Small Form Factor Committee
Specification Draft for
Self-Monitoring, Analysis and
Reporting Technology
(S.M.A.R.T.)

SFF-8035i

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SFF Specification for S.M.A.R.T.

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Implementation Philosophy

The intent of S.M.A.R.T. is to protect user data and prevent unscheduled system downtime that may be caused by predictable degradation and/or fault of the device. By monitoring and storing critical performance and calibration parameters, S.M.A.R.T. devices employ sophisticated data analysis algorithms to predict the likelihood of near-term degradation or fault condition. By alerting the host system of a negative reliability status condition, the host system can then warn the user of the impending risk of data loss and advise the user of appropriate action.

Since S.M.A.R.T. utilizes the internal device microprocessor and other device resources, there may be some small overhead associated with its operation. However, special care has been taken in the design of the S.M.A.R.T. algorithms to minimize the impact to host system performance. Actual impact of S.M.A.R.T. overhead is dependent on the specific device design and the usage patterns of the host system. To further ensure minimal impact to the user, S.M.A.R.T. capable devices are shipped from the device manufacturer's factory with the S.M.A.R.T. feature disabled. S.M.A.R.T. capable devices can be enabled by system OEMs at time of system integration or in the field by aftermarket products.

This document is intended primarily for storage device manufacturers who plan to implement these features on their devices. A companion specification will be provided which defines the "higher level" software interfaces that will be supported in order to allow for compatibility across all software products utilizing the S.M.A.R.T. features.

1. Definitions

1.1. S.M.A.R.T.

The method by which a device monitors, stores and analyzes information relative to its internal performance and calibration factors to determine the likelihood of a future degrading or faulty condition.

1.2. Attributes

Attributes are the specific performance or calibration parameters that are used in analyzing the status of the device. Attributes are selected by the device manufacturer based on that Attribute's ability to contribute to the prediction of degrading or faulty conditions for that particular device. The specific set of Attributes being used and the identity of these Attributes is vendor specific and proprietary.

1.3. Attribute Values

Attribute Values are used to represent the relative reliability of individual performance or calibration Attributes. The valid range of Attribute Values is from 1 through 253 decimal. Higher Attribute Values indicate that the analysis algorithms being used by the device are predicting a lower probability of a degrading or faulty condition existing. Accordingly, lower Attribute Values indicate that the analysis algorithms being used by the device are predicting a higher probability of a degrading or faulty condition existing.
1.4. Attribute Thresholds

Each Attribute Value has a corresponding Attribute Threshold limit which is used for direct comparison to the Attribute Value to indicate the existence of a degrading or faulty condition. The numerical value of the Attribute Thresholds are determined by the device manufacturer through design and reliability testing and analysis. Each Attribute Threshold represents the lowest limit to which its corresponding Attribute Value can be equal while still retaining a positive reliability status. Attribute Thresholds are set at the device manufacturer's factory and cannot be changed in the field. The valid range for Attribute Thresholds is from 1 through 253 decimal.

1.5. Threshold Exceeded Condition

If one or more Attribute Values are less than or equal to their corresponding Attribute Thresholds, then the device reliability status is negative, indicating an impending degrading or faulty condition.

2. EXECUTE S.M.A.R.T. FUNCTION Command

OPCODE - 0B0h

The EXECUTE S.M.A.R.T. FUNCTION command provides access to Attribute Values, Attribute Thresholds and other low level subcommands that can be used for logging and reporting purposes and to accommodate special user needs. The EXECUTE S.M.A.R.T. FUNCTION command has several separate subcommands which are selectable via the device's Features Register when the EXECUTE S.M.A.R.T. FUNCTION command is issued by the host.

Prior to writing the EXECUTE S.M.A.R.T. FUNCTION command to the device's Command Register, key values must be written by the host into the device's Cylinder Low and Cylinder High Registers, or the command will be aborted and will report an error as defined in Section 6. of this specification. For any S.M.A.R.T. command: if a device register is not specified as being written with a value by the host, then the value in that register is undefined and shall be ignored by the device. The key values are shown below.

Key Register
0x4F Cylinder Low (1F4h)
0xC2 Cylinder High (1F5h)

In order to select a subcommand the host must write the subcommand code to the device's Features Register before issuing the EXECUTE S.M.A.R.T. FUNCTION command. The subcommands and their respective codes are listed below.

Code Subcommand
0xD0 READ ATTRIBUTE VALUES
0xD1 READ ATTRIBUTE THRESHOLDS
0xD2 ENABLE/DISABLE ATTRIBUTE AUTOSAVE
0xD3 SAVE ATTRIBUTE VALUES
0xD4 thru Reserved
0xD6
0xD7 Vendor Specific
0xD8 ENABLE S.M.A.R.T. OPERATIONS
0xD9 DISABLE S.M.A.R.T. OPERATIONS
0xDA RETURN S.M.A.R.T. STATUS
After the host writes the keys to the appropriate registers, the subcommand code to the device's Features Register and then issues the EXECUTE S.M.A.R.T. FUNCTION Command, the device proceeds to execute the subcommand requested in the Features Register.

2.1. READ ATTRIBUTE VALUES

This subcommand returns the device's Attribute Values to the host. Upon receipt of the READ ATTRIBUTE VALUES subcommand from the host, the device asserts BSY, saves any updated Attribute Values to non-volatile memory, asserts DRQ, clears BSY, asserts INTRQ, and then waits for the host to transfer the 512 bytes of Attribute Value information from the device via the Data Register.

2.2. READ ATTRIBUTE THRESHOLDS

This subcommand returns the device's Attribute Thresholds to the host. Upon receipt of the READ ATTRIBUTE THRESHOLDS subcommand from the host, the device asserts BSY, reads the Attribute Thresholds from non-volatile memory, asserts DRQ, clears BSY, asserts INTRQ, and then waits for the host to transfer the 512 bytes of Attribute Threshold information from the device via the Data Register.

2.3. ENABLE/DISABLE ATTRIBUTE AUTOSAVE (optional)

This subcommand enables and disables the optional Attribute AutoSave feature of the device. Depending upon the implementation, the ENABLE/DISABLE ATTRIBUTE AUTOSAVE subcommand may either allow the device, after some vendor specified event, to automatically save its updated Attribute Values to non-volatile memory; or this subcommand may cause the AutoSave feature to be disabled. The state of the Attribute AutoSave feature (either enabled or disabled) will be preserved by the device across power cycles.

A value of zero written by the host into the device's Sector Count register before issuing the ENABLE/DISABLE ATTRIBUTE AUTOSAVE subcommand will cause this feature to be disabled. Disabling this feature does not preclude the device from saving Attribute values to non-volatile memory during some other normal operation such as during a power-up or power-down sequence or during an error recovery sequence.

A value of 0xF1 written by the host into the device's Sector Count register before issuing the ENABLE/DISABLE ATTRIBUTE AUTOSAVE subcommand will cause this feature to be enabled. Any other meaning of this value or any other non-zero value written by the host into this register before issuing the ENABLE/DISABLE ATTRIBUTE AUTOSAVE subcommand is vendor specific. The meaning of any non-zero value written to this register at this time will be preserved by the device across power cycles.

If the ENABLE/DISABLE ATTRIBUTE AUTOSAVE is supported by the device: Upon
receipt of the subcommand from the host, the device asserts BSY, enables or
disables the AutoSave feature (depending upon the implementation), clears BSY
and asserts INTRQ.

If the ENABLE/DISABLE ATTRIBUTE AUTOSAVE subcommand is not supported by the
device: The device will abort the subcommand upon receipt from the host,
returning the error code specified in Section 6.

During execution of its AutoSave routine the device shall not assert BSY nor
deassert DRDY. If the device receives a command from the host while executing
its AutoSave routine it must respond to the host within two seconds.

Implementation of this feature is optional and vendor specific.

2.4. SAVE ATTRIBUTE VALUES

This subcommand causes the device to immediately save any updated Attribute
Values to the device's non-volatile memory regardless of the state of the
Attribute AutoSave timer. Upon receipt of the SAVE ATTRIBUTE VALUES subcommand
from the host, the device asserts BSY, writes any updated Attribute Values to
non-volatile memory, clears BSY and asserts INTRQ.

2.5. ENABLE S.M.A.R.T. OPERATIONS

This subcommand enables access to all S.M.A.R.T. capabilities within the
device. Prior to receipt of an ENABLE S.M.A.R.T. OPERATIONS subcommand
Attribute Values are neither monitored nor saved by the device. The state of
S.M.A.R.T. (either enabled or disabled) will be preserved by the device across
power cycles. Once enabled, the receipt of subsequent ENABLE S.M.A.R.T.
OPERATIONS subcommands shall not affect any of the Attribute Values.

Upon receipt of the ENABLE S.M.A.R.T. OPERATIONS subcommand from the host, the
device asserts BSY, enables S.M.A.R.T. capabilities and functions, clears BSY
and asserts INTRQ.

2.6. DISABLE S.M.A.R.T. OPERATIONS

This subcommand disables all S.M.A.R.T. capabilities within the device
including any and all timer functions related exclusively to this feature.
After receipt of the DISABLE S.M.A.R.T. OPERATIONS subcommand the device will
disable all S.M.A.R.T. operations. Attribute Values will no longer be
monitored or saved by the device. The state of S.M.A.R.T. (either enabled or
disabled) will be preserved by the device across power cycles.

Upon receipt of the DISABLE S.M.A.R.T. OPERATIONS subcommand from the host, the
device asserts BSY, disables S.M.A.R.T. capabilities and functions, clears
BSY and asserts INTRQ.

After receipt by the device of the DISABLE S.M.A.R.T. OPERATIONS subcommand
from the host, all other S.M.A.R.T. subcommands -- with the exception of
ENABLE S.M.A.R.T. OPERATIONS subcommand -- are disabled and invalid and will
be aborted by the device (including the DISABLE S.M.A.R.T. OPERATIONS
subcommand), returning the error code specified in Section 6.

Any Attribute Values accumulated and saved to non-volatile memory prior to
receipt of the DISABLE S.M.A.R.T. OPERATIONS command will be preserved in the
device's non-volatile memory. If the device is re-enabled, these Attribute
Values will be updated, as needed, upon receipt of a READ ATTRIBUTE VALUES or SAVE ATTRIBUTE VALUES command.

2.7. RETURN S.M.A.R.T. STATUS (optional)

This command is used to communicate the reliability status of the device to the host at the host's request. Upon receipt of the RETURN S.M.A.R.T. STATUS subcommand the device asserts BSY, saves any updated Attribute Values to non-volatile memory and compares the updated Attribute Values to the Attribute Thresholds.

If the device does not detect a Threshold Exceeded Condition, the device loads 0x4F into the Cylinder Low register, 0xC2 into the Cylinder High register, clears BSY, and asserts INTRQ.

If the device does detect a Threshold Exceeded Condition, the device loads 0xF4 into the Cylinder Low register, 0x2C in the Cylinder High register, clears BSY, and asserts INTRQ.

If RETURN S.M.A.R.T. STATUS subcommand is not supported by the device, the device will abort the subcommand upon receipt from the host, returning the error code specified in Section 6.

3. Device Attributes Data Structure

The following defines the 512 bytes that make up the Attribute value information. This data structure is accessed by the host in its entirety using the READ ATTRIBUTE VALUES subcommand. All multi-byte fields shown in these data structures follow the ATA-2 specification for byte ordering, namely that the least significant byte occupies the lowest numbered byte address location in the field.

The number of active Attributes and, therefore, number of active Attribute values is determined independently by the device manufacturer for each individual device. All active Attribute entries should be concatenated together directly after the data structure revision number. If there are fewer than thirty active Attributes implemented on a device, the excess locations in the data structure are reserved for future Attribute implementations and are designated as blanks containing the value 0x00. Thus the first Reserved byte following the Attribute entries shall be the 363rd byte in the structure, the first S.M.A.R.T. Capability byte shall be the 369th byte in the structure, etc.
### Description | Bytes | Format | Type
---|---|---|---
Data Structure Revision Number = 0x0004 for this spec revision | 2 | binary | Rd only
1st Device Attribute | 12 | see below | Rd/Wrt
| | | | 
| | | | 
| | | | 
| | | | 
30th Device Attribute | 12 | see below | Rd/Wrt
Reserved (0x00) | 6 | | Rd only
S.M.A.R.T. Capability | 2 | | Rd only
Reserved (0x00) | 16 | | Rd/Wrt
Vendor Specific | 125 | | Rd only
Data Structure Checksum | 1 | | Rd only

**Total Bytes** | 512 | 

#### Table 1 - Device Attributes Data Structure

### 3.1. Data Structure Revision Number

The Data Structure Revision Number identifies which version of this data structure is implemented by a device. Upon initial release of this specification, the revision number will be set to 0x0004. Later revisions, if any, will increment the revision number by one for each new revision. The revision number will be the same for both the Attribute Value and Attribute Threshold structures.

### 3.2. Individual Attribute Data Structure

The following defines the twelve bytes that make up the information for each Attribute entry in the Device Attributes Data Structure.
3.2.1. Attribute ID Numbers

The Attribute ID Numbers and their definitions are vendor specific. Any non-zero value in the Attribute ID Number indicates an active attribute. Valid values for this byte are from 0x01 through 0xFF.

3.2.2. Status Flags

The following describes the definitions for the Status Flags:

3.2.2.1. Pre-Failure/Advisory Bit = 0x0001

If the value of this bit = 0, an Attribute Value less than or equal to its corresponding Attribute Threshold indicates an Advisory condition where the usage or age of the device has exceeded its intended design life period.

If the value of this bit = 1, an Attribute Value less than or equal to its corresponding Attribute Threshold indicates a Pre-Failure condition where imminent loss of data is being predicted.

3.2.2.2. Reserved = 0x0002

This bit is reserved for future use.

3.2.2.3. Vendor Specific = 0x0004, 0x0008, 0x0010 and 0x0020

The values of these bits are vendor specific.

3.2.2.4. Reserved = all remaining

All bits other not defined in this section are reserved for future use.
3.2.3. Attribute Values

The range and meaning of the Attribute Values is defined in Table 2. Prior to the monitoring and saving of Attribute Values, all values are set to 0x64. The Attribute Values of 0x00 and 0xFF are reserved and should not be used by the device.

3.3. S.M.A.R.T. Capability

This word of bit flags describes the S.M.A.R.T. capabilities of the device.

3.3.1. Pre-Power Mode Attribute Saving Capability Bit = 0x0001

If the value of this bit = 1, the device will save its Attribute Values prior to going into a power saving mode (Idle, Standby or Sleep modes.)

3.3.2. Attribute AutoSave After Event Capability Bit = 0x0002

If the value of this bit = 1, the device supports the ENABLE/DISABLE ATTRIBUTE AUTOSAVE subcommand.

3.3.3. Reserved = all remaining

All bits other not defined in this section are reserved for future use.

3.4. Data Structure Checksum

The Data Structure Checksum is the two's compliment of the result of a simple eight-bit addition of the first 511 bytes in the data structure.

4. Device Attribute Thresholds Data Structure

The following defines the 512 bytes that make up the Attribute Threshold information. This data structure is accessed by the host in its entirety using the READ ATTRIBUTE THRESHOLDS subcommand. All multi-byte fields shown in these data structures follow the ATA-2 specification for byte ordering, namely that the least significant byte occupies the lowest numbered byte address location in the field.

The sequence of active Attribute Thresholds must appear in the same order as their corresponding Attribute Values (see Section 4. Device Attribute Data Structure).
4.1. Data Structure Revision Number

This value will be the same as the value used in the Device Attributes Values Data Structure (See Section 3.1.)

4.2. Individual Threshold Data Structure

The following defines the twelve bytes that make up the information for each Threshold entry in the Device Attribute Thresholds Data Structure. Attribute entries in the Individual Threshold Data Structure must be in the same order and correspond to the entries in the Individual Attribute Data Structure.

<table>
<thead>
<tr>
<th>Description</th>
<th>Bytes</th>
<th>Format</th>
<th>Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>Data Structure Revision Number = 0x0004 for this spec revision</td>
<td>2</td>
<td>binary</td>
<td>Rd only</td>
</tr>
<tr>
<td>1st Attribute Threshold</td>
<td>12</td>
<td>see below</td>
<td>Rd/Wrt</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>30th Attribute Threshold</td>
<td>12</td>
<td>see below</td>
<td>Rd/Wrt</td>
</tr>
<tr>
<td>Reserved (0x00)</td>
<td>18</td>
<td>Rd/Wrt</td>
<td></td>
</tr>
<tr>
<td>Vendor Specific</td>
<td>131</td>
<td>Rd only</td>
<td></td>
</tr>
<tr>
<td>Data Structure Checksum</td>
<td>1</td>
<td>Rd only</td>
<td></td>
</tr>
<tr>
<td>Total Bytes</td>
<td>512</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 3 - Device Attribute Thresholds Data Structure

4.2.1. Attribute ID Numbers

The Attribute ID Numbers are Vendor Specific. Any non-zero value in the Attribute ID Number indicates an active attribute.
4.2.2. Attribute Threshold

These values are intended to be set at the factory and are not meant to be changeable in the field.

4.3. Data Structure Checksum

The Data Structure Checksum is the two's compliment of the result of a simple eight-bit addition of the first 511 bytes in the data structure.

5. S.M.A.R.T. Operation with Power Management Modes

It is recommended that, when used in a system that is utilizing ATA-2 Power Management Commands, a S.M.A.R.T. Enabled device automatically saves its Attribute Values upon receipt of an IDLE IMMEDIATE, STANDBY IMMEDIATE or SLEEP Command. If the device has been set to utilize the Power Management Auto Timer, it is recommended that the device automatically perform a SAVE ATTRIBUTE VALUES function prior to going from an Idle state to the Auto Standby state.

6. Error Reporting

The following table shows the values returned in the Status and Error Registers when specific error conditions are encountered by a device.

<table>
<thead>
<tr>
<th>Error Condition</th>
<th>Status Register</th>
<th>Error Register</th>
</tr>
</thead>
<tbody>
<tr>
<td>A EXECUTE S.M.A.R.T. FUNCTION Command was received by the device without the</td>
<td>0x51</td>
<td>0x04</td>
</tr>
<tr>
<td>required key being loaded into the Cylinder High and Cylinder Low registers.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>A EXECUTE S.M.A.R.T. FUNCTION Command was received by the device with a</td>
<td>0x51</td>
<td>0x04</td>
</tr>
<tr>
<td>subcommand value in the Features Register that is either invalid or not</td>
<td></td>
<td></td>
</tr>
<tr>
<td>supported by this device.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>A EXECUTE S.M.A.R.T. FUNCTION Command subcommand other than ENABLE S.M.A.R.T.</td>
<td>0x51</td>
<td>0x04</td>
</tr>
<tr>
<td>OPERATIONS was received by the device while the device was in a &quot;S.M.A.R.T.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>disabled&quot; state.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>The device is unable to read its Attribute Values or</td>
<td>0x51</td>
<td>0x10 or 0x40</td>
</tr>
<tr>
<td>Attribute Thresholds data structure.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>The device is unable to write to its Attribute Values data</td>
<td>0x71</td>
<td>0x04</td>
</tr>
<tr>
<td>structure.</td>
<td>0x51</td>
<td>0x10 or 0x01</td>
</tr>
<tr>
<td>The Data Structure Revision Number in the device's Attribute Values data</td>
<td>0x51</td>
<td>0x01</td>
</tr>
<tr>
<td>structure does not match the Data Structure Revision Number in the device's</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Attribute Thresholds data structure.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>A mismatch has occurred between the entries in the device's Attribute</td>
<td>0x51</td>
<td>0x01</td>
</tr>
<tr>
<td>Values data structure and Attribute Thresholds data structure.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>The device has detected a checksum error in its Attribute Thresholds data</td>
<td>0x51</td>
<td>0x10</td>
</tr>
<tr>
<td>structure.</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 5 - S.M.A.R.T. Error Codes