are unique to the SATA specification.

5.2.1 Native Command Queuing (NCQ)

The Element SATA SSD supports the Native Command Queuing (NCQ) command set, which consists of

- READ FPDMA QUEUED
- WRITE FPDMA QUEUED

Notes: With a maximum queue depth less than or equal to 32.

6 Certifications and Compliance

Table 6-1: Device Certifications

| Certification/Compliance | Description |
|--------------------------|--|
| RoHS | Viking Modular Solutions(TM), Sanmina Corporation ("Viking") shall use commercially reasonable efforts to provide components, parts, materials, products and processes to customers that do not contain: (i) lead, mercury, hexavalent chromium, polybrominated biphenyls (PBB) and polybrominated diphenyl ethers (PBDE) above 0.1% by weight in homogeneous material or (ii) cadmium above 0.01% by weight of homogeneous material, except as provided in any exemption(s) from RoHS requirements (including the most current version of the "Annex" to Directive\ 2002/95/EC of 27 January, 2003), as codified in the specific laws of the EU member countries. Viking strives to obtain appropriate contractual protections from its suppliers in connection with the RoHS Directives. |
| China RoHS | Restriction of hazardous substances |
| Serial ATA | Requirements for logo |
| EU WEEE Compliant | The Waste Electrical and Electronic Equipment Directive (WEEE Directive) is the European Community directive 2002/96/EC on waste electrical and electronic equipment (WEEE) which, together with the RoHS Directive 2002/95/EC, became European Law in February 2003, setting collection, recycling and recovery targets for all types of electrical goods. |

7 References

- JEDEC Mechanical Outline MO-297A
- Environmental Specification: MIL-STD-810F
- Amphenol SATA Connector, SATA-001-0095-3-T
- Serial ATA Specification, revision 2.6 and 3.x

8 Glossary

This document incorporates many industry- and device-specific words. Use the following list to define a variety of terms and acronyms.

| Term | Definition |
|------------|--|
| ATA | Advanced Technology Attachment |
| ATAPI | Advanced Technology Attachment Packet Interface |
| BER | Bit error rate, or percentage of bits that have errors relative to the total number of bits received |
| DIPM | Device Initiated Link Power Management. The ability of the device to request SATA link power state changes. |
| DMA | Direct Memory Access |
| eMLC | Enterprise Multi-Level Cell |
| EXT | Extended |
| FP | First Party |
| GB | Giga-byte defined as 1×10^9 bytes |
| HDD | Hard Disk Drive |
| Hot Plug | A term used to describe the removal or insertion of a SATA storage drive when the system is powered on. |
| IOPS | Input output operations per second |
| LBA | Logical Block Address |
| MB | Mega-bytes defined as 1×10^6 bytes |
| MLC | Multi-Level Cell |
| MTBF | Mean Time Between Failures |
| NCQ | Native Command Queuing. The ability of the SATA hard drive to queue and re-order commands to maximize execution efficiency. |
| NOP | No Operation |
| OS | Operating System |
| Port | The point at which a SATA drive physically connects to the SATA controller. |
| RMS | Root Mean Squared |
| RPM | Revolutions Per Minute |
| SAS | Serial Attached SCSI |
| SATA | Serial ATA |
| SFF | Small Form Factor |
| SLC | Single Level Cell |
| S.M.A.R.T. | Self-Monitoring, Analysis and Reporting Technology: an open standard for developing hard drives and software systems that automatically monitors a hard drive's health and reports potential problems. |
| SSD | Solid-State Drive |