SATA 6Gb/s
M.2 SATA
Manual

M.2 SATA is a non-volatile, solid-state storage device delivering Serial ATA performance, reliability and ruggedness for environmentally challenging applications.

Revision History

Date	Revision	Description	Checked By
3/10/17	A	Initial Release. Revised based on PSFEM6XXXGSXXX_D with new PN's performance, block diagram, TBW, power consumption. Add VPFEM6030GZCDMTL. Add Industrial Temperature PN's	
3/13/17	B	Add VPFEM6030GZCDMTL.	
3/21/17	C	Add Industrial Temperature PN's. Revise note 2 on Extended SMART Attribute Actual Data table. Add 8GB and 16GB info. Add section on Flash Management	
5/18/17	D	Add PN's VPFEM5008GZCWMTL and VPFEM5016GZCDMTL. Remove I.T. from page1. Add 8GB LBA	
7/24/17	E	Add IOPS and MB/s performance based on IOMETER06	

Legal Information

Legal Information

Ordering Information: M.2 SATA SSD Solid-State Drive

Part Number	Length (mm)	Interface	Application	User Capacity (GB)	Temperature (C)	NAND
VPFEM5008GZCWMTL	80	SATA 6GB	Client	8	0 to 70	TSB 15nm MLC
VPFEM5016GZCDMTL	80	SATA 6GB	Client	16	0 to 70	TSB 15nm MLC
VPFEM5032GZCDMTL	80	SATA 6GB	Client	32	0 to 70	TSB 15nm MLC
VPFEM5060GZCDMTL	80	SATA 6GB	Client	60	0 to 70	TSB 15nm MLC
VPFEM5256GZCAMTL	80	SATA 6GB	Client	256	0 to 70	TSB 15nm MLC
VPFEM5008GZIWMTL	80	SATA 6GB	Client	8	-40 to +85	TSB 15nm MLC
VPFEM5016GZIDMTL	80	SATA 6GB	Client	16	-40 to +85	TSB 15nm MLC
VPFEM5032GZIDMTL	80	SATA 6GB	Client	32	-40 to +85	TSB 15nm MLC
VPFEM5064GZIDMTL	80	SATA 6GB	Client	64	-40 to +85	TSB 15nm MLC
VPFEM5128GZIBMTL	80	SATA 6GB	Client	128	-40 to +85	TSB 15nm MLC
VPFEM5256GZIAMTL	80	SATA 6GB	Client	256	-40 to +85	TSB 15nm MLC
VPFEM5512GZIZMTL	80	SATA 6GB	Client	512	-40 to +85	TSB 15nm MLC

Notes:

• Refer to Product Specifications for Capacity and LBA count
• Lower case "x" is the NAND device code

Client SSD's – Viking's client SSD contains sophisticated provisions to protect firmware and data from corruption due to unexpected power loss. However, should power fail unexpectedly, "in-flight" write data may be lost if the SSD power is not managed at the system level for these power fail events.

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1 Introduction

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.

1.1 Features

The SSD delivers the following features:
- Offers seamless SATA Revision 3.0 interface support for SATA up to 6Gb/s
- Low overall SSD power consumption
- Supports Native Command Queuing (NCQ) to 32 commands
- Compatible with all major SLC and MLC flash technologies
- S.M.A.R.T.
- Superior wear-leveling algorithm
- Efficient error recovery
- Compliant with ONFI 4.0 interface:
  - SDR up to mode 5
  - NV-DDR up to mode 5
  - NV-DDR2 up to mode 7
  - NV-DDR3 up to mode 8

1.2 Block Diagram

Figure 1-1: High-Level Block Diagram
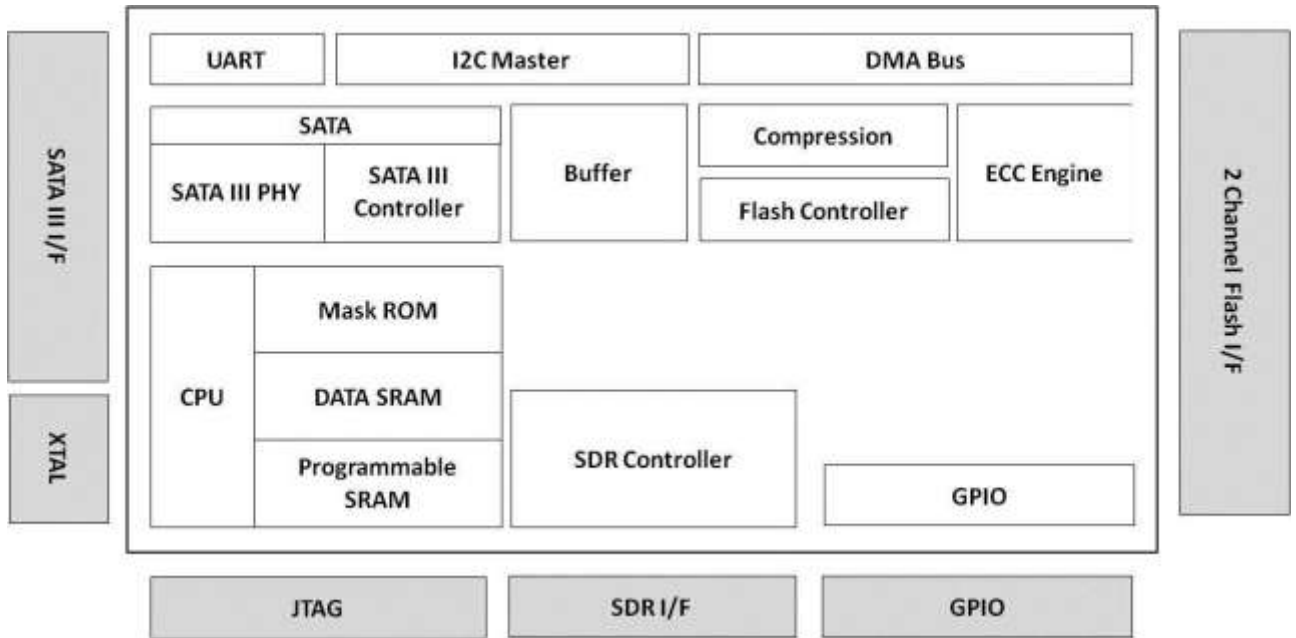
Notes:
1. Support for up to 2-channels and 2 CE in the NAND Flash interface

1.3 SATA Interface

- The Serial ATA (SATA) interface is compliant with the SATA IO Serial ATA specification, revision 3.0 that supports 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 (Giga-bits 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 Gbps or 1.5 Gbps.

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

2 Product Specifications

2.1 Capacity and LBA count

Raw Capacity (GB)	User Capacity (GB)	LBA Count
8	8	15,649,200
16	14	27,370,224
16	16	31,277,232
32	30	58,626,288
32	32	62,533,296
64	60	117,231,408
64	64	125,045,424
128	120	234,441,648
128	128	250,069,680
256	240	468,862,128
256	256	500,118,192
512	480	937,703,088
512	512	1,000,215,216

Notes:
1. Per www.idema.org, LBA1-03 spec,
   LBA counts = (97,696,368) + (1,953,504 * (Advertised Capacity in GBytes – 50))
2. GB capacities based on power of 10, GiB capacities are based on powers of 2

2.2 Performance

Table 2-1: Maximum Sustained Read and Write Bandwidth

Capacity	Flash Structure	Performance			
		CrystalDiskMark		ATTO	
		Read (MB/s)	Write (MB/s)	Read (MB/s)	Write (MB/s)
8GB	8GBx1, TSOP, TSB 15nm	320	105	560	540
16GB	16GBx1, TSOP, TSB 15nm	320	85	560	540
30/32GB	32GBx1, BGA, TSB 15nm	550	175	550	540
60/64GB	32GBx2, BGA, TSB 15nm	550	335	550	540
120/128GB	64GBx2, BGA, TSB 15nm	550	465	550	540
240/256GB	128GBx2, BGA, TSB 15nm	550	465	550	540
480/512GB	256GBx2, BGA, TSB 15nm	550	470	550	540

Notes:
1. Performance measured using CrystalDiskMark.
2. Performance may vary from flash configuration, SDR configuration, and platform.
3. Refer to Application Note AN0006 for Viking SSD Benchmarking Methodology.
4. Data is based on SSD's using Toshiba A15nm Toggle NAND devices
5. L95A data not currently available

Table 2-2: Sequential Read and Write Bandwidth (Iometer 06)

Capacity	Flash Type	Read MB/s (256K)	Write MB/s (256K)
8GB	15nm	537[1]	366[1]
16GB	15nm	537[1]	366[1]
32GB	15nm	537[1]	366[1]
64GB	15nm	537[1]	366[1]
128GB	15nm	537[1]	366[1]
256GB	15nm	537	366
512GB	15nm	537[1]	366[1]

Notes:
1. Estimated Performance measured using Iometer 06 with queue depth set to 32.
2. Write Cache enabled with DDR cache.
3. Tested with VPFEM5256GZIAMTL (Toshiba MLC L die)

Table 2-3: Random Read/ Write Input/Output Operations per Second (IOPS) (Iometer 06)

Capacity	Flash Type	Random Read IOPS (4K)	Random Write IOPS (4K)
8GB	15nm	14200[1]	1100[1]
16GB	15nm	14200[1]	1100[1]
32GB	15nm	14200[1]	1100[1]
64GB	15nm	14200[1]	1100[1]
128GB	15nm	14200[1]	1100[1]
256GB	15nm	14200	1100
512GB	15nm	14200[1]	1100[1]

Notes:
1. Estimated Performance measured using Iometer 06 with queue depth set to 32.
2. Write Cache enabled with DDR cache.
3. Tested with VPFEM5256GZIAMTL (Toshiba MLC L die)
4. 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).
5. Performance may vary by NAND type and host.
6. Refer to Application Note AN0006 for Viking SSD Benchmarking Methodology.
7. Data is based on SSD's using Toshiba A15nm NAND devices
8. L95A data not currently available

2.3 Timing

Table 2-4: Timing Specifications

Type	Average Latency
Power-On-to-Ready (POR)	TBD
Command to DRQ	TBD
Time to Erase (ATA Secure Erase)	TBD

Notes:
1. Device measured using Drivemaster.
2. Sector Read/Write latency measured up to 2048 block transfers (512B/sector = 1 Block)
3. Queue depth set to 32 for NCQ
4. 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
5. DRQ (Data Transfer Requested) bit being asserted

2.3.1 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 2-5: STANDBY IMMEDIATE Timing

Power Cycle Endurance	Min	Max	Unit
STANDBY IMMEDIATE to WE completed	-	72.9	Ms

Notes:
1. From Standby Immediate command to NAND Write Protect enable.

2.4 Flash Management

2.4.1 Error Correction Code (ECC)

Flash memory cells will deteriorate with use, which might generate random bit errors in the stored data. Thus, the Viking M.2 2280 applies the LDPC (Low Density Parity Check) of ECC algorithm, which can detect and correct errors occur during read process, ensure data been read correctly, as well as protect data from corruption.

2.4.2 Wear Leveling

NAND flash devices can only undergo a limited number of program/erase cycles, and in most cases, the flash media are not used evenly. If some areas get updated more frequently than others, the lifetime of the device would be reduced significantly. Thus, Wear Leveling is applied to extend the lifespan of NAND flash by evenly distributing write and erase cycles across the media.
Viking SSDs provides advanced Wear Leveling algorithm, which can efficiently spread out the flash usage through the whole flash media area. Moreover, by implementing both dynamic and static Wear Leveling algorithms, the life expectancy of the NAND flash is greatly improved.

2.4.3 Bad Block Management

Bad blocks are blocks that include one or more invalid bits, and their reliability is not guaranteed. Blocks that are identified and marked as bad by the manufacturer are referred to as "Initial Bad Blocks". Bad blocks that are developed during the lifespan of the flash are named "Later Bad Blocks". Viking SSDs implements an efficient bad block management algorithm to detect the factory-produced bad blocks and manages any bad blocks that appear with use. This practice further prevents data being stored into bad blocks and improves the data reliability.

2.4.4 TRIM

TRIM is a feature which helps improve the read/write performance and speed of solid-state drives (SSD). Unlike hard disk drives (HDD), SSDs are not able to overwrite existing data, so the available space gradually becomes smaller with

each use. With the TRIM command, the operating system can inform the SSD which blocks of data are no longer in use and can be removed permanently. Thus, the SSD will perform the erase action, which prevents unused data from occupying blocks all the time.

2.4.5 SMART

SMART, an acronym for Self-Monitoring, Analysis and Reporting Technology, is an open standard that allows a hard disk drive to automatically detect its health and report potential failures. When a failure is recorded by SMART, users can choose to replace the drive to prevent unexpected outage or data loss. Moreover, SMART can inform users of impending failures while there is still time to perform proactive actions, such as copy data to another device.

2.4.6 Over-Provision

Over Provisioning refers to the inclusion of extra NAND capacity in a SSD, which is not visible and cannot be used by users. With Over Provisioning, the performance and IOPS (Input/Output Operations per Second) are improved by providing the controller additional space to manage P/E cycles, which enhances the reliability and endurance as well. Moreover, the write amplification of the SSD becomes lower when the controller writes data to the flash.

2.4.7 Firmware Upgrade

Firmware can be considered as a set of instructions on how the device communicates with the host. Firmware will be upgraded when new features are added, compatibility issues are fixed, or read/write performance gets improved.

2.5 Low Power Management

2.5.1 DEVSLP Mode (Optional)

With the increasing need of aggressive power/battery life, SATA interfaces include a new feature, Device Sleep (DEVSLP) mode, which helps further reduce the power consumption of the device. DEVSLP enables the device to completely power down the device PHY and other sub-systems, making the device reach a new level of lower power operation. The DEVSLP does not specify the exact power level a device can achieve in the DEVSLP mode, but the power usage can be dropped down to 5mW or less.

2.5.2 DIPM/HIPM Mode

SATA interfaces contain two low power management states for power saving: Partial and Slumber modes. For Partial mode, the device has to resume to full

operation within 10 microseconds, whereas the device will spend 10 milliseconds to become fully operational in the Slumber mode. SATA interfaces allow low power modes to be initiated by Host (HIPM, Host Initiated Power Management) or Device (DIPM, Device Initiated Power Management). As for HIPM, Partial or Slumber mode can be invoked directly by the software. For DIPM, the device will send requests to enter Partial or Slumber mode.

2.6 Power Loss Protection: Flushing Mechanism *(Optional)*

Power Loss Protection is a mechanism to prevent data loss during unexpected power failure. DRAM is a volatile memory and frequently used as temporary cache or buffer between the controller and the NAND flash to improve the SSD performance. However, one major concern of the DRAM is that it is not able to keep data during power failure. Accordingly, the SSD requests the controller to transfer data to the cache. SDR performs as a cache, and its size is 32MB. Only when the data is fully committed to the NAND flash will the controller send acknowledgement (ACK) to the host. Such implementation can prevent false-positive performance and the risk of power cycling issues.
Additionally, it is critical for a controller to shorten the time the in-flight data stays in the cache. Thus, the Viking SSD applies an algorithm to reduce the amount of data resides in the cache to provide a better performance. This technology allows incoming data to only have a "pit stop" in the cache and then move to the NAND flash at once. If the flash is jammed due to particular file sizes (such as random 4KB data), the cache will be treated as an "organizer", consolidating incoming data into groups before written into the flash to improve write amplification. In summary, provide the reliability required by consumer, industrial, and enterprise-level applications.

2.7 Advanced Device Security Features

2.7.1 Secure Erase

Secure Erase is a standard ATA command and will write all "0xFF" to fully wipe all the data on hard drives and SSDs. When this command is issued, the SSD controller will erase its storage blocks and return to its factory default settings.

2.7.2 Write Protect

When a SSD contains too many bad blocks and data are continuously written in, then the SSD might not be usable anymore. Thus, Write Protect is a mechanism to prevent data from being written in and protect the accuracy of data that are already stored in the SSD.

2.8 SSD Lifetime Management

2.8.1 Terabytes Written (TBW)

TBW (Terabytes Written) is a measurement of SSDs' expected lifespan, which represents the amount of data written to the device. To calculate the TBW of a SSD, the following equation is applied:

$$TBW = [(NAND\ Endurance) \times (SSD\ Capacity) \times (WLE)] / WAF$$

NAND Endurance: Refers to the P/E (Program/Erase) cycle of a NAND flash.
SSD Capacity: The SSD capacity is the specific capacity in total of a SSD.
WLE: Wear Leveling Efficiency (WLE)   ratio of the average #of erases on all the blocks to the erases on any block at maximum.
WAF: Write Amplification Factor (WAF) is a numerical value representing the ratio between the amount of data that a SSD controller needs to write and the amount of data that the host's flash controller writes. A better WAF, which is near 1, guarantees better endurance and lower frequency of data written to flash memory.

2.8.2 Thermal Monitor (Optional)

Thermal monitors are devices for measuring temperature, and can be found in SSDs in order to issue warnings when SSDs go beyond a certain temperature. The higher temperature the thermal monitor detects, the more power the SSD consumes, causing the SSD to get aging quickly. Hence, the processing speed of a SSD should be under control to prevent temperature from exceeding a certain range. Meanwhile, the SSD can achieve power savings.

2.9 An Adaptive Approach to Performance Tuning

2.9.1 Throughput

Based on the available space of the disk, the SSD will regulate the read/write speed and manage the performance of throughput. When there still remains a lot of space, the firmware will continuously perform read/write action. There is still no need to implement garbage collection to allocate and release memory, which will accelerate the read/write processing to improve the performance. Contrarily, when the space is going to be used up, the SSD will slow down the read/write processing, and implement garbage collection to release memory. Hence, read/write performance will become slower.

2.9.2 Predict & Fetch

Normally, when the host tries to read data from the SSD, the SSD will only perform one read action after receiving one command. However, the SSD applies "Predict & Fetch" to improve the read speed. When the host issues

sequential read commands to the SSD, the SSD will automatically expect that the following will also be read commands. Thus, before receiving the next command, flash has already prepared the data. Accordingly, this accelerates the data processing time, and the host does not need to wait so long to receive data.

2.9.3 Compression

Write data to the NAND Flash costs time. To improve the write speed performance, the SSD launches a compression technique. Whether a file could be compressed or not depending on the file type, for file types have redundancy data pattern, through our embedded encode engine, we could reduce the amount of data that is actually written to the Flash. Comparing to the SSD without the compression, write efficiency is raised and the SSD endurance is also improved since Flash could be benefit from less data written for a longer SSD lifetime.

2.10 Electrical Characteristics

2.10.1 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 2-6: Absolute Maximum Ratings

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

2.10.2 Supply Voltage

The operating voltage is 3.3V

Table 2-7: Operating Voltage

Description	Min	Max	Unit
Operating Voltage for 3.3 V (+/- 5%)	3.135	3.465	V

2.10.3 Power Consumption

All onboard power requirements of the SSD are derived from the SATA 3.3V rail.

Table 2-8: Typical Power Consumption at 3.3V

		Power Consumption		
		Read	Write	Devslp
Capacity	Flash Structure	(mW)	(mW)	(mW)
8GB	8GBx1, TSOP, TSB 15nm	830	765	4.9
16GB	16GBx1, TSOP, TSB 15nm	895	805	4.9
30/32GB	32GBx1, BGA, TSB 15nm	1,190	1,280	4.9
60/64GB	32GBx2, BGA, TSB 15nm	1,190	1,295	4.9
120/128GB	64GBx2, BGA, TSB 15nm	1,170	1,525	4.9
240/256GB	128GBx2, BGA, TSB 15nm	1,250	1,555	4.9
480/512GB	256GBx2, BGA, TSB 15nm	1,455	1,675	4.9

Notes:
1. Measured using Toshiba A15 Toggle MLC NAND

2.11 Environmental Conditions

2.11.1 Temperature and Altitude

Table 2-9: Temperature and Altitude Related Specifications

Conditions	Operating	Shipping	Storage
Commercial Temperature- Ambient	0 to 70°C	-40 to 85°C	-40 to 85°C
Industrial Temperature- Ambient	-40 to 85°C	-40 to 85°C	-40 to 85°C
Humidity (non-condensing)	95% under 55C	93% under 40C	93% under 40C

2.11.2 Shock and Vibration

SSD products are tested in accordance with environmental specification for shock and vibration

Table 2-10: Shock and Vibration Specifications

Stimulus	Description
Shock	500G, 2ms
Vibration	20 – 80 Hz/1.52mm, 80 – 2000 Hz/20G, (X,Y,Z axis / 30 min for each)

2.11.3 Electromagnetic Immunity

M.2 is an embedded product for host systems and is designed not to impair with system functionality or hinder system EMI/FCC compliance.

2.12 Reliability

Table 2-11: Reliability Specifications

Parameter	Description						
MTBF	Over 2,000,000 hours						
ECC	72-bit per 1KByte						
Read Endurance	Unlimited						
Write Endurance	**8GB**	**16GB**	**32GB**	**64GB**	**128GB**	**256GB**	**512GB**
	12 TBW	23 TBW	45 TBW	90 TBW	181 TBW	262 TBW	544 TBW
Data retention	> 90 days at NAND expiration						

NOTES:

1. Tested to JEDEC219A client endurance workloads using Toshiba 15nm Toggle MLC NAND.
2. TBW may differ according to flash configuration and platform.
3. The endurance of SSD could be estimated based on user behavior, NAND endurance cycles, and write amplification factor. It is not guaranteed by flash vendor
4. TBW=(GB capacity x DWPD x 365 x years)/1000

3   Mechanical Information

3.1   Dimensions

Figure 3-1: Dimensions
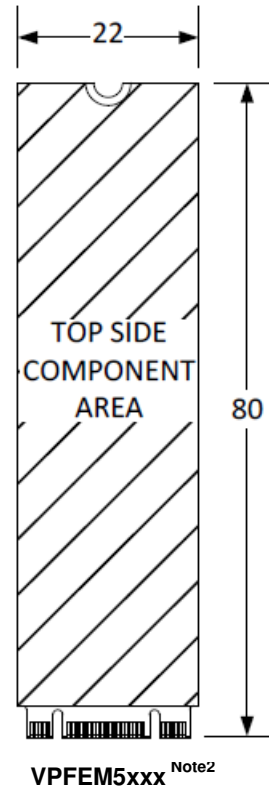
VPFEM5xxx [Note2]

Notes:
1.   All dimensions are in millimeter. General tolerance is ± 0.15. PCB thickness 0.8 ± 0.08
2.   Refer to Ordering Information table for the complete Viking part number that describes the "xxx".

Figure 3-2: Dimension Details for M.2 80mm length
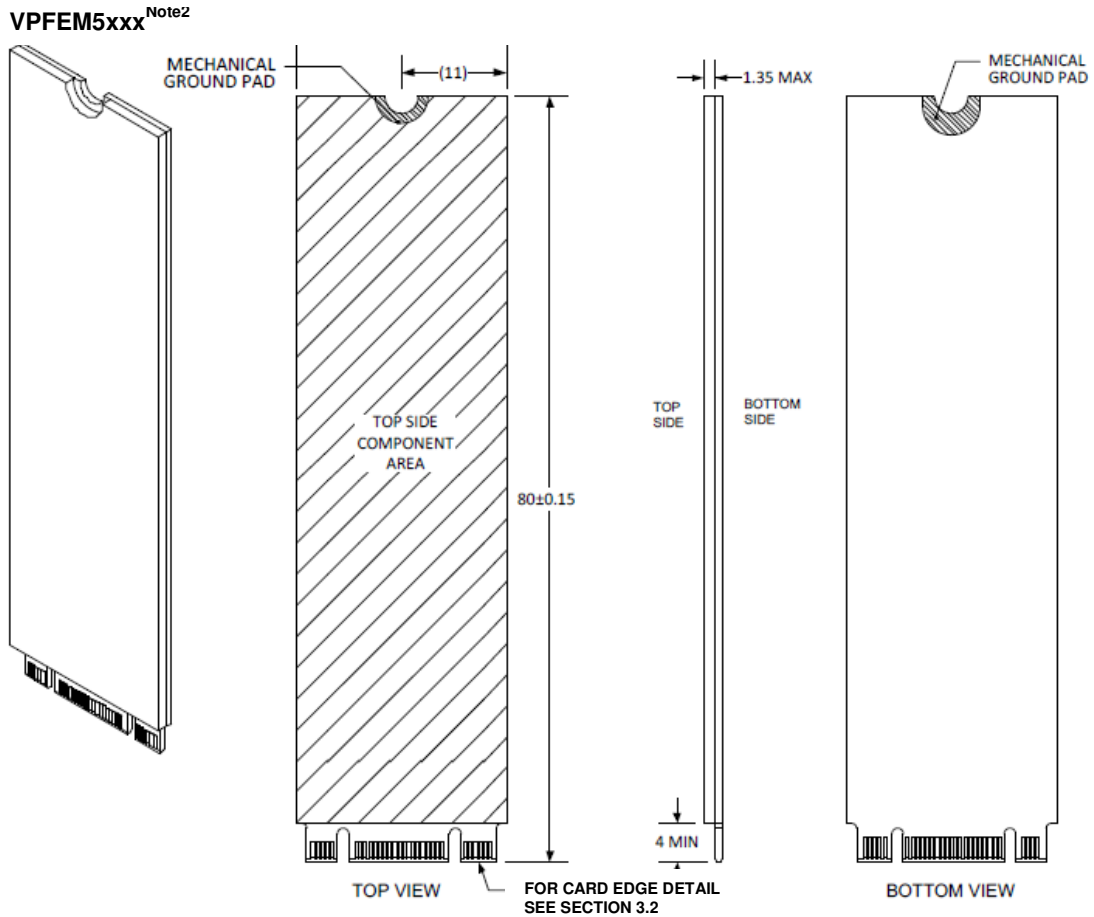
VPFEM5xxx[Note2]

Notes:
1. All dimensions are in millimeter. General tolerance is ± 0.15. PCB thickness 0.8 ± 0.08
2. Refer to Ordering Information table for the complete Viking part number that describes the "xxx".

3.2 Card Edge Detail

Figure 3-3: Dimension Details for M.2 card edge

Card Edge Bevel

Card Edge Outline-Topside
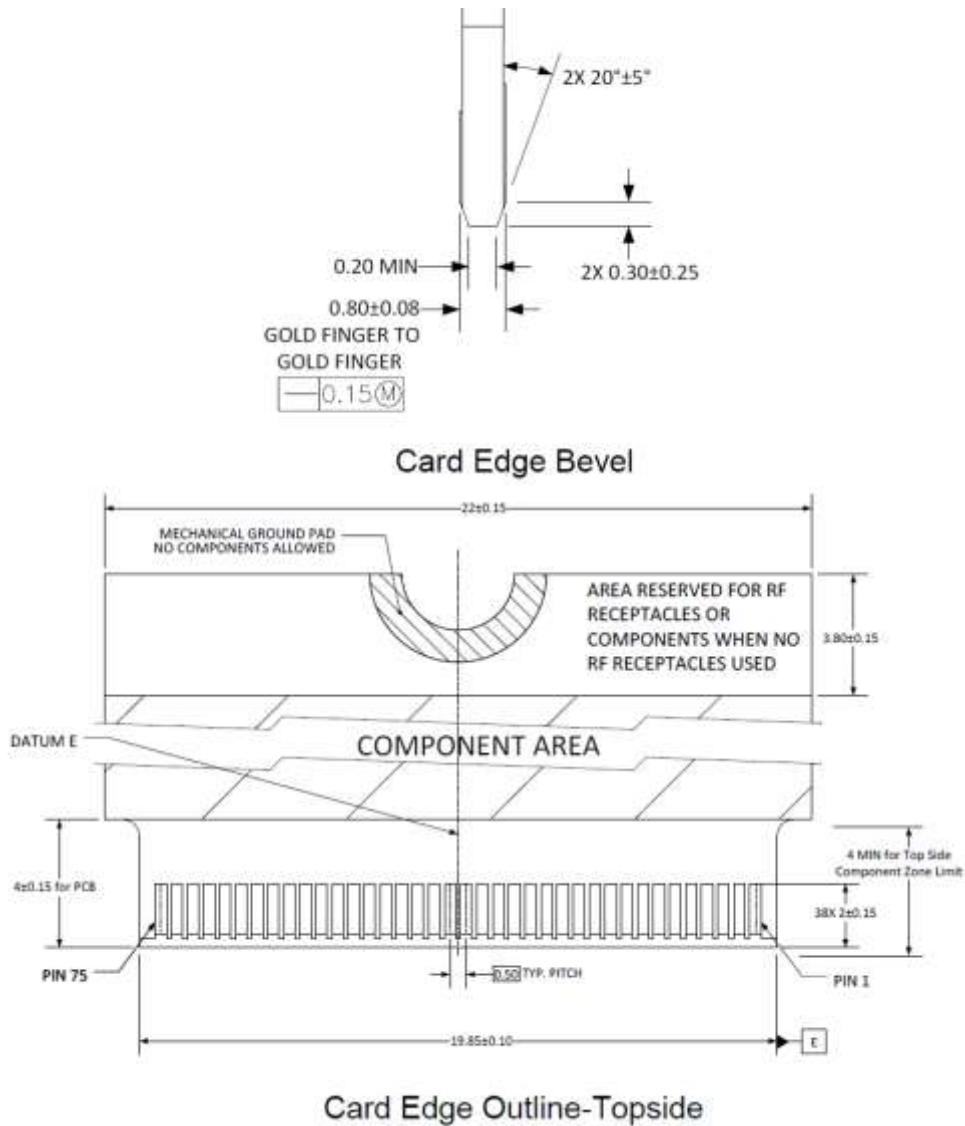
Figure 3-4: Dimension Details for M.2 connector and notch
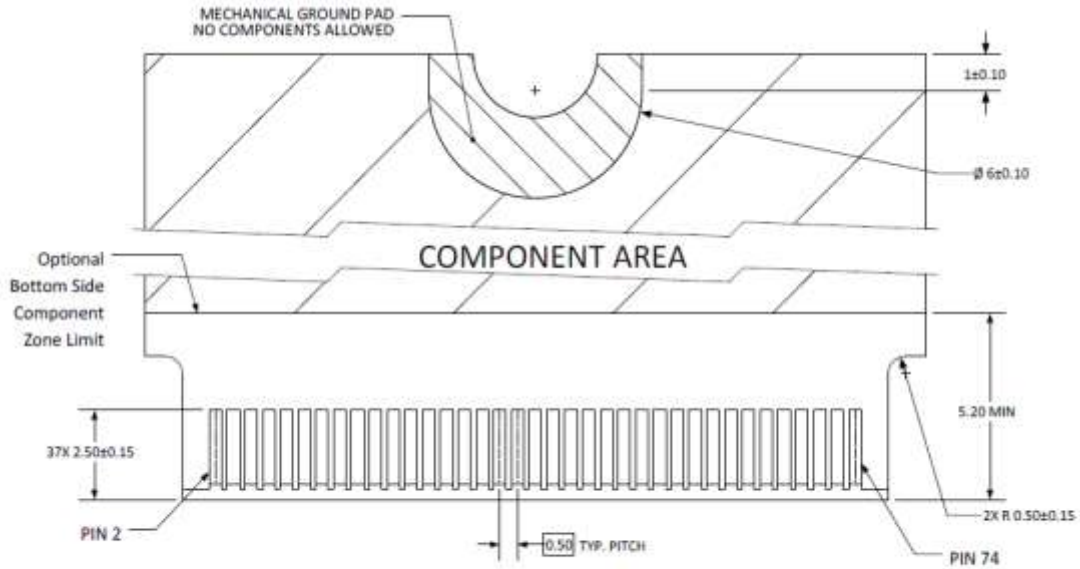
Card Edge Outline-Backside
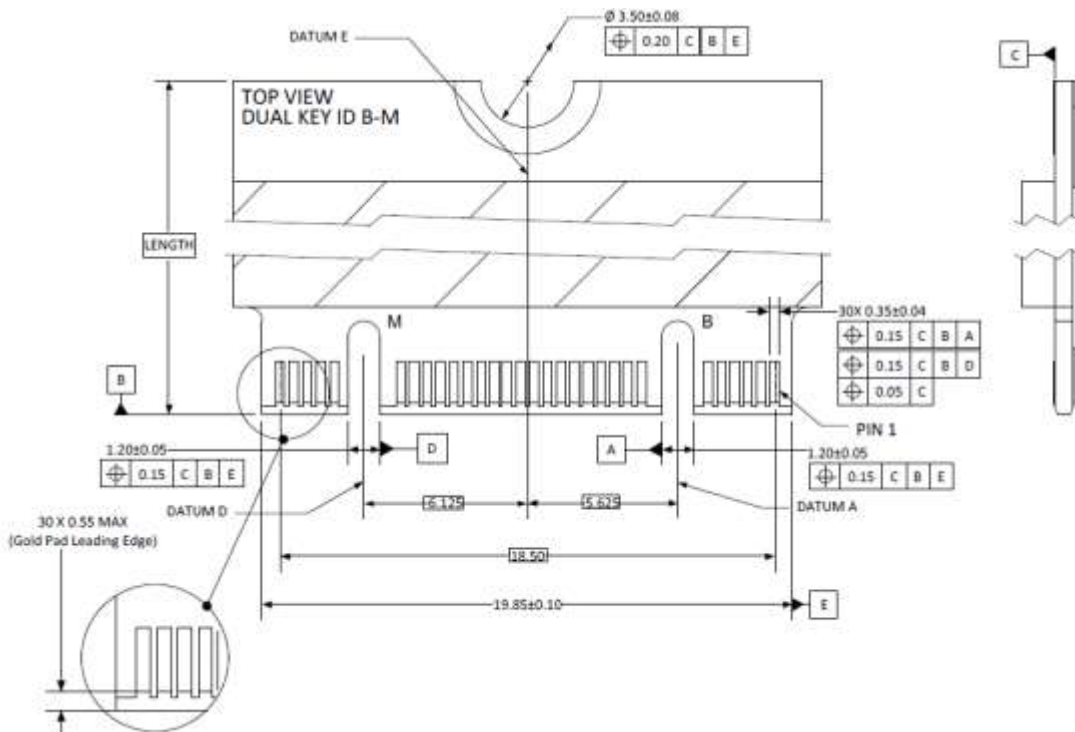
Key notch detail

3.3 M.2 SSD Weight

Table 3-1: M.2 SSD weight

Weight	Unit of measure
< 7	Grams

4 Pin and Signal Descriptions

4.1 Signal and Power Description Tables

Table 4-1: M.2 SATA Connector Pin Signal Definitions

Pin	Description	Description	Pin
74	3.3V	CONFIG_2 = GND	75
72	3.3V	GND	73
70	3.3V	GND	71
68	SUSCLK(32kHz) (I)(0/3.3V)	CONFIG_1 = GND	69
66	Module Key	N/C	67
64	Module Key	Module Key	65
62	Module Key	Module Key	63
60	Module Key	Module Key	61
58	N/C	Module Key	59
56	Reserved for MFG_DATA	GND	57
54	N/C	N/C	55
52	N/C	N/C	53
50	N/C	GND	51
48	N/C	SATA-A+	49
46	N/C	SATA-A-	47
44	N/C	GND	45
42	N/C	SATA-B-	43
40	N/C	SATA-B+	41
38	DEVSLP (I)(0/3.3V) Note4	GND	39
36	N/C	N/C	37
34	N/C	N/C	35
32	N/C	GND	33
30	N/C	N/C	31
28	N/C	N/C	29

Pin	Description	Description	Pin
26	N/C	GND	27
24	N/C	N/C	25
22	N/C	N/C	23
20	N/C	CONFIG_0 = GND	21
18	Module Key	Module Key	19
16	Module Key	Module Key	17
14	Module Key	Module Key	15
12	Module Key	Module Key	13
10	DAS/DSS# (I/O) Note3	N/C	11
8	N/C	N/C or GND Note5	9
6	N/C	N/C	7
4	3.3V	N/C	5
2	3.3V	GND	3
		CONFIG_3 = GND	1

Notes:
1. No connect on the host side.
2. Socket-2 SATA-based SSD Module pinout per PCI Express M.2 Specification, Revision 1.0 (p134)
3. Status indicators via LED devices that will be provided by the system Active Low. A pulled-up LED with series current limiting resistor should allow for 9mA when On.
4. Device Sleep, Input when driven high, the host is informing the SSD to enter a low power state
5. N/C for Socket 2, and GND for Socket 3

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 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

5.1   ATA Commands

Table 5-1: Supported ATA Commands

Description	Op Code	Description	Op Code
Check power mode	E5h	Security Disable Password	F6h
Data Set management	06h	Security Erase Prepare	F3h
DCO	B1h	Security Erase Unit	F4h
Download Microcode PIO	92h	Security Freeze Lock	F5h

Description	Op Code	Description	Op Code
Download Microcode DMA	93h	Security Set Password	F1h
Execute drive diagnostic	90h	Security Unlock	F2h
Flush cache	E7h	Seek	70h
Flush cache Ext	EAh	Set features	EFh
Identify device	ECh	Set Max Address	F9h
Idle	E3h	Set Max Address Ext	37h
Idle immediate	E1h	Set multiple mode	C6h
Initialize drive parameters	91h	Sleep	E6h
Read buffer	E4h	Smart	B0h
Read DMA (w/o retry)	C9h	Standby	E2h
Read DMA (w/retry)	C8h	Standby immediate	E0h
Read DMA Ext	25h	Write buffer	E8h
Read FPDMA QUEUED	60h	Write DMA (w/o retry)	CBh
Read Log Ext	2Fh	Write DMA (w/retry)	CAh
Read multiple	C4h	Write DMA Ext	35h
Read multiple Ext	29h	Write DMA FUA Ext	3Dh
Read native max address	F8h	Write FPDMA QUEUED	61h
Read native max Ext	27h	Write Log Ext	3Fh
Read sector(s) (w/o retry)	21h	Write multiple	C5h
Read sector(s) (w/retry)	20h	Write multiple Ext	39h
Read sector(s) Ext	24h	Write multiple FUA Ext	CEh
Read Verify Ext	42h	Write sector(s) (w/o retry)	31h
Read verify sector(s) (w/o retry)	41h	Write sector(s) (w/retry)	30h
Read verify sector(s) (w/retry)	40h	Write sector(s) Ext	34h
Recalibrate	10h	Write uncorrectable	45h

5.1.1 48-Bit Address Command Set

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

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

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

SSD supports the General Purpose Log command set consisting of:
- Read Log Ext
- Write Log Ext

5.1.5 Host Protected Area Command Set

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

SSD supports the Power Management command set consisting of:
- Check Power Mode
- Idle
- Idle Immediate
- Sleep
- Standby
- Standby Immediate
- Slumber
- Partial Mode

5.1.7 Security Mode Feature Set

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)
- Standby Immediate

5.1.8 Identify Device Data

The table below lists the sector data that will be returned by the SSD upon an IDENTIFY DEVICE command.

Table 5-2: List of Device Identification

Word	F: Fixed V: Variable X: Both	Default Value	Description
0	F	0040h	General configuration bit-significant information
1	X	See *1	Obsolete – Number of logical cylinders (16383)
2	V	C837h	Specific configuration
3	X	0010h	Obsolete – Number of logical heads (16)
4-5	X	00000000h	Retired
6	X	003Fh	Obsolete – Number of logical sectors per logical track (63)
7-8	V	00000000h	Reserved for assignment by the Compact Flash Association
9	X	0000h	Retired
10-19	F	Varies	Serial number (20 ASCII characters)
20-21	X	0000h	Retired
22	X	0000h	Obsolete
23-26	F	Varies	Firmware revision (8 ASCII characters)
27-46	F	Varies	Model number (xxxxxxxx)
47	F	8010h	7:0- Maximum number of sectors transferred per interrupt on MULTIPLE commands
48	F	0000h	Reserved
49	F	2F00h	Capabilities
50	F	4000h	Capabilities
51-52	X	000000000h	Obsolete
53	F	0007h	Words 88 and 70:64 valid
54	X	See *1	Obsolete – Number of logical cylinders (16383)
55	X	0010h	Obsolete – Number of logical heads (16)
56	X	003Fh	Obsolete – Number of logical sectors per track (63)
57-58	X	See *2	Obsolete – Current capacity in sectors –
59	F	0110h	Number of sectors transferred per interrupt on MULTIPLE commands
60-61	F	See *3	Total number of user addressable sectors
62	X	0000h	Obsolete
63	F	0407h	Multi-word DMA modes

Word	F: Fixed V: Variable X: Both	Default Value	Description
			supported/selected
64	F	0003h	PIO modes supported
65	F	0078h	Minimum Multiword DMA transfer cycle time per word
66	F	0078h	Manufacturer's recommended Multiword DMA transfer cycle time
67	F	0078h	Minimum PIO transfer cycle time without flow control
68	F	0078h	Minimum PIO transfer cycle time with IORDY flow control
69	F	0100h	Additional Supported (support download microcode DMA)
70	F	0000h	Reserved
71-74	F	0000000000000000h	Reserved for the IDENTIFY PACKET DEVICE command
75	F	001Fh	Queue depth
76	F	670eh	Serial SATA capabilities
77	F	0084h	Reserved for future Serial ATA definition
78	F	0014h	Serial ATA features supported
79	V	0040H	Serial ATA features enabled
80	F	01F8h	Major Version Number
81	F	0000h	Minor Version Number
82	F	346Bh	Command set supported
83	F	7D09h	Command set supported
84	F	6063h	Command set/feature supported extension
85	V	3469h	Command set/feature enabled
86	V	BC01h	Command set/feature enabled
87	V	6063h	Command set/feature default
88	V	003Fh	Ultra DMA Modes
89	F	001Eh	Time required for security erase unit completion
90	F	001Eh	Time required for Enhanced security erase completion
91	V	0000h	Current advanced power management value
92	V	FFFEh	Master Password Revision Code
93	F	0000h	Hardware reset result. The contents of the bits (12:0) of this word shall change only during the execution of s hardware reset.
94	V	0000h	Vendor's recommended and actual acoustic management value
95	F	0000h	Stream Minimum Request Size
96	V	0000h	Streaming Transfer Time – DMA

Word	F: Fixed V: Variable X: Both	Default Value	Description
97	V	0000h	Streaming Access Latency – DMA and PIO
98-99	F	0000h	Streaming Performance Granularity
100-103	V	See *4	Maximum user LBA for 48 bit Address feature set
104	V	0000h	Streaming Transfer Time – PIO
105	F	0000h	Maximum number of 512-byte blocks per DATA SET MANAGEMENT command
106	F	4000h	Physical sector size / Logical sector size
107	F	0000h	Inter-seek delay for ISO-7779 acoustic testing in microseconds
108-111	F	0000000000000000h	Unique ID
112-115	F	0000000000000000h	Reserved
116	V	0000h	Reserved
117-118	F	00000000h	Words per logical Sector
119	F	4014h	Supported settings
120	F	4014h	Command set/Feature Enabled/Supported
121-126	F	0h	Reserved
127	F	0h	Removable Media Status Notification feature set support
128	V	0021h	Security status
129-159	X	0h	Vendor specific
160	F	0h	Compact Flash Association (CFA) power mode 1
161-167	X	0h	Reserved for assignment by the CFA
168	F	3h: 2.5 inch 4h: 1.8 inch 5h: < 1.8 inch	Device Nominal Form Factor
169	F	0001h	DATA SET MANAGEMENT command is supported
170-173	F	0h	Additional Product Identifier
174-175		0h	Reserve
176-205	V	0h	Current media serial number
206	F	0h	SCT Command Transport(
207-208	F	0h	Reserved
209	F	4000h	Alignment of logical blocks within a physical block
210-211	V	0000h	Write-Read-Verify Sector Count Mode 3 (not supported)
212-213	F	0000h	Write-Read-Verify Sector Count Mode 2 (not supported)
214-216		0000h	NV Cache relate (not supported)
217	F	0001h	Non-rotating media device
218	F	0h	Reserved

Word	F: Fixed V: Variable X: Both	Default Value	Description
219	F	0h	NV Cache relate (not supported)
220	V	0h	Write read verify feature set current mode
221		0h	Reserved
222	F	107Fh	Transport major version number
223	F	0h	Transport minor version number
224-229		0h	reserved
230-233		0h	Extend number of user addressable sectors
234		0001h	Minimum number of 512-byte data blocks per DOWNLOAD MICROCODE command for mode 03h
235		0080h	Maximum number of 512-byte data blocks per DOWNLOAD MICROCODE command for mode 03h
236-254	F	0h	Reserved
255	X	XXA5h XX is variable	Integrity word (Checksum and Signature)

Notes for Capacity specific Device Identification

Capacity (GB)	*1 (Word 1/Word 54)	*2 (Word 57-58)	*3 (Word 60-61)	*4 (Word 100-103)
4	1E5Dh	778E3Oh	778E3Oh	778E3Oh
8	3CA5h	EEC9BOh	EEC9BOh	EEC9BOh
16	3FFFh	FBFC1Oh	1DD4OBOh	1DD4OBOh
24	3FFFh	FBFC1Oh	2CBB7BOh	2CBB7BOh
32	3FFFh	FBFC1Oh	3BA2EBOh	3BA2EBOh
64	3FFFh	FBFC1Oh	774OABOh	774OABOh
128	3FFFh	FBFC1Oh	EE7C2BOh	EE7C2BOh
256	3FFFh	FBFC1Oh	FFFFFFFh	1DCF32BOh

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.

See the AT Attachment standard for implementation details.

5.1.2 SATA 3.0 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   Extended SMART Attributes

Table 5-4: Extended SMART Attribute Table

SMART Attribute ID	Description
01h	Number of accumulated Uncorrectable errors (Range 0-255) Read Error Rate
05h	Reallocated Sector Count
09h	Power-On hours Count (Range 0-4294967295)
0Ch	Drive Power Cycle Count (Number of accumulated power on/off cycles)
A8h	SATA PHY Error Count (only record from power on, when power off this value will clear to zero) this value include all PHY error count, ex data FIS CRC ,code error, disparity error ,command FIS CRC …..)
AAh	Max Bad Block Count (will show early bad and later bad block count)
ADh	Erase count (average, max, erase count)

SMART Attribute ID	Description
B1h	Wear Range delta [(most wear block – average wear block)/Max P/E cycles] x 100
B5h	Program Fail Count
B6h	Erase Failure Block Count
BBh	Reported Uncorrectable Errors (ECC fail count) 4bytes 01h only 1 bytes
C0h	Unexpected Power Loss Count
C2h	N/A
C7h	Number of accumulated CRC Error (read/write data FIS CRC error) CRC Error Count (R CRC + W CRC)
DAh	Number of accumulated CRC Error (read/write data FIS CRC error) Number of CRC Errors
E7h	SSD life remaining
E8h	Read Failure Block Count
E9h	Lifetime Writes to Flash ((GB)
F1h	Lifetime Writes from Host (each G)
F2h	Lifetime Reads from Host (each G)
F3h	Total internal copy ecc error count
F4h	Average erase count (4bytes)
F5h	Max erase count (4 bytes)
F6h	Total Erase Count (6 bytes)
FAh	Read retry count
FBh	Do wearleveling count
FCh	CRC error write count

Notes:
1. Dummy is null and not used

Table 5-5: Extended SMART Attribute Actual Data

0	1	2	3	4	5	6	7	8	9	10	11	
ID	Flag	Flag	Value	Worse	DATA							Threshold
01h	0Bh	00h	64h	64h	0	0	ECC error	0	0	0	0	32h
05h	13h	00h	64h	64h	0	0	0	0	0	0	0	32h
09h	12h	00h	64h	64h	Power on hour		0	0	0	0	0	00h
0Ch	12h	00h	64h	64h	Power on/off cycles			0	0	0	0	00h
A8h	12h	00h	64h	64h	SATA PHY error count			0	0	0	0	00h
AAh	03h	00h	Note 1	Note 1	Early bad block NO		0	0	Later bad block NO		0	0Ah

0	1	2	3	4	5	6	7	8	9	10	11	
ID	Flag	Flag	Value	Worse	DATA							Threshold
ADh	12h	00h	64h	64h	Max erase count (MAX 65535)		Average erase count (MAX 65535)		0 0		0	00h
B1h	00h	00h	00h	00h	The value				0	0	0	00h
B5h	12h	00h	00h	00h	Total program bad blocks count				0	0	0	00h
B6h	32h	00h	00h	00h	Total erase bad blocks count				0	0	0	00h
BBh	03h	00h	00h	00h	Total ECC error count				0	0	0	00h
C0h	12h	00h	64h	64h	number of accidental power loss count				0	0	0	00h
C2h	N/A	N/A	N/A	N/A	N/A		N/A		N/A		N/A	N/A
C7h	12h	00h	64h	64h	CRC Error Count (R CRC + W CRC)				0	0	0	00h
DAh	0Bh	00h	64h	64h	Number of CRC Error				0	0	0	32h
E7h	13h	00h	64h	64h	% SSD life remaining (Note 2)				0	0	0	00h
E8h	0Bh	00h	64h	64h	Total Read bad Block Count				0	0	0	00h
E9h	0Bh	00h	64h	64h	Flash write 64GB each count				0	0	0	00h
F1h	32h	00h	00h	00h	Host write 64GB count				0	0	0	00h
F2h	32h	00h	00h	00h	Host read 64GB count)				0	0	0	00h
F3h	02h	00h	64h	64h	Total internal copy ecc error count				0	0	0	00h
F4h	02h	00h	64h	64h	Total Average erase count				0	0	0	00h
F5h	02h	00h	64h	64h	Max erase count				0	0	0	00h
F6h	02h	00h	64h	64h	Total Erase Count						0	00h
FAh	02h	00h	64h	64h	Read retry Count						0	00h
FBh	02h	00h	64h	64h	Cool down Count						0	00h
FCh	02h	00h	64h	64h	CRC write Count						0	00h

Note 1 Formula:
MABN: Maximum acceptable bad block number
CBBN: Current bad block number
Value = ((MABN – CBBN)/ (MABN)) x 100
This formula calculates percentage of spare blocks. Value will be from 100 to 1

Note 2 Formula:
Average erase count / MAX erase count (SLC PE, MLC PE) * 100 (percentage)
Micron L95B or Toshiba 15nm MLC PE is 3000
SLC PE is 100000

5.1.2.2   Off-line Mode

SSD's support 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 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 5-6: 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

5.2   SATA Commands

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

5.2.1 Native Command Queuing (NCQ)

SSD's support 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   References

- Serial ATA Specification, Revision 3
- PCI Express M.2 Specification, Revision 1.0

7 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
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 $1x10^6$ 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