2.5”
ELEMENT SSD

The SATA Element SSD is a non-volatile, solid-state storage device. With its Serial ATA interface and industry-standard form factors, it is a drop in replacement for hard disk drives. The Element SSD delivers extremely high levels of performance, reliability and ruggedness for I/O intensive or environmentally challenging applications.

Revision History

Date	Revision	Description
2/19/12	A	Release of new format. Changed supply voltage to +/-5%. Deleted part numbers VRFS21120GAIPSTF (2.5"). Added notes for operating temperature. Updated SMART attribute table. Added VRFS22025GFxySz. Corrected SMART threshold table. Added power and current numbers. Add new PN's.
3/01/12	A1	Add new PN VRFS22480GFCyEz. Added VRFS2xGHxx VRFS2xGJxx. Added "Ambient" to temperature range, Added info on Immediate Standby timings and PN's VRFS21050GAIyMz, VRFS21050GAIyMz.
5/01/12	A2	Add mass/weight of SSD.
6/04/12	A3	Added application column to PN table. Added a PN. Added note on enterprise vs client
6/07/12	A4	Added note features not available for industrial versions, which are VRFS2xGA, VRFS2xGK and VRFS2xGM. Added a note on SMART attributes. Added note on enterprise vs client. Update usage on SMART tables.

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Legal Information

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Ordering Information: Element 2.5" SSD Family

Viking High Performance Solid-State Drive Ordering Information

Part Number	SATA Interface	Application	Raw Capacity (GB)	Unformatted Useable Capacity (GB)[1]	Minimum Total User Addressable Sectors in LBA Mode	NAND Technology	Temperature Range
VRFS22480GFCyMz	6Gbps	Enterprise	512	480	937,703,088	MLC	0 to 70°C
VRFS22400GFCyMz	6Gbps	Enterprise	512	400	781,422,768	MLC	0 to 70°C
VRFS22400GFCyEz	6Gbps	Enterprise	512	400	781,422,768	eMLC	0 to 70°C
VRFS22400GFCySz	6Gbps	Enterprise	512	400	781,422,768	SLC	0 to 70°C
VRFS22400GFIyMz	6Gbps	Enterprise	512	400	781,422,768	MLC	-40 to +85°C
VRFS22300GFCyMz	6Gbps	Enterprise	384	300	585,937,500	MLC	0 to 70°C
VRFS22300GFCyEz	6Gbps	Enterprise	384	300	585,937,500	eMLC	0 to 70°C
VRFS22300GFIyMz	6Gbps	Enterprise	384	300	585,937,500	MLC	-40 to +85°C
VRFS22240GFCyEz	6Gbps	Enterprise	256	240	468,862,128	eMLC	0 to 70°C
VRFS22240GFCySz	6Gbps	Enterprise	256	240	468,862,128	SLC	0 to 70°C
VRFS22200GFCyMz	6Gbps	Enterprise	256	200	390,721,968	MLC	0 to 70°C
VRFS22200GFCyEz	6Gbps	Enterprise	256	200	390,721,968	eMLC	0 to 70°C
VRFS22200GFCySz	6Gbps	Enterprise	256	200	390,721,968	SLC	0 to 70°C
VRFS22200GFIyMz	6Gbps	Enterprise	256	200	390,721,968	MLC	-40 to +85°C
VRFS22100GFCyMz	6Gbps	Enterprise	128	100	195,371,568	MLC	0 to 70°C
VRFS22100GFCyEz	6Gbps	Enterprise	128	100	195,371,568	eMLC	0 to 70°C
VRFS22100GFCySz	6Gbps	Enterprise	128	100	195,371,568	SLC	0 to 70°C
VRFS22100GFIyMz	6Gbps	Enterprise	128	100	195,371,568	MLC	-40 to +85°C
VRFS22075GFCySz	6Gbps	Enterprise	128	75	146,533,968	SLC	0 to 70°C
VRFS22050GFCyEz	6Gbps	Enterprise	64	50	97,696,368	eMLC	0 to 70°C
VRFS22050GFCySz	6Gbps	Enterprise	64	50	97,696,368	SLC	0 to 70°C
VRFS22025GFCySz	6Gbps	Enterprise	32	25	48,858,768	SLC	0 to 70°C
VRFS22012GFCySz	6Gbps	Enterprise	16	12	23,437,500	SLC	0 to 70°C
VRFS21400GBCyMz	3Gbps	Enterprise	512	400	781,422,768	MLC	0 to 70°C
VRFS21200GBCyMz	3Gbps	Enterprise	256	200	390,721,968	MLC	0 to 70°C
VRFS21200GBCyEz	3Gbps	Enterprise	256	200	390,721,968	eMLC	0 to 70°C
VRFS21200GBCySz	3Gbps	Enterprise	256	200	390,721,968	SLC	0 to 70°C
VRFS21100GBCyMz	3Gbps	Enterprise	128	100	195,371,568	MLC	0 to 70°C
VRFS21100GBCyEz	3Gbps	Enterprise	128	100	195,371,568	eMLC	0 to 70°C
VRFS21100GBCySz	3Gbps	Enterprise	128	100	195,371,568	SLC	0 to 70°C

Part Number	SATA Interface	Application	Raw Capacity (GB)	Unformatted Useable Capacity (GB)[1]	Minimum Total User Addressable Sectors in LBA Mode	NAND Technology	Temperature Range
VRFS21050GBCySz	3Gbps	Enterprise	64	50	97,696,368	SLC	0 to 70°C
VRFS21025GBCySz	3Gbps	Enterprise	32	25	48,858,768	SLC	0 to 70°C
VRFS22480GMCyMz	6Gbps	Client	512	480	937,703,088	MLC	0 to 70°C
VRFS22480GMCyEz	6Gbps	Client	512	480	937,703,088	eMLC	0 to 70°C
VRFS22480GKIyMz	6Gbps	Client	512	480	937,703,088	MLC	-40 to +85°C
VRFS22400GKIyMz	6Gbps	Client	512	400	781,422,768	MLC	-40 to +85°C
VRFS22400GKIyEz	6Gbps	Client	512	400	781,422,768	eMLC	-40 to +85°C
VRFS22400GKIySz	6Gbps	Client	512	400	781,422,768	SLC	-40 to +85°C
VRFS22240GMCyMz	6Gbps	Client	256	240	468,862,128	MLC	0 to 70°C
VRFS22240GKIyEz	6Gbps	Client	256	240	468,862,128	eMLC	-40 to +85°C
VRFS22240GMIySz	6Gbps	Client	256	240	468,862,128	SLC	-40 to +85°C
VRFS22240GKIySz	6Gbps	Client	256	240	468,862,128	SLC	-40 to +85°C
VRFS22200GKIyMz	6Gbps	Client	256	200	390,721,968	MLC	-40 to +85°C
VRFS22200GKIyEz	6Gbps	Client	256	200	390,721,968	eMLC	-40 to +85°C
VRFS22200GKIySz	6Gbps	Client	256	200	390,721,968	SLC	-40 to +85°C
VRFS21200GKMySz	6Gbps	Client	256	200	390,721,968	SLC	-40 to +85°C
VRFS22120GMCyMz	6Gbps	Client	128	120	234,441,648	MLC	0 to 70°C
VRFS22120GMCySz	6Gbps	Client	128	120	234,441,648	SLC	0 to 70°C
VRFS21120GKMySz	6Gbps	Client	128	120	234,441,648	SLC	-40 to +85°C
VRFS22120GMIySz	6Gbps	Client	128	120	234,441,648	SLC	-40 to +85°C
VRFS22120GKIySz	6Gbps	Client	128	120	234,441,648	SLC	-40 to +85°C
VRFS22100GKIyMz	6Gbps	Client	128	100	195,371,568	MLC	-40 to +85°C
VRFS22100GKIyEz	6Gbps	Client	128	100	195,371,568	eMLC	-40 to +85°C
VRFS22100GKIySz	6Gbps	Client	128	100	195,371,568	SLC	-40 to +85°C
VRFS21100GKMySz	6Gbps	Client	128	100	195,371,568	SLC	-40 to +85°C
VRFS22360GMCyMz	6Gbps	Client	64	60	117,231,408	MLC	0 to 70°C
VRFS22060GMCySz	6Gbps	Client	64	60	117,231,408	SLC	0 to 70°C
VRFS21060GKMySz	6Gbps	Client	64	60	117,231,408	SLC	-40 to +85°C
VRFS22060GMIySz	6Gbps	Client	64	60	117,231,408	SLC	-40 to +85°C
VRFS22060GKIySz	6Gbps	Client	64	60	117,231,408	SLC	-40 to +85°C
VRFS22050GKIyMz	6Gbps	Client	64	50	97,696,368	MLC	-40 to +85°C
VRFS22050GKIyEz	6Gbps	Client	64	50	97,696,368	eMLC	-40 to +85°C
VRFS22050GKIySz	6Gbps	Client	64	50	97,696,368	SLC	-40 to +85°C

Part Number	SATA Interface	Application	Raw Capacity (GB)	Unformatted Useable Capacity (GB)[1]	Minimum Total User Addressable Sectors in LBA Mode	NAND Technology	Temperature Range
VRFS21050GKMySz	6Gbps	Client	64	50	97,696,368	SLC	-40 to +85°C
VRFS22045GMCySz	6Gbps	Client	64	45	87,890,625	SLC	0 to 70°C
VRFS22030GMCySz	6Gbps	Client	32	30	58,593,750	SLC	0 to 70°C
VRFS22030GMIySz	6Gbps	Client	32	30	58,593,750	SLC	-40 to +85°C
VRFS22030GKIySz	6Gbps	Client	30	30	58,626,288	SLC	-40 to +85°C
VRFS22025GKIySz	6Gbps	Client	64	25	48,858,768	SLC	-40 to +85°C
VRFS21025GKMySz	6Gbps	Client	32	25	48,858,768	SLC	-40 to +85°C
VRFS22014GMCySz	6Gbps	Client	16	14	27,343,750	SLC	0 to 70°C
VRFS21480GACyMz	3Gbps	Client	512	480	937,703,088	MLC	0 to 70°C
VRFS21400GACyMz	3Gbps	Client	512	400	781,422,768	MLC	0 to 70°C
VRFS21240GAIySz	3Gbps	Client	256	240	468,862,128	SLC	-40 to +85°C
VRFS21235GACyMz	3Gbps	Client	256	235	458,984,375	MLC	0 to 70°C
VRFS21235GAIyMz	3Gbps	Client	256	235	458,984,375	MLC	-40 to +85°C
VRFS21200GACyMz	3Gbps	Client	256	200	390,721,968	MLC	0 to 70°C
VRFS21200GACySz	3Gbps	Client	256	200	390,721,968	SLC	0 to 70°C
VRFS21115GACyMz	3Gbps	Client	128	115	224,609,375	MLC	0 to 70°C
VRFS21115GAIyMz	3Gbps	Client	128	115	224,609,375	MLC	-40 to +85°C
VRFS21100GACySz	3Gbps	Client	128	100	195,371,568	SLC	0 to 70°C
VRFS21060GAIyMz	3Gbps	Client	64	60	117,231,408	MLC	-40 to +85°C
VRFS21060GAIySz	3Gbps	Client	64	60	117,231,408	SLC	-40 to +85°C
VRFS21050GACyMz	3Gbps	Client	64	50	97,696,368	MLC	0 to 70°C
VRFS21050GACySz	3Gbps	Client	64	50	97,696,368	SLC	0 to 70°C
VRFS21050GAIyMz	3Gbps	Client	64	50	97,696,368	MLC	-40 to +85°C
VRFS21025GACySz	3Gbps	Client	32	25	48,858,768	SLC	0 to 70°C
VRFS21025GAIySz	3Gbps	Client	32	25	48,858,768	SLC	-40 to +85°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) Contact Viking for the character that "y" represents in the part number.
5) z = character(s) for device die revisions and 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.

Viking's solid state drives are available in Enterprise and Client versions:

Enterprise – An Enterprise SSD contains hardware and firmware that detect and manage power failures. This allows the drive to flush the controller cache and harden data to NAND flash. No data is lost or corrupted.

Client – A Client SSD does not include power failure detection or management features. MLC NAND, as opposed to SLC NAND, can become corrupted if power is removed during a write, also known as lower page corruption. Therefore, a Client SSD using MLC NAND is well-suited in a system that already manages power fail events, allowing for graceful SSD shutdown. Accordingly, system support should include issuing a Standby Immediate command to the SSD while maintaining power for at least 50ms.

If a Client drive with MLC NAND is used in a system that does not manage power failures and shutdowns, there is a small chance of data corruption. Viking Client SSDs take sophisticated hardware and firmware measures to prevent or mitigate such issues making the chance of corruption very small.

If the SSD controller detects data corruption, the drive will be locked. The only way to recover the drive is to return it to the factory for reprogramming; all data will be lost.

Product Picture(s)

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1 Introduction

1.1 Features

Viking's rugged industrial 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

Table 1-1: Element SSD Features

The Element SSD delivers the following features:

Feature	VRFS2xGA (3 Gbps)	VRFS2xGB (3 Gbps)	VRFS2xGF (6 Gbps)	VRFS2xGK VRFS2xGM (6 Gbps)
Best in class sequential and random Read/Write performance		•	•	•
Seamless SATA Revision 2.x interface support for SATA up to 3 Gbps)	•	•	•	•
Seamless SATA Revision 3.x interface support for SATA up to 6 Gbps)			•	•
Power hold-up circuit technology ensures no data loss resulting from an unexpected power loss and is supported for industrial temperatures		•	•	
PFAIL/DHARD signaling with the host	•			
Support for ONFi and Toggle Mode NAND			•	•
Low overall SSD power consumption	•	•	•	•
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, eMLC and MLC NAND flash technologies	•	•	•	•
Protection against catastrophic flash page and block failures	•	•	•	•
AES-128 encryption in CTR mode	•	•	•	•
AES-256 encryption in XTS 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	•	•	•	•
Customer selectable Drive Life Protection (Factory setting is 3 years)	•	•	•	•
Thermal sensing energy management	•	•	•	•
Stainless steel housing for ruggedness, low EMI/ESD, and thermal management	•	•	•	•
RoHS and WEEE compliant	•	•	•	•

1.2 Block Diagram

Figure 1-1: Block Diagram for Enterprise Series: VRFS2xGB and VRFS2xGF

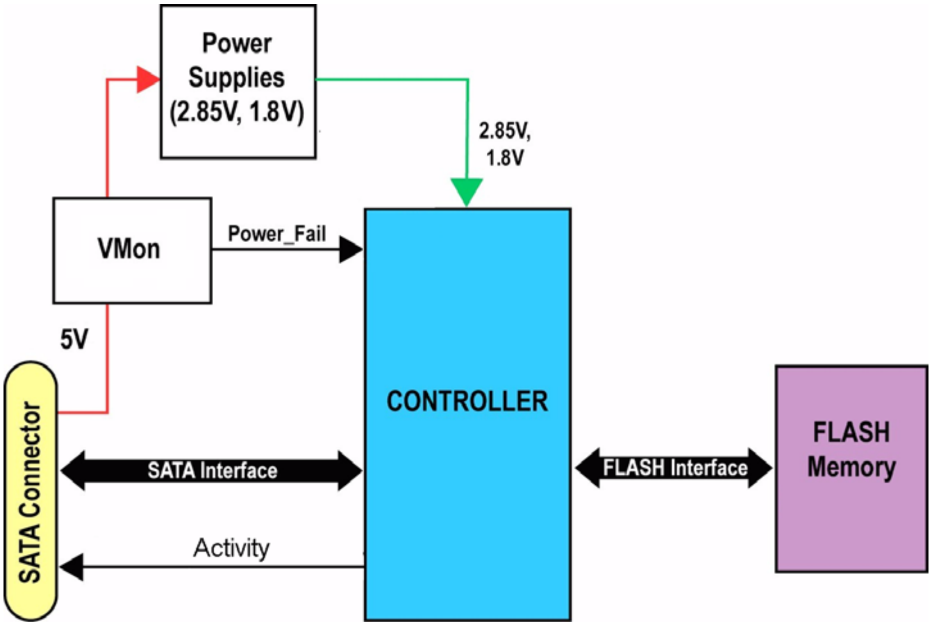
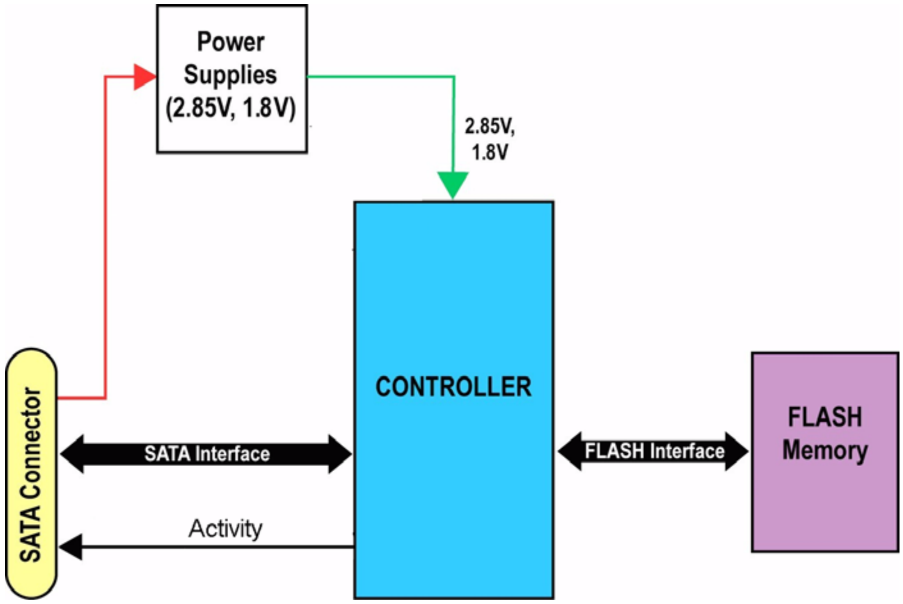


Figure 1-2: Block Diagram for Client/Industrial: VRFS2xGA, VRFS2xGK, VRFS2xGM, VRFS2xGH, VRFS2xGJ



1.3 3 Gbps SATA Interface for VRFS2xGA and VRFS2xGB

- The Serial ATA (SATA) interface is compliant with the SATA IO Serial ATA specification, Revision 2.6 that supports SATA up to 3 Gbps.
- The SATA interface connects the host computer to the SSD subsystem.
- The SATA interface runs at a maximum speed of 3Gbps (gigabits per second). If the host computer is unable to negotiate a speed of 3 Gbps, the SATA interface automatically renegotiates to a speed of 1.5 Gbps.

1.4 6 Gbps SATA Interface for VRFS2xGF, VRFS2xGK, VRFS2xGM, VRFS2xGH, VRFS2xGJ

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

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

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 LBAs that 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

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

Access Type	VRFS2xGA VRFS2xGB	VRFS2xGF	VRFS2xGK	VRFS2xGM	Units
Sequential Read, 128K block size	Up to 260	Up to 520	TBD	TBD	MB/s
Sequential Write, 128K block size	Up to 260	Up to 520	TBD	TBD	MB/s
Random Read, 4K block size	Up to 30,000	Up to 60,000	TBD	TBD	IOPS
Random Write, 4K block size	Up to 30,000	Up to 60,000	TBD	TBD	IOPS

Notes:

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

2.2 Timing

Table 2-2: Timing Specifications

Type	**Average Latency (**ms) Write Cache Enabled
Power On to Ready	<1
Reset to Ready	<2
Command to DRQ	<1
Time to Erase (ATA Secure Erase)	4 second (entire drive)

Notes:

1. Based on MLC NAND
2. Device measured using IOMETER 08, Queue depth set to 32 for NCQ
3. Sector Read/Write latency measured up ton 4K block size (512B/sector = 1 Block), random access
4. Sequential IOPS cover the entire range of valid logical block addresses (LBAs). Measurements are performed on a full drive (all LBAs 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 Timing

Power Cycle Endurance	Min	Max	Unit
STANDBY IMMEDIATE to WE completed		40	ms

2.3 Electrical Characteristics

2.3.1 Absolute Maximum Ratings

Table 2-4: Absolute Maximum Ratings

Description	Min	Max	Unit
Maximum Voltage Range for Vin	-0.6	6.0	V
Maximum Temperature Range	-40	85	c

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

2.3.2 Supply Voltage

2.5" SDD's operate at 5V. (3.3V not connected = open circuit).

Table 2-5: Operating Voltage

Description	Min	Max	Unit
Operating Voltage for 5 V (+/- 5%)	4.75	5.25	V

Note: The maximum charge time for the hold-up circuit from zero charge to full charge/ready is 17 seconds.

2.3.3 Supply Current

Table 2-6: Current, 5V input

Mode	VRFS2xxGAxx, VRFS2xxGBxx [1]	VRFS2xxGFxx	VRFS2xxGKxx	VRFS2xxGMxx VRFS2xGHxx VRFS2xGJxx	Unit
Initial Power up[2]	3000	2000	TBD	TBD	mA max
Idle (> 3.5 seconds after Power up (hold-up circuit fully charged)	100	232	TBD	TBD	mA rms
Read/Writes	200	460 to 860	TBD	TBD	mA rms
Peak	400	1730	TBD	TBD	mA

Notes:
1. Table values based on 400GB drive.
2. The charging of the hold-up circuit contributes to a higher inrush current upon initial power up when the hold-up circuit is discharged. Maximum current is limited to 3A.

2.3.4 Power Consumption

All onboard power requirements of the Element SSD are derived from the SATA 5V input rail.

Table 2-7: Typical Power Consumption at 5V

Mode	VRFS2xxGAxx, VRFS2xxGBxx	VRFS2xxGFxx	VRFS2xxGKxx	VRFS2xxGMxx VRFS2xGHxx VRFS2xGJxx	Unit
Typical	1	2.3 to 4.3	TBD	TBD	W
Worse Case (max)	2	8.65	TBD	TBD	W
Idle	0.5	1.16	TBD	TBD	W

Notes:

1. Typical power consumption is that of a device with 400GB of physical capacity.

2.4 Environmental Conditions

2.4.1 Temperature and Altitude

Table 2-8: Temperature and Altitude Related Specifications

Condition	Operating	Shipping	Storage
Commercial Temperature - Ambient	0 to 70°c (32 to 158° F)	-40 to 85°c (-40 to 185° F)	-40 to 85°c (-40 to 185° F)
Industrial Temperature[1] - Ambient	-40 to 85°c (-40 to 185° 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	-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 24,384m (-1,000 to 80,000 ft)
Storage Time	n/a	n/a	1 year[2]

Notes:

1. For 3GBps VRFS2xGB series SSD's only, the maximum ambient temperature outside the SSD should not exceed 55° so that the internal holdup circuit has a lifespan of 5 years.
2. Also refer to data retention specifications.

2.4.2 Shock and Vibration

Table 2-9: Shock and Vibration Specifications

Stimulus	Mode	Timing	Max	Unit
Shock[1]	Operating and Non-Operating	50g (11ms/Axis)x3 Axis, 1/2 Sine Wave, positive and negative		
Vibration[2]	Operating and Non-Operating	16.4g rms 10~2000Hz 3 Axis		

Notes:

1. Shock and Vibration specifications assumes that the SSD is mounted securely with the input vibrations applied to the drive mounting screws. Stimulus may be applied in the X, Y, or Z axis.
2. Sine wave sweeping x oct/min.
3. Tested in accordance to MIL STD-810F

2.4.3 Electromagnetic Compatibility

Electromagnetic Compatibility tests assume the SSD is properly installed in the representative host system. The drive will operate properly without errors or degradation in performance when subjected to environments defined in the following table:

Table 2-10: Electromagnetic Compatibility Specifications

Test	Description	Performance Criteria	Reference Standard
Electrostatic discharge	Contact, HCP, VCP: ±8 kV; Air: ±15 kV	B	EN 61000-4-2: 1995
Radiated RF Immunity	80 to 6,000 MHz, 3 V/m, 80% AM with 1 kHz sine	A	EN 61000-4-3: 2002 ENV 50204: 1995
Surge Immunity	±1 kV differential, ±2 kV common, AC mains	B	EN 61000-4-5: 1995
Conducted RF Immunity	150 kHz to 80 MHz, 3 Vrms, 80% AM with 1 kHz sine	A	EN 61000-4-6: 1996

Notes:

1. **Performance Criteria A of CE spec =** The device shall continue to operate as intended, i.e., normal unit operation with no degradation of performance.
2. **Performance Criteria B of CE spec =** The device shall continue to operate as intended after completion of the test. However, during the test, some function degradation of performance is allowed as long as there is no data loss operator intervention to restore device function.
3. Electrostatic discharge applied to drive enclosure.

2.5 Reliability

Table 2-11: Reliability Specifications

Parameter	Value
Non-recoverable read errors (UBER)[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 cell
Data retention	See Note 5

Notes:

1. Uncorrectable Bit Error rate (UBER) 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^{o}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 write/erase cell endurance than MLC NAND; varies by NAND component.
5. 10 years for P-E cycle counts < 10% of NAND spec and 1 year for max-spec P-E cycle counts per JEDEC-STD-JESD47) Refer to Viking Application Note AN0011 – Flash Data Retention

2.5.1 Data, MetaData, and Firmware Code Protection

Element SSD 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:

- For Flash memory devices providing 128 bytes of redundancy per 4k of data (normally this is SLC Flash)
  - 16 bytes of redundancy applied to 512 bytes of data
  - Up to seven 9-bit symbols (up to 63 bits if contiguous) correctable
- For Flash memory devices providing 218 or more bytes of redundancy per 4k of data (normally this is MLC Flash)
  - 27 bytes of redundancy applied to 512 bytes of data
  - Up to twelve 9-bit symbols (up to 108 bits if contiguous) correctable

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 to correct silent errors not detected by other schemes.

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

Element SSD implements proprietary R.A.I.S.E.™ (Redundant Array of Independent Silicon Elements) data protection, to overcome the probabilistic risk of page or block failure inherent in all Flash memory technology.

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.

Element SSD 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 impacted, but after recovery is complete, Element SSD 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, Element SSD 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, Element SSD 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 Element SSD with RAISE™ approach is significant. Additionally, following recovery from a page failure or block failure, Element SSD is fully functional and fully reliable, whereas a page-failed or block-failed drive recovered by system RAID must be immediately replaced.

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 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 minimizes re-writes of identical data, to maximize the effectiveness of the wear-leveling process.

2.5.4 Data Integrity Assurance After Unexpected Power Loss

2.5.4.1 Integrated Hold Up Circuit

The Element architecture has an integrated hold-up circuit that powers the module for short period of time after a power failure. In the event of an unexpected loss of power, the hold up circuit is used to supply power to the module to allow the controller time to harden data to the non-volatile NAND flash.

Note: This feature is not available for client and industrial versions which are VRFS2xGA and VRFS2xGK. These configurations utilizes routine check-pointing to limit data loss in the event of power failure.

1. Check-pointing writes meta data to flash
2. Checkpoints occur
    - Regularly, while writing
    - After 2 seconds of idle time
    - When a Standby Immediate command is issued
    - As Optional setting to support Flush Cache command
3. On power loss event
    - Data in transit is lost
    - Data being written to flash is lost
4. On Startup, firmware checks if power loss occurred or if drive was safely shutdown
    - If this check fails, then the drive will verify last good checkpoint and rebuild meta data
    - The Quick Boot is ~ 1.5 seconds after safe shutdown and a longer boot is ~ 5-10 seconds if recovering from an unsafe shutdown

2.6 Data Security

Viking Element SSD's are self-encrypting drives (SED), with a bulk data encryption feature that provides automatic hardware-based data security and enhanced secure erase capability.

A self-encrypting drive, scrambles data using a data encryption key as it is written to the drive and then descrambles it with the key as it is retrieved. This gives the user the highest level of data protection available and provides a fast erase simply by deleting the encryption key, eliminating the need for time consuming data-overwrite. Data on the drive is instantly rendered unreadable.

The Element SSD supports AES-128 encryption (in CTR mode) and ATA Secure Erase features to protect sensitive data. The VRFS2xGF, VRFS2xGM, VRFS2xGK, VRFS2xxGMxx, VRFS2xGHxx and VRFS2xGJxx series also supports AES-256 encryption (in XTS mode) and TCG security enhancements.

The ATA Security Erase Unit command, which is usually password protected, will erase:

- All map data
- The encryption key (All data in flash is scrambled and unrecoverable)

and the resulting condition of the drive after an ATA Security Erase will be:

- Any reads to the drive will respond with zero for every LBA
- Any writes to the drive will act as if the drive has nothing; a T0 state.

If the flash memory was directly probed, some scrambled data might be retrievable, but there would be no way to decode it without the encryption key.

2.6.1 Secure Erase Support

In the following table are the supported Secure Erase Commands for the Element SSD.

Table 2-12: Element SSD Secure Erase Commands

Command	Action	SSD Code[1]	Time to Execute
Secure Erase	• Erase all map data • Erase encryption key • Erase all LBAs • Erase SMART attributes, logs, thresholds • Reset/Regenerate a new AES key	Note 1	< 4 seconds
Secure Erase with Flash Erase	Secure Erase actins plus the erasure of all encrypted data and blocks in flash memory	Note 1	~1 second/GB

Notes:

1. Enabled in firmware at the time of manufacture and prior to shipping from the factory

There are two primary reasons for performing a Secure Erase on an SSD. The first and perhaps the most important is to remove ultra-sensitive data from the drive to prevent any access and ensure the privacy of information previously stored in the flash. This aspect of the secure erase is often required by some military or government agencies.

The second reason for a Secure Erase is to initialize the drive to a known starting point for benchmarking purposes or to increase performance and/or capacity by eliminating any preconditioning.

Unlike the ATA Security Erase Unit command which only erases the map data and the encryption key for the encrypted data in flash memory, the Secure Erase command will also:

- Erase all map data (and checks the drive to ensure map loss is persistent)
- Erase encryption key (All data in flash is scrambled and unrecoverable)
- Erase all LBAs (0 to MAX) in DEVICE CONFIGURATION IDENTIFY
- Erase SMART Attributes 1, 13, 195, 199, 201, 204 (clear by power cycle)
- Erase SMART Logs
- Erase SMART Thresholds (and return to default)
- Reset and regenerate a new AES key to apply to all data

In less than 4 seconds after a Secure Erase command, scrambled encrypted data cannot be located or retrieved.

The SSD also has an optional Cryptographic Erase *plus Physical Flash Erase* command where in addition to a Secure Erase, all encrypted, unreadable data and all Flash blocks (excluding FW blocks) are erased. Persistent drive life data is rewritten to the flash blocks after erase. The operation time for a Cryptographic Erase with Physical Flash Erase is ~ 1 second/GByte.

2.6.1.1 Military Secure Erase / Sanitization

Many government and military organizations such as NIST/NSA define their own standard and procedures for performing a Military Secure Erase which overwrite different patterns to sanitize the flash media. Some of the more common military or government purge routines are defined in the following table and the data security features of the drive comply with Department of Defense (DoD) and US military data security standards.

Table 2-13: Military Secure Erase / Sanitize Routines

Standard	Action	SSD Code[1]
NSA/CSS 9-12	Erase and overwrite all locations with a known unclassified pattern. Verify the overwrite procedure by randomly rereading the overwritten information to confirm that only the known pattern can be recovered.	Note 1
NSA/CSS 130-2	Erase the media and overwrite with random data 2 times, then erase and overwrite with a character	Note 1
DoD5220.22-M NISPOM	Erase the media and overwrite with single character, then erase again	Note 1
DoD5220.22-M NISPOM Sup 1	Erase the media and overwrite with single character, then erase again and overwrite with single character, then erase again and overwrite with random character then erase again	Note 1
USA Army 380-19	Erase the media and overwrite with random data, erase and overwrite with a character, then erase and overwrite with complement of the character	Note 1
Navy NAVSO P-5239-26	Erase the media and overwrite with random data, then erase again	Note 1
Air Force AFSSI 5020	Erase the media and overwrite with pattern, repeat 3 times	Note 1
IRIG 106-2007 IRIG 106-07, Ch. 10.8	Erase the media, overwrite with 0x55, erase, overwrite with 0xAA, and then erase again. Then fill the drive with a repeating string of Secure Erase.	N/A

Notes:

1. Enabled in firmware at the time of manufacture and prior to shipping from the factory
2. NSA/CSS 9-12 is the factory default unless otherwise requested.

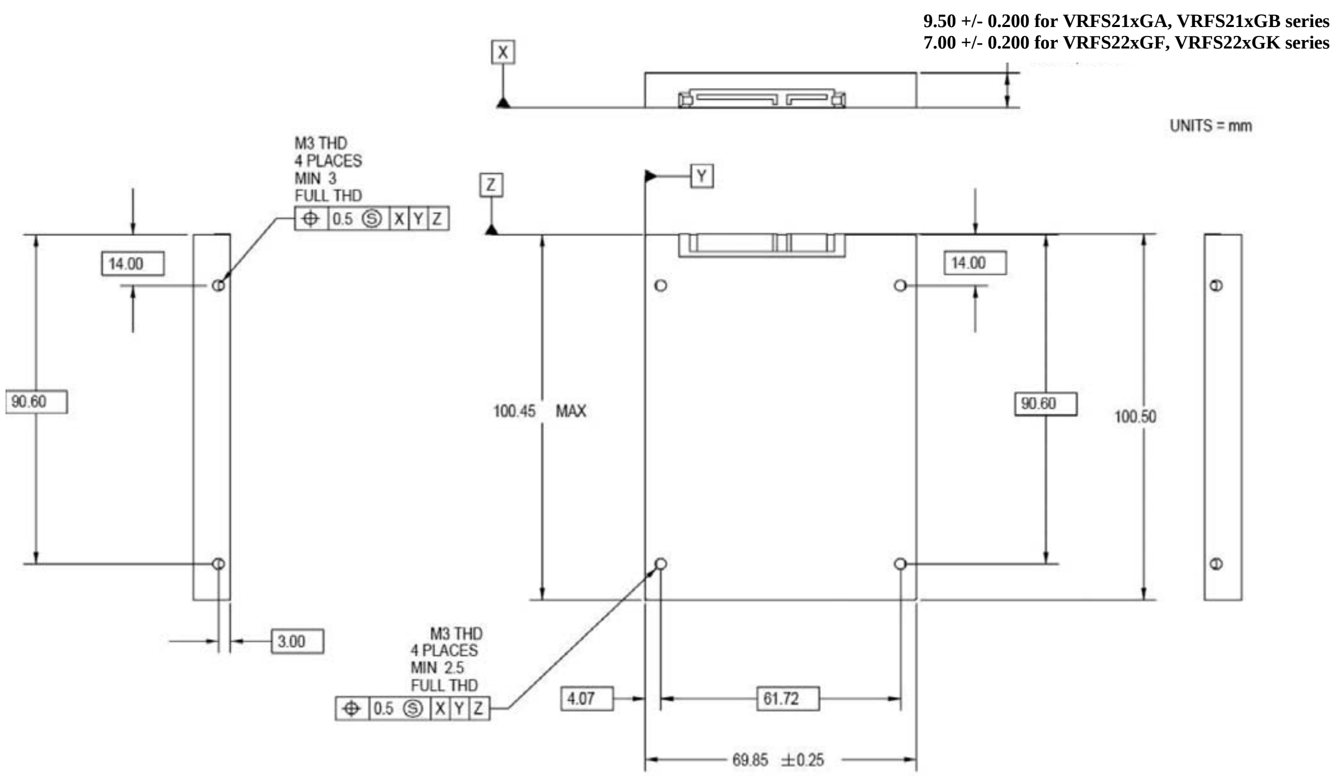
3 Mechanical Information

3.1 *Element SSD Physical Dimensions*

Table 3-1: Physical Dimensions

Dimensions	VRFS21xGA , VRFS21xGB	VRFS22xGF, VRFS22xGK, VRFS22xGM VRFS2xGH VRFS2xGJ	Units
Height / Thickness	9.5	7	mm
Width	69.85	69.85	mm
Length	100.50 max	100.50 max	mm

Figure 3-1: 2.5" SSD Dimensions



Note: All dimensions are in millimeters, +/- 0.2mm, unless otherwise stated . Reference SATA connector specifications

3.2 Element SSD Weight

The weight of a 2.5" SSD is approximately 80 grams.

4 Pin and Signal Descriptions

4.1 SSD Signal and Power Description Tables

Table 4-1: Serial ATA Connector Pin Signal Definitions

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

Note: 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 (open circuit)	2nd
P2	3.3V_2	No connection (open circuit)	2nd
P3	3.3V_3	No connection (open circuit)	1st
P4	GND_1	Ground	1st
P5	GND_2	Ground	1st
P6	GND_3	Ground	1st
P7	5V_1	5VDC Power	1st
P8	5V_2	5VDC Power	2nd
P9	5V_3	5VDC Power	2nd
P10	GND_4	Ground	1st
P11	Activity	Device Activity Signal[1]	2nd
P12	GND_5	Ground	1st
P13	12V_1	No connection (open circuit) Optional 10k-ohm PD for legacy support on old versions.	
P14	12V_2		
P15	12V_3		

Note:

1) Open drain to drive host or LED. Pullup to 2.85V through 11K. V_o<0.4V@30mA

4.2 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 and SATA 3 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

		Support	
Feature Set	**ATA-8 REF**	**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			

5.1 ATA Commands

Table 5-2: ATA Commands

ATA-8 REF	Commands	ATA-8	Sup	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	DevCgfldfy, 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	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
-	SEEK	M	YES			70h-7Fh
7.47	SERVICE	O	NO	Service, SRVC	TCQ	A2h
7.48	SET FEATURES	M	YES	SetFeature, SETF	General	EFh

ATA-8 REF	Commands	ATA-8	Sup	Key Word Option	Feature Set	OP
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	S.M.A.R.T. DISABLE OPERATION	M	YES	SmDisable, SDSO, SMDI	S.M.A.R.T.	B0h/D9h
-	S.M.A.R.T. ENABLE/DISABLE AUTO OFF-LINE	Obs	YES		S.M.A.R.T.	B0h-DBh
7.53.3	S.M.A.R.T. ENABLE/DISABLE AUTOSAVE	M	YES	SmAutoSv, SAAS, SMAS	S.M.A.R.T.	B0h/D2h
7.53.4	S.M.A.R.T. ENABLE OPERATION	M	YES	SmEnable, SESO, SMEN	S.M.A.R.T.	B0h/D8h
7.53.5	S.M.A.R.T. EXECUTE OFFLINE IMMEDIATE	O	YES	ExeSmOL, SEOI, SMOI	S.M.A.R.T.	B0h/D4h
7.53.6	S.M.A.R.T. READ DATA	O	YES	SmRdData, SRLS, SMRD	S.M.A.R.T.	B0h/D0h
7.53.7	S.M.A.R.T. READ LOG	O	YES	SmRdLog, SRLS, SMRL	S.M.A.R.T.	B0h/D5h
-	S.M.A.R.T. READ THRESHOLD	Obs	YES		S.M.A.R.T.	B0h-D1h
7.53.8	S.M.A.R.T. RETURN STATUS	O	YES	SmStatus, SRSS	S.M.A.R.T.	B0h/DAh
-	S.M.A.R.T. SAVE ATB VALUES	Obs	YES		S.M.A.R.T.	B0h-D3h
7.53.9	S.M.A.R.T. WRITE LOG	O	YES	SmWrLog, SWLS, SMWL	S.M.A.R.T.	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
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

ATA-8 REF	Commands	ATA-8	Sup	Key Word Option	Feature Set	OP
-	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

The Element SSD 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

The Element SSD supports the ATA General Feature command set consisting of:

- 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

The Element SSD 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

The Element SSD supports the General Purpose Log command set consisting of:

- Read Log Ext
- Write Log Ext

5.1.5 Host Protected Area Command Set

The Element SSD 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)
- Set Max Unlock (optional)

5.1.6 Power Management Command Set

The Element SSD 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

The Element SSD 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)

5.1.8 S.M.A.R.T. Support

Data storage drives capture a variety of information during operation that may be used to analyze drive —health. Drive manufacturers have adopted S.M.A.R.T. (Self-Monitoring, Analysis, and Reporting Technology) to help warn system software, a system administrator, or a user of impending drive failure, while time remains to take preventive 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.

5.1.8.1 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.*	

5.1.8.2 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

Value	Description
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

5.1.8.3 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.

5.1.8.4 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.

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.

5.1.9 S.M.A.R.T. Attributes

5.1.9.1 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.
13	0x0D	Soft Read Error Rate	The number of corrected (CECC) read errors reported. This feature is not available for industrial versions, which are VRFS2xGA, VRFS2xGK and VRFS2xGM.
100	0x64	Gigabytes Erased	This attribute counts the Gigabytes of Flash memory erases across the entire drive, over the life of the drive. This feature is not available for industrial versions, which are VRFS2xGA, VRFS2xGK and VRFS2xGM.
170	0xAA	Reserved Block Count	The number of reserved spares for bad block handling. This feature is not available for industrial versions, which are VRFS2xGA, VRFS2xGK and VRFS2xGM.
171/181	0xAB	Program Fail Count	Counts the number of flash program failures
172/182	0xAC	Erase Fail Count	Counts the number of flash erase failures
174	0xAE	Unexpected power loss	Controller has detected a loss of power

ID	Hex	Attribute Name	Description
177	0xB1	Wear range Delta	% from most to least worn
184	0xB8	Reported I/O Error Detection Code Rate	I/O Error Detection Code rate. This attribute tracks the number of end-to-end CRC errors encountered during host initiated reads and writes. This feature is not available for industrial versions, which are VRFS2xGA, VRFS2xGK and VRFS2xGM.
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 ISTW interface.
195	0xC3	ECC On the Fly Count	This attribute tracks the number of uncorrectable errors (UECC).
196	0xC4	Reallocation Count	This attribute tracks the number of blocks that fail programming which are reallocated.
198	0xC6	Uncorrectable Sector Count	The total number of uncorrectable RAISE (URAISE) errors when reading/writing a sector. A rise in the value of this attribute indicates defects of the flash memory device. This feature is not available for industrial versions, which are VRFS2xGA, VRFS2xGK and VRFS2xGM.
199	0xC7	SATA R-Errors (CRC) Error Count	SATA R-Errors (CRC) Error Count. This feature is not available for industrial versions, which are VRFS2xGA, VRFS2xGK and VRFS2xGM.
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)
230	0xE6	Life Curve Status	A life curve used to help predict life in terms of the endurance based on the number of writes to flash. This feature is not available for industrial versions, which are VRFS2xGA, VRFS2xGK and VRFS2xGM.
231	0xE7	SSD Life Left	Indicates the approximate percentage of SSD life left.
232	0xE8	Available Reserved Space	The number of reserved blocks remaining. This feature is not available for industrial versions, which are VRFS2xGA, VRFS2xGK and VRFS2xGM.
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.

A number of S.M.A.R.T. attributes relate to correctable and uncorrectable ECC, and RAISE errors. The figure below summarizes each ECC and RAISE error category and shows which errors the applicable S.M.A.R.T. attributes track.

Figure 5-1: S.M.A.R.T. ECC and RAISE Error Summary for Enterprise versions: VRFS2xGB and VRFS2xGF

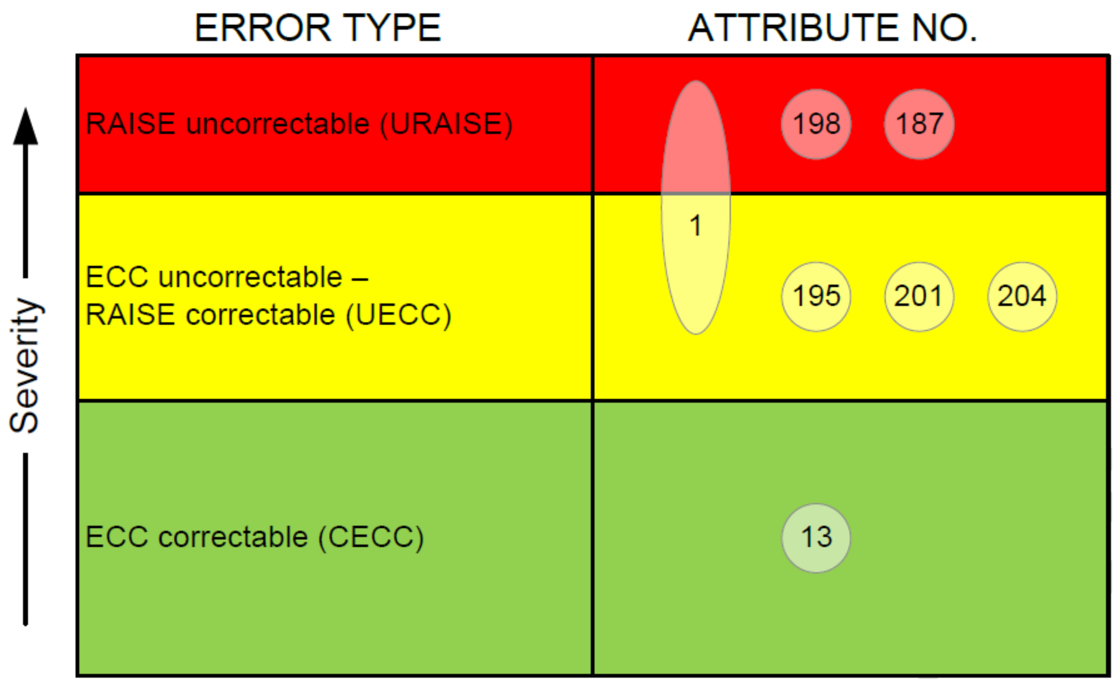
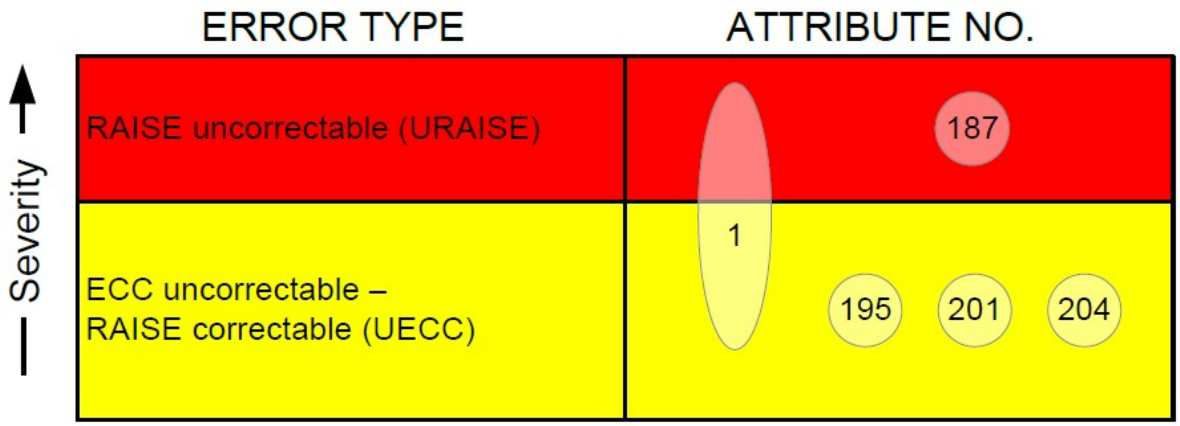


Figure 5-2: S.M.A.R.T. ECC and RAISE Error Summary for Client/Industrial versions: VRFS2xGA, VRFS2xGK, VRFS2xxGM, VRFS2xGH, VRFS2xGJ



5.1.9.2 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	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. Normalized Equation: 10log10(BitsRead/ReadErrors + 1) SectorsRead= Number of sectors read SectorsToBits= 512*8 BitsRead= SectorsRead*SectorsToBits Normalized Value Range: Best = 120 Worst = 38 Invalid = 0 Raw Usage: [3-0] : Number of sectors read [6-4]: Read errors (UECC+URAISE)	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 120 to 38 (representing a BER range of 1.00E-13 to 1.68E-04) are presented. This Attribute reads ‘0’ until a sample size between 10E10 and 10E12 is available to be tracked by this Attribute.

ID	Attribute Name	Description	Rational
5	Retired Block Count	Tracks the total number of retired blocks. <u>Normalized Equation:</u> Count = 100 - (100* RBC / MRB) *RBC = RetiredBlockCount = Number of retired blocks.* *MRB = MinimumReqBlocks = Minimum number of reserve blocks available for CONTROLLER use. This value is set at factory configuration time.* <u>Normalized Value Range:</u> Best = 100 Worst = 0 <u>Raw Usage:</u> [3-0] : Retired block count [6-4] : None (0x00)	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.) As defined, this attribute is identical to the Reallocation Event Count attribute (#196).
9	Power-On Hours (POH)	Count of hours in power-on state. The raw value of this attribute shows total count of hours in the power-on state. <u>Normalized Equation:</u> 100 - (POH / HPY * 10) <u>Normalized Value Range:</u> Best = 100 Worst = 0 <u>Raw Usage:</u> [3-0] : Total number of power-on hours [6-4]: total number of milliseconds since last hour update	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.

ID	Attribute Name	Description	Rational
12	Device Power Cycle Count	This attribute indicates the count of full hard disk power on/off cycles. Normalized Equation: 100 - (PCC / 1024) Normalized Value Range: Best = 100 Worst = 0 Raw Usage: [3-0] : Cumulative lifetime power cycle count (PCC) [6-4] : None (0x00)	The normalized equation for Power Cycle Count decrements by 1 for each 1024 power cycle.
13	Soft Read Error Rate	This attribute tracks the number of correctable ECC errors (CECC). 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. Normalized Equation: 10log10(BitsRead/SoftReadErrors + 1) SectorsRead= Number of sectors read SectorsToBits= 512*8 BitsRead= SectorsRead*SectorsToBits Normalized Value Range: Best = 120 Worst = 38 Invalid = 0 Raw Usage: [3-0] : Number of sectors read [6-4]: Soft Read Error Count (CECC)	The Soft Read Error Rate includes all correctable ECC (CECC) errors tracked by the CONTROLLER. The normalized equation for 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 120 to 38 (representing a BER range of 1.00E-13 to 1.68E-04) are presented. This Attribute reads ‘0’ until a sample size between 10E10 and 10E12 is available to be tracked by this Attribute.

ID	Attribute Name	Description	Rational
100	Gigabytes Erased	This attribute counts the Gigabytes of Flash memory erases across the entire drive, over the life of the drive. Raw Usage: [3-0]: Gigabytes Erased [6-4]: None (0x00)	This Attribute returns a byte count in increments of 64 GBytes. The count represents the number of bytes erased. The The Attribute reads ‘0’ until the byte count reaches 64 GB, at which time the Attribute changes to read ‘64’ (decimal). For Flash memory consisting of 128-page blocks, each page of which is 4k bytes, each 64 GB increment represents an additional 128,000 blocks erased.
170	Reserve Block Count	The number of reserve Flash memory blocks. Usage: [3-0] : Reserve block count [6-4] : None (0x00)	This Attribute is related to attribute 5: Retired Block Count. It provides a count of reserve (over-provisioned) blocks. (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.) The Attribute value is initially the total Reserve Block count. The value is decremented as the reserve block count diminishes over the drive’s life.
171	Program Fail Count	Counts the number of flash program failures. Usage: [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. Usage: [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.

ID	Attribute Name	Description	Rational
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?). Usage: [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.
177	Wear Range Delta	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. Equation: Wear Range Delta = [(MW - LW) / MRW] x 100 *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* Usage: [3-0] : Wear Range delta [6-4] : None (0x00)	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. 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. This attribute may not be accurate until approximately 10% of drive life has been used.
181	Program Fail Count	Counts the number of flash program failures. Usage: [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 171.
182	Erase Fail Count	Counts the number of flash erase failures. Usage: [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 172.

ID	Attribute Name	Description	Rational
184	Reported I/O Error Detection Code Errors (IOEDC errors)	Error Detection Code Errors (IOEDC errors) This attribute tracks the number of I/O errors encountered during reads from flash memory. Normalized Equation: 100 - (IOEDCErrors) Normalized Value Range: Best = 100 Worst = 0 Raw Usage: [3-0] : Cumulative lifetime IOEDC error count [6-4] : None (0x00)	The CONTROLLER SSD processor minimizes the risk of unreported data miscompares by calculating and appending a CRC based on the data and L-page location as it writes to flash. The CRC is subsequently verified when data is read. This attribute tracks any CRC errors encountered in this path. The normalized equation for IOEDC Error Count decrements by 1 for each IOEDC error.
187	Reported Uncorrectable Errors (URAISE)	Uncorrectable Errors (URAISE) This attribute tracks the number of uncorrectable RAISE (URAISE) errors reported back to the host for all data access commands. Normalized Equation: 100 - (URAISE) Normalized Value Range: Best = 100 Worst = 0 Raw Usage: [1-0] : Cumulative lifetime URAISE errors [6-2] : None (0x00)	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.

ID	Attribute Name	Description	Rational
194	Temperature	Temperature of the SSD assembly. That is, the temperature inside the SSD housing. Normalized Equation: Temperature = Temperature (Celsius) Normalized Value Range: Best (lowest) = -127 Worst (highest) = 127 Raw Usage: [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)	The normalized temperature is a straight Celsius value as obtained from the primary SSD temperature sensor. The raw values represent current and historical Celsius temperature values from the primary SSD temperature sensor. 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.

ID	Attribute Name	Description	Rational
195	ECC On-the-Fly Error Count	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 10^10 to 10^12. The count is cleared at power on reset and when >10^12 bits have been read. Normalized Equation: 10log10(BitsRead/ECCOnTheFlyErrors + 1) *SectorsRead= Number of sectors read* *SectorsToBits= 512*8* *BitsRead= SectorsRead*SectorsToBits* Normalized Value Range: Best = 120 Worst = 38 Invalid = 0 Raw Usage: [3-0] : Number of sectors read [6-4]: ECCOnTheFlyErrors (UECC) count	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 120 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. This Attribute reads '0' until a sample size between 10E10 and 10E12 is available to be tracked by this Attribute. Note that many UECC errors counted by this Attribute are corrected by RAISE correction.

ID	Attribute Name	Description	Rational
196	Reallocation Event Count	Tracks the total number of reallocated Flash blocks. <u>Normalized Equation:</u> Count = 100 - (100* RBC / MRB) RBC = RetiredBlockCount = Number of retired blocks. MRB = MinimumReqBlocks = Minimum number of reserve blocks available for CONTROLLER use. This value is set at factory configuration time. <u>Normalized Value Range:</u> Best = 100 Worst = 0 <u>Raw Usage:</u> [3-0] : Retired block count [6-4] : None (0x00)	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.) As defined, this attribute is identical to the Retired Block Count attribute (#5).
198	Uncorrectable Sector Count	The total number of uncorrectable errors when reading/writing a sector. A rise in the value of this attribute indicates defects of the flash memory device. Note that the native CONTROLLER sector size is 4k bytes. Normalized Equation: 10*log10(TotalSectors/URAISE + 1) TotalSectors= Total number of sectors on the drive. URAISE= Uncorrectable Error Count Normalized Value Range: Best = 120 Worst = 38 Invalid = 0 Raw Usage: [3-0] : Uncorrectable sector count (URAISE) this power cycle [6-4] : Number of sectors read this power cycle	The difference between this count and reported uncorrectable will be those errors correctable by RAISE. The normalized equation for this Attribute is logarithmic since the valid BER range of the attribute spans from 1.00E-10 to 1.00E-12. This Attribute reads '120' until a sample size between 10E10 and 10E12 is available to be tracked by this Attribute.

ID	Attribute Name	Description	Rational
199	SATA R-Errors Error Count	This attribute tracks the number SATA TX R_Errors + SATA RX R_Errors. Normalized Equation: 200 - (RErrors * SampleSize / NumSectorsTransferred) Samplesize= 8000 NumSectorsTransferred= Total number of sectors transferred to/from Host Normalized Value Range: Best = 200 Worst = 0 Raw Usage: [3-0] : Current SATA RError count [6-4] : None (0x00)	Normalized equation implemented per Customer request.
201	Uncorrectable Soft Read Error (UECC)	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. Normalized Equation: 10log10(BitsRead/UECC + 1) SectorsRead= Number of sectors read SectorsToBits= 512*8 BitsRead= SectorsRead*SectorsToBits Normalized Value Range: Best = 120 Worst = 38 Invalid = 0 Raw Usage: [3-0] : Number of sectors read [6-4]: Uncorrectable Soft error count (UECC)	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 120 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. This Attribute reads ‘0’ until a sample size between 10E10 and 10E12 is available to be tracked by this Attribute.

ID	Attribute Name	Description	Rational
204	Soft ECC Correction Rate (UECC)	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 10^10 to 10^12. The count is cleared at power on reset and when >10^12 bits have been read. Normalized Equation: 10log10(BitsRead/UECC + 1) SectorsRead= Number of sectors read SectorsToBits= 512*8 BitsRead= SectorsRead*SectorsToBits Normalized Value Range: Best = 120 Worst = 38 Invalid = 0 Raw Usage: [3-0] : Number of sectors read [6-4]: Soft ECC correction count (UECC)	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 120 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. This Attribute reads '0' until a sample size between 10E10 and 10E12 is available to be tracked by this Attribute.
230	Life Curve Status	Current state of drive operation based upon the Life Curve, which is the Flash Program-Erase Cycle usage schedule defined for the drive's warranty period configured by Viking at manufacturing time. Normalized Equation: 100=usage does not require throttling, 90=throttling Normalized Value Range: Best = 100 (positive wrt Life Curve) Worst = 90 (throttling) RawUsage: none	When no throttling is in effect, this value reads 100. If the PE Cycle usage trajectory threatens to violate the Life Curve usage schedule for the block that has the minimum PE cycles left unused, throttling commences to forbid such violation; this value reads 90 while throttling is in effect. If throttling is disabled, this value reads 100 (i.e., throttling is not in effect).

ID	Attribute Name	Description	Rational
231	SSD Life Left	Indicates the approximate SSD life left, in terms of PE cycles and Flash blocks currently available for use. 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) Normalized Value Range: 100 = Best = Full SSD life remains 10 = Replace = Sufficient Flash blocks still in service, but rated PE Cycles consumed 0 = Worst = Insufficient Flash blocks remain in service; EOL; drive is read-only	SSD life left is based on actual usage and takes into account PE cycle consumption and Flash block retirement. 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. Note that block retirement rate also affects SSD life and this Attribute value.
232	Available Reserved Space	Indicates the amount of Flash memory space in reserve. This is the Reserve Block Count (Attribute 170) represented in Gigabytes. Usage: [3-0]: [(RB) x (PPB) x (BPP)] / (1024^3) [6-4] : None (0x00) RB = Reserve Blocks (see Attribute 170) PPB = Pages per Block BPP = Bytes per Page	This Attribute returns a count of GB equal to the number of Flash Blocks in service over and above the minimum block count required. This Attribute is Attribute 170 presented in units of GB. The Attribute value is returned in units of Gigabytes at an update resolution of 64 GBytes. The value is initially the number of GB equal to the total Reserve Block Count. As the value is updated (decremented), it decrements in 64GB resolution. For example, if the initial value is n, the next update will decrement the value to (n – 64GB).

ID	Attribute Name	Description	Rational
235	Power Fail Backup Health	Indicates the condition of an external holdup circuit based on test results from the flash controller "Holdup Circuit Test". Normalized Equation: min(100, (100* (scapCurDischgMs - 10) / (min(scapTestDischgToutMs, scapInitDischgMs) - 10))) where scapCurDischgMs = Most recent discharge time (limited by apTestDischgToutMs). scapTestDischgToutMs = timeout "ceiling" (msec), specified via ConfigDrive Unique scapInitDischgMs = Initial discharge time for Holdup Circuit characterization at mfg time (characterization may be performed with a higher timeout "ceiling") Normalized Value Range: Best = 100 ("Holdup Circuit Test" passed) Worst = 1 (indicates the hold-up capability has degraded too far) Raw Usage: [1-0]: Latest "Holdup Circuit Test" discharge time (in milliseconds). [6-2]:None (0x00)	Power Fail Backup is an estimation of capacitive hold-up capability based on a timed discharge test, wherein discharge (past a predefined voltage threshold) faster than a predefined time-value threshold indicates a capacitor bank whose capacitance value is degraded past the point of reliability to protect SSD data. If an SSD has never run a "Holdup Circuit Test", the normalized value of this Attribute remains at '100'. This feature is not available.
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. Usage: [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).

ID	Attribute Name	Description	Rational
242	Lifetime Reads to 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).

Table 5-7: S.M.A.R.T Attribute Default Threshold Values & Clear Conditions

This table shows the default threshold values and conditions that clear the S.M.A.R.T attributes.

ID	Attribute Name	Power Cycle	Format (Function Code 1)	Secure Erase	FW Update	ClearSMART Diag Cmd	Mfg load (MF + FW)	Default SMART Trip Threshold
1	Raw Read Error Rate	Clear	Clear	Clear	Clear	Clear	Clear	32h
5	Retired Block Count					Note 2	Clear	3
9	Power-On Hours (POH)					Clear	Clear	0
12	Device Power Cycle Count					Clear	Clear	0
13*	Soft Read Error Rate	Clear	Clear	Clear	Clear	Clear	Clear	0
100*	Gigabytes Erased					Clear	Clear	0
170*	Reserved Block Count						Clear	0
171/181	Program Fail Count					Clear	Clear	0
172/182	Erase Fail Count					Clear	Clear	0
174	Unexpected power loss					Clear	Clear	0
177	Wear range Delta					Clear	Clear	0
184*	Reported I/O Error Detection Code Rate					Clear	Clear	5Ah
187	Reported Uncorrectable Errors					Clear	Clear	0
194	Temperature					Clear	Clear	0
195	ECC On the Fly Count	Clear	Clear	Clear	Clear	Clear	Clear	0
196	Reallocation Count					Clear	Clear	3
198*	Uncorrectable Sector Count	Clear	Clear	Clear	Clear	Clear	Clear	0
199*	SATA R-Errors (CRC) Error Count	Clear	Clear	Clear	Clear	Clear	Clear	0
201	Uncorrectable Soft Read Error Rate	Clear	Clear	Clear	Clear	Clear	Clear	0
204	Soft ECC Correction Rate	Clear	Clear	Clear	Clear	Clear	Clear	0
230	Life Curve Status						Clear	0

ID	Attribute Name	Power Cycle	Format (Function Code 1)	Secure Erase	FW Update	ClearSMART Diag Cmd	Mfg load (MF + FW)	Default SMART Trip Threshold
231	SSD Life Left						Clear	0Ah
232*	Available Reserved Space					Clear	Clear	0
235**	Power Fail Backup Health					Clear	Clear	2
241	Lifetime Writes from Host					Clear	Clear	0
242	Lifetime Reads to Host					Clear	Clear	0

Notes:

1. All attributes are persistent (not cleared) unless otherwise specified.
2. Raw data is cleared by the ClearSMART Diagnostic Command
3. * indicates that this attribute is for the enterprise series only (VRFS2xGB and VRFS2xGF).
4. ** indicates that this feature is not available.
5. SMART ID# 233 and 234 are for Internal Reserved.

5.1.10 Attribute Sector

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

Table 5-8: 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

Byte	Description
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)

Note: Bytes 2:361 are vendor unique

5.1.11 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 5-9: 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

5.1.12 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 3 specification is a super set of the ATA/ATAPI-7 specification with regard to supported commands. The Element SSD supports the following features that are unique to the SATA specification.

5.2.1 Native Command Queuing (NCQ)

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

- READ FPDMA QUEUED
- WRITE FPDMA QUEUED

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

6 Certifications and Compliance

Table 6-1: Device Certifications

Certification/Compliance	Description
CE Compliant	Indicate conformity with the essential health and safety requirements set out in European Directives Low Voltage Directive and EMC directive.
FCC	Class A
TUV	Worldwide Safety Compliance
RoHS	Viking Technology (TM), Sanmina-SCI 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	
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

- Viking Technology Environmental Test Report for 2.5” SSD
- Viking Technology EMI/EMC Test Report for 2.5” SSD
- Viking Technology EMI/EMC Test Report for 2.5” SSD
- Environmental Specification: MIL-STD-810F
- Serial ATA Specification, Revision 2.6 and Revision 3

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 $1x10^9$ bytes
DD	Hard Disk Drive
Hot Plug	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 $1x10^6$ bytes
MLC	Multi-Level Cell
MTBF	Mean Time Between Failures
NCQ	Native Command Queuing. The ability of the SATA storage 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 storage drives and software systems that automatically monitors a drive's health and reports potential problems.
SSD	Solid-State Drive