SFF Committee
Specification for

Self-Monitoring, Analysis and
Reporting Technology
(S.M.A.R.T.)

SFF-8035i
Revision 2.0

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This document is endorsed by Compaq Computer Corporation, Hitachi, Ltd., IBM Storage Products Company, Maxtor Corporation, Quantum Corporation, Seagate Technology, Toshiba Corporation and Western Digital Corporation.

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"Self-Monitoring, Analysis and Reporting Technology," "S.M.A.R.T." and "The S.M.A.R.T. System" are not trademarks nor are they intended to be trademarks but rather are industry terms of art that describe technology used to monitor and predict device performance and/or reliability.

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Document status

Revision 1.0 - Initial preliminary document.

Revision 2.0 - Off-line data collection activities and subcommands are defined. The format of this document has been modified to be similar to the most recent draft of the ATA-3 document.

References

Working Draft of the proposed American National Standard X3T10/948D Revision 3, AT Attachment Interface with Extensions (ATA-2).

Working Draft of the proposed American National Standard X3T10/2008D Revision 6, Information Technology AT Attachment-3 Interface (ATA-3).

SFF Committee Specification Draft for S.M.A.R.T. Applications Guide, SFF-8055i Revision 1.1

Implementation Philosophy

The intent of S.M.A.R.T. (Self-Monitoring, Analysis and Reporting Technology) is to protect user data and minimize the likelihood of 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 attempt to predict the likelihood of near-term degradation or fault condition. Providing the host system the knowledge of a negative reliability condition allows the host system to warn the user of the impending risk of data loss and advise the user of appropriate action.

1. Definitions

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 fault conditions for that particular device. The specific set of attributes being used and the identity of these attributes is vendor specific and proprietary.

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 fault 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 greater than while still retaining a positive reliability status. Attribute thresholds are set at the device manufacturer's factory and cannot be changed in the field.

Attribute values - Attribute values are used to represent the relative reliability of individual performance or calibration attributes. Higher attribute values indicate that the analysis algorithms being used by the device are predicting a lower probability of a degrading or fault 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 fault condition existing. There is no implied linear reliability relationship corresponding to the numerical relationship between different attribute values for any particular attribute.

Off-line data collection - Collection of attribute data in an "off-line" mode shall have a vendor-specific impact on device performance if the device is required to respond to commands from the host while performing its off-line data collection routine. The set of attributes for which data is collected or the methods by which data is collected in this mode may be different than those in the on-line data collection mode.

On-line data collection - Collection of attribute data in an "on-line" mode shall have no impact on device performance. The set of attributes for which data is collected or the methods by which data is collected in this mode may be different than those in the off-line data collection mode.

Reserved - Reserved bit, byte, word, field and code values are set aside for future standardization. Their use and interpretation may be specified by future extensions to this or other specifications or standards. A reserved bit, byte, word or field shall be set to zero, or in accordance with future extensions to this or other specifications or standards. The recipient shall not check reserved bits, bytes, words or fields. Receipt of reserved code values in defined fields shall be treated as an error.

S.M.A.R.T. (Self-Monitoring, Analysis and Reporting Technology) - 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 fault condition.

Threshold exceeded condition - If one or more attribute values are less than or equal to their corresponding attribute thresholds, then the device reliability status indicates an impending degrading or fault condition.

Vendor specific - This term is used to describe bit, byte, word, field and code values which are reserved for vendor specific purposes. These bit, byte, word, field and code values are not described in this specification and their meaning may vary among vendors. This term is also applied to levels of functionality whose definitions is left to the vendor.

2. The S.M.A.R.T. Command

The subcommands that follow comprise the ATA S.M.A.R.T. feature set. The S.M.A.R.T. subcommands provide access to S.M.A.R.T. attribute values, attribute thresholds and other logging and reporting information.

Prior to writing any S.M.A.R.T. command to the device's Command register, key values shall be written by the host into the device's Cylinder Low and Cylinder High registers, or the command shall be aborted. For any S.M.A.R.T. subcommand: 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 in Table 1 below.

Table 1 - S.M.A.R.T. command keys

Key	Register
4Fh	Cylinder Low (1F4h)
C2h	Cylinder High (1F5h)

The S.M.A.R.T. subcommands use a single command code (B0h) and are differentiated from one another by the value placed in the Features register. In order to issue a command, the host shall write the subcommand-specific code to the device's Features register before writing the command code to the Command register. The subcommands and their respective codes are listed in Table 2 below.

Table 2 - S.M.A.R.T. subcommands and codes

Code	Subcommand
D0h	S.M.A.R.T. READ ATTRIBUTE VALUES
D1h	S.M.A.R.T. READ ATTRIBUTE THRESHOLDS
D2h	S.M.A.R.T. ENABLE/DISABLE ATTRIBUTE AUTOSAVE
D3h	S.M.A.R.T. SAVE ATTRIBUTE VALUES
D4h	S.M.A.R.T. EXECUTE OFF-LINE IMMEDIATE
D5h	Reserved
D6h	Reserved
D7h	Vendor specific
D8h	S.M.A.R.T. ENABLE OPERATIONS
D9h	S.M.A.R.T. DISABLE OPERATIONS
DAh	S.M.A.R.T. RETURN STATUS
DBh	S.M.A.R.T. ENABLE/DISABLE AUTOMATIC OFF-LINE
DCh thru DFh	Reserved
E0h thru EFh	Vendor specific

If the S.M.A.R.T. feature set is implemented, S.M.A.R.T. ENABLE/DISABLE ATTRIBUTE AUTOSAVE, S.M.A.R.T. ENABLE OPERATIONS, S.M.A.R.T. DISABLE OPERATIONS, and S.M.A.R.T. RETURN STATUS subcommands shall be implemented. The implementation of other S.M.A.R.T. subcommands is optional and vendor specific.

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

COMMAND CODE - B0h

PROTOCOL - Non-data subcommand

INPUTS - The Features register shall be set to D9h. The Cylinder Low register shall be set to 4Fh. The Cylinder High register shall be set to C2h.

Register	7	6	5	4	3	2	1	0
Features	D9h							
Sector Count								
Sector Number								
Cylinder Low	4Fh							
Cylinder High	C2h							
Device/Head	1		1	D				
Command	B0h							
Note: No entry indicates register or bit not used by the device. If the register is written by the host, bits with no entry shall be written to zero.								

NORMAL OUTPUTS - None

ERROR OUTPUTS - If the device does not support the S.M.A.R.T. feature set, if S.M.A.R.T. is not enabled or if the values in the Features, Cylinder Low or Cylinder High registers are invalid, an Aborted command error is posted.

Status register				Error register				
DRDY	DF	CORR	ERR	UNC	IDNF	ABRT	TK0NF	AMNF
V			V			V		
Note: No entry indicates register or bit not required. V indicates bit is valid.								

PREREQUISITES - DRDY set equal to one. S.M.A.R.T. enabled.

DESCRIPTION - 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 this subcommand the device shall disable all S.M.A.R.T. operations. Attribute values shall no longer be monitored or saved by the device. The state of S.M.A.R.T. (either enabled or disabled) shall be preserved by the device across power cycles.

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

After receipt of this subcommand by the device, all other S.M.A.R.T. subcommands, with the exception of S.M.A.R.T. ENABLE OPERATIONS, are disabled and invalid and shall be aborted by the device (including S.M.A.R.T. DISABLE OPERATIONS subcommands), returning Aborted command error.

2.2. S.M.A.R.T. ENABLE/DISABLE ATTRIBUTE AUTOSAVE

COMMAND CODE - B0h

PROTOCOL - Non-data subcommand

INPUTS - The Features register shall be set to D2h. The Cylinder Low register shall be set to 4Fh. The Cylinder High register shall be set to C2h. The Sector Count register is set to 00h to disable attribute autosaving or F1h to enable autosaving of attributes.

Register	7	6	5	4	3	2	1	0
Features	D2h							
Sector Count	00h or F1h							
Sector Number								
Cylinder Low	4Fh							
Cylinder High	C2h							
Device/Head	1		1	D				
Command	B0h							
Note: No entry indicates register or bit not used by the device. If the register is written by the host, bits with no entry shall be written as zero.								

NORMAL OUTPUTS - None

ERROR OUTPUTS - If the device does not support the S.M.A.R.T. feature set, if S.M.A.R.T. is disabled or if the values in the Features, Cylinder Low or Cylinder High registers are invalid, an Aborted command error is posted.

Status register				Error register				
DRDY	DF	CORR	ERR	UNC	IDNF	ABRT	TK0NF	AMNF
V			V			V		
Note: No entry indicates register or bit not required. V indicates bit is valid.								

PREREQUISITES - DRDY set equal to one. S.M.A.R.T. enabled.

DESCRIPTION - This subcommand enables and disables the attribute autosave feature of the device. Depending upon the implementation, this 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.

A value of zero written by the host into the device's Sector Count register before issuing this subcommand shall 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-on or power-off sequence or during an error recovery sequence.

A value of F1h written by the host into the device's Sector Count register before issuing this subcommand shall 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 this subcommand is vendor specific. The meaning of any non-zero value written to this register at this time shall be preserved by the device across power cycles.

Upon receipt of S.M.A.R.T. ENABLE/DISABLE ATTRIBUTE AUTOSAVE from the host, the device sets BSY to one, enables or disables the autosave feature (depending upon the implementation), clears BSY to zero and asserts INTRQ.

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 shall respond to the host within two seconds.

The state of the attribute autosave feature (either enabled or disabled) shall be preserved by the device across power cycles.

2.3. S.M.A.R.T. ENABLE/DISABLE AUTOMATIC OFF-LINE (optional)

COMMAND CODE - B0h

PROTOCOL - Non-data subcommand

INPUTS - The Features register shall be set to DBh. The Cylinder Low register shall be set to 4Fh. The Cylinder High register shall be set to C2h. The Sector Count register is set to 00h to disable automatic collection of off-line data or F8h to enable automatic collection of off-line data.

Register	7	6	5	4	3	2	1	0
Features	DBh							
Sector Count	00h or F8h							
Sector Number								
Cylinder Low	4Fh							
Cylinder High	C2h							
Device/Head	1		1	D				
Command	B0h							
Note: No entry indicates register or bit not used by the device. If the register is written by the host, bits with no entry shall be written to zero.								

NORMAL OUTPUTS - None

ERROR OUTPUTS - If the device does not support this subcommand, if S.M.A.R.T. is disabled or if the values in the Features, Cylinder Low or Cylinder High registers are invalid, an Aborted command error is posted.

Status register				Error register				
DRDY	DF	CORR	ERR	UNC	IDNF	ABRT	TK0NF	AMNF
V			V			V		
Note: No entry indicates register or bit not required. V indicates bit is valid.								

PREREQUISITES - DRDY set equal to one. S.M.A.R.T. enabled.

DESCRIPTION - This subcommand enables and disables the optional feature that causes the device to perform the set of off-line data collection activities that automatically collect attribute data in an off-line mode and then save this data to the device's non-volatile memory. Depending upon the implementation, this subcommand may either cause the device, after some vendor-specified event, to automatically initiate or resume performance of its off-line data collection activities; or this subcommand may cause the automatic off-line data collection feature to be disabled.

A value of zero written by the host into the device's Sector Count register before issuing this subcommand shall cause the 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-on or power-off sequence or during an error recovery sequence.

A value of F8h written by the host into the device's Sector Count register before issuing this subcommand shall 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 subcommand is vendor specific. The meaning of any non-zero value written to this register at this time shall be preserved by the device across power cycles.

The state of the automatic off-line data collection feature (either enabled or disabled) shall be preserved by the device across power cycles.

If the S.M.A.R.T. ENABLE/DISABLE AUTOMATIC OFF-LINE subcommand is supported by the device: upon receipt of the subcommand from the host, the device sets BSY to one, enables or disables the automatic off- line data collection feature (depending upon the implementation), clears BSY to zero and asserts INTRQ. During execution of its off-line data collection activities the device shall not set BSY nor clear DRDY.

If the device is in the process of performing its off-line data collection activities and is interrupted by any command from the host except a S.M.A.R.T. DISABLE AUTOMATIC OFF-LINE, S.M.A.R.T. DISABLE OPERATIONS, S.M.A.R.T. EXECUTE OFF-LINE IMMEDIATE or STANDBY IMMEDIATE command, the device shall suspend or abort its off-line data collection activities and service the host within two seconds after receipt of the command. The event that initiates resumption of off-line data collection activities after interruption of self-initiated off-line data collection activities is vendor specific.

If the device is in the process of performing its off-line data collection activities and is interrupted a STANDBY IMMEDIATE command from the host, the device shall suspend or abort its off-line data collection activities and service the host within two seconds after receipt of the command. After receiving a new command from the host that causes the device to leave the standby power saving mode, the device may initiate or resume its automatic off-line data collection activities. The event that initiates resumption of off-line data collection activities after interruption of self-initiated off-line data collection activities is vendor specific.

If the device is in the process of performing its off-line data collection activities and is interrupted by a S.M.A.R.T. DISABLE AUTOMATIC OFF-LINE subcommand from the host, the device shall suspend or abort its off-line data collection activities and service the host within two seconds after receipt of the command. Upon receipt of the next S.M.A.R.T. ENABLE AUTOMATIC OFF-LINE subcommand the device shall, after the next vendor specified event, either re-initiate its off-line data collection activities or resume those off-line data collection activities from where they had been previously suspended.

If the device is in the process of performing its off-line data collection activities and is interrupted by a S.M.A.R.T. DISABLE OPERATIONS subcommand from the host, the device shall suspend or abort its off-line data collection activities and service the host within two seconds after receipt of the command. Upon receipt of the next S.M.A.R.T. ENABLE OPERATIONS subcommand the device shall, after the next vendor specified event, either re-initiate its off-line data collection activities or resume those activities from where they had been previously suspended.

If the device is in the process of performing its off-line data collection activities and is interrupted by a S.M.A.R.T. EXECUTE OFF-LINE IMMEDIATE subcommand from the host, the device shall abort its off-line data collection activities and service the host within two seconds after receipt of the command. The device will then re-initiate its off-line data collection activity in response to the new EXECUTE OFF-LINE IMMEDIATE command.

When this feature is enabled, the device shall not initiate or resume its set of off-line data collection activities if the device is in the standby power saving mode when the event occurs.

If a S.M.A.R.T. enabled device has been set to utilize its Standby timer and the device has its automatic off-line data collection feature enabled, the device may automatically perform a set of S.M.A.R.T. off-line data collection activities prior to going from its idle power saving mode to its standby power saving mode as initiated by its Standby timer.

Implementation of this feature is optional and vendor specific.

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

COMMAND CODE - B0h

PROTOCOL - Non-data subcommand

INPUTS - The Features register shall be set to D8h. The Cylinder Low register shall be set to 4Fh. The Cylinder High register shall be set to C2h.

Register	7	6	5	4	3	2	1	0
Features	D8h							
Sector Count								
Sector Number								
Cylinder Low	4Fh							
Cylinder High	C2h							
Device/Head	1		1	D				
Command	B0h							
Note: No entry indicates register or bit not used by the device. If the register is written by the host, bits with no entry shall be written to zero.								

NORMAL OUTPUTS - None

ERROR OUTPUTS - If the device does not support the S.M.A.R.T. feature set, or if the values in the Features, Cylinder Low or Cylinder High registers are invalid, an Aborted command error is posted.

Status register				Error register				
DRDY	DF	CORR	ERR	UNC	IDNF	ABRT	TK0NF	AMNF
V			V			V		
Note: No entry indicates register or bit not required. V indicates bit is valid.								

PREREQUISITES - DRDY set equal to one.

DESCRIPTION - This subcommand enables access to all S.M.A.R.T. capabilities within the device. Prior to receipt of this subcommand attribute values are neither monitored nor saved by the device.

The state of S.M.A.R.T. (either enabled or disabled) shall be preserved by the device across power cycles.

Once enabled, the receipt of subsequent S.M.A.R.T. ENABLE OPERATIONS subcommands shall not affect any of the attribute values or other S.M.A.R.T. data or functions.

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

2.5. S.M.A.R.T. EXECUTE OFF-LINE IMMEDIATE (optional)

COMMAND CODE - B0h

PROTOCOL - Non-data subcommand

INPUTS - The Features register shall be set to D4h. The Cylinder Low register shall be set to 4Fh. The Cylinder High register shall be set to C2h.

Register	7	6	5	4	3	2	1	0
Features				D4h				
Sector Count								
Sector Number								
Cylinder Low				4Fh				
Cylinder High				C2h				
Device/Head	1		1	D				
Command				B0h				
Note: No entry indicates register or bit not used by the device. If the register is written by the host, bits with no entry shall be written to zero.								

NORMAL OUTPUTS - None

ERROR OUTPUTS - If the device does not support this subcommand, if S.M.A.R.T. is disabled or if the values in the Features, Cylinder Low or Cylinder High registers are invalid, an Aborted command error is posted.

Status register				Error register				
DRDY	DF	CORR	ERR	UNC	IDNF	ABRT	TK0NF	AMNF
V			V			V		
Note: No entry indicates register or bit not required. V indicates bit is valid.								

PREREQUISITES - DRDY set equal to one. S.M.A.R.T. enabled.

DESCRIPTION - This subcommand causes the device to immediately initiate the optional set of off-line data collection activities that collect attribute data in an off-line mode and then save this data to the device's non-volatile memory.

If the S.M.A.R.T. EXECUTE OFF-LINE IMMEDIATE subcommand is supported by the device: upon receipt of the subcommand from the host, the device sets BSY to one, begins its set of off-line data collection activities, clears BSY to zero and asserts INTRQ.

During execution of its off-line activities the device shall not set BSY nor clear DRDY.

If the device is in the process of performing its set of off-line data collection activities as a result of receiving a S.M.A.R.T. EXECUTE OFF-LINE IMMEDIATE subcommand from the host and is interrupted by any new command from the host except a S.M.A.R.T. DISABLE OPERATIONS, S.M.A.R.T. EXECUTE OFF-LINE IMMEDIATE or STANDBY IMMEDIATE command, the device shall suspend or abort its off-line data collection activities and service the host within two seconds after receipt of the new command. After servicing the interrupting command from the host the device may immediately re-initiate or resume its off-line data collection activities without any additional commands from the host (see the definition for Bit 2 in the Off-line data collection capability byte in Section 2.7).

If the device is in the process of performing its off-line data collection activities and is interrupted by a STANDBY IMMEDIATE command from the host, the device shall suspend or abort its off-line data collection activities, and service the host within two seconds after receipt of the command. After receiving a new command that causes the device to exit a power saving mode, the device shall immediately re-initiate or resume off-line data collection activities without any additional commands from the host unless these activities were aborted by the device (see Table 7 - off-line data collection status byte values).

If the device is in the process of performing its off-line data collection activities and is interrupted by a S.M.A.R.T. DISABLE OPERATIONS subcommand from the host, the device shall suspend or abort its off-line data collection activities and service the host within two seconds after receipt of the command. Upon receipt of the next S.M.A.R.T. ENABLE OPERATIONS subcommand the device shall, after the next vendor specified event, either re-initiate its off-line data collection activities or resume those activities from where they had been previously suspended.

If the device is in the process of performing its off-line data collection activities and is interrupted by a S.M.A.R.T. EXECUTE OFF-LINE IMMEDIATE subcommand from the host, the device shall abort its off-line data collection activities and service the host within two seconds after receipt of the command. The device shall then re-initiate its off-line data collection activities in response to the new EXECUTE OFF-LINE IMMEDIATE subcommand.

Implementation of this feature is optional and vendor specific.

2.6. S.M.A.R.T. READ ATTRIBUTE THRESHOLDS (optional)

COMMAND CODE - B0h

PROTOCOL - PIO data in

INPUTS - The Features register shall be set to D1h. The Cylinder Low register shall be set to 4Fh. The Cylinder High register shall be set to C2h.

Register	7	6	5	4	3	2	1	0
Features	D1h							
Sector Count								
Sector Number								
Cylinder Low	4Fh							
Cylinder High	C2h							
Device/Head	1		1	D				
Command	B0h							
Note: No entry indicates register or bit not used by the device. If the register is written by the host, bits with no entry shall be written to zero.								

NORMAL OUTPUTS - None

ERROR OUTPUTS - If the device does not support this subcommand, if S.M.A.R.T. is disabled or if the values in the Features, Cylinder Low or Cylinder High registers are invalid, an Aborted command error is posted.

Status register				Error register				
DRDY	DF	CORR	ERR	UNC	IDNF	ABRT	TK0NF	AMNF
V			V			V		
Note: No entry indicates register or bit not required. V indicates bit is valid.								

PREREQUISITES - DRDY set equal to one. S.M.A.R.T. enabled.

DESCRIPTION - This subcommand returns the device's attribute thresholds to the host. Upon receipt of this subcommand from the host, the device sets BSY to one, reads the attribute thresholds from non-volatile memory, sets DRQ to one, clears BSY to zero, asserts INTRQ, and then waits for the host to transfer the 512 bytes of attribute threshold information from the device via the Data register.

The following defines the 512 bytes that make up the attribute threshold information. All multi-byte fields shown in these data structures follow the ATA-3 specification for byte ordering, namely that the least significant byte occupies the lowest numbered byte address location in the field.

The number of individual attributes (and thus attribute thresholds) is determined independently by the device manufacturer for each individual device. All attribute threshold entries in the device attribute thresholds data structure shall be concatenated together directly after the data structure revision number. If there are fewer than thirty 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 00h. Thus the first reserved byte shall be the 363rd byte in the device attribute thresholds data structure, the first vendor specific byte shall be the 381st byte in the device attribute threshold data structure, etc.

Table 3 - Device attribute thresholds data structure

Description	Bytes	Format	Type
Data structure revision number = 0005h for this spec revision	2	binary	Rd only
1st individual attribute threshold data	12	see below	Rd/Wrt
..			
30th individual attribute threshold data	12	see below	Rd/Wrt
Reserved (00h)	18		Rd/Wrt
Vendor specific	131		Rd only
Data structure checksum	1		Rd only
Total bytes	512		

The data structure revision number identifies which version of this data structure is implemented by a device. The data structure revision number for this revision of the specification shall be set to 0005h. Later revisions, if any, shall increment the revision number by one for each new revision. The revision number shall be the same for both the device attribute thresholds data structure and the device attributes structures.

The following defines the twelve bytes that make up the information for each individual attribute threshold entry in the device attribute thresholds data structure. Individual attribute threshold entries in the device attribute thresholds data structure shall be in the same order and correspond to the individual attribute entries in the device attributes data structure.

Table 4 - Individual attribute threshold data structure

Description	Bytes	Format	Type
Attribute ID number	1	binary	Rd only
Attribute threshold (for comparison with attribute values from 01h to FDh) 00h = "always passing" threshold value to be used for code test purposes or advisory attributes 01h = minimum threshold value FDh = maximum threshold value FEh = invalid for threshold value-- not to be used FFh = "always failing" threshold value to be used for code test purposes only	1	binary	Rd only
Reserved	10		Rd only
Total bytes	12		

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 01h through FFh.

The range and meaning of attribute threshold values is defined in Table 4. Attribute threshold values are intended to be set at the factory and are not changeable in the field. Attribute threshold values for advisory attributes may be set to "always passing" in some devices.

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.

Implementation of this feature is optional and vendor specific.

2.7. S.M.A.R.T. READ ATTRIBUTE VALUES (optional)

COMMAND CODE - B0h

PROTOCOL - PIO data in

INPUTS - The Features register shall be set to D0h. The Cylinder Low register shall be set to 4Fh. The Cylinder High register shall be set to C2h.

Register	7	6	5	4	3	2	1	0
Features	D0h							
Sector Count								
Sector Number								
Cylinder Low	4Fh							
Cylinder High	C2h							
Device/Head	1		1	D				
Command	B0h							
Note: No entry indicates register or bit not used by the device. If the register is written by the host, bits with no entry shall be written to zero.								

NORMAL OUTPUTS - None

ERROR OUTPUTS - If the device does not support this subcommand, if S.M.A.R.T. is disabled or if the values in the Features, Cylinder Low or Cylinder High registers are invalid, an Aborted command error is posted.

Status register				Error register				
DRDY	DF	CORR	ERR	UNC	IDNF	ABRT	TK0NF	AMNF
V			V			V		
Note: No entry indicates register or bit not required. V indicates bit is valid.								

PREREQUISITES - DRDY set equal to one. S.M.A.R.T. enabled.

DESCRIPTION - This subcommand returns the device's attribute values to the host. Upon receipt of this subcommand from the host, the device sets BSY to one, saves any updated attribute values to non-volatile memory, sets DRQ to one, clears BSY to zero, asserts INTRQ, and then waits for the host to transfer the 512 bytes of attribute value information from the device via the Data register.

The following defines the 512 bytes that make up the attribute value information All multi-byte fields shown in these data structures follow the ATA-3 specification for byte ordering, namely that the least significant byte occupies the lowest numbered byte address location in the field.

The number of individual attributes is determined independently by the device manufacturer for each individual device. All attribute entries in the device attributes data structure shall be concatenated together directly after the data structure revision number. If there are fewer than thirty 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 00h. Thus the off-line data collection status byte shall be the 363rd byte in the device attributes data structure, the first S.M.A.R.T. capability byte shall be the 369th byte in the device attributes data structure, etc.

Table 5 - Device attributes data structure

Description	Bytes	Format	Type
Data structure revision number = 0005h for this spec revision	2	binary	Rd only
1st individual attribute data	12	see below	Rd/Wrt
..			
30th individual attribute data	12	see below	Rd/Wrt
Off-line data collection status	1	see below	Rd only
Vendor specific	1		Rd only
Total time in seconds to complete off-line data collection activity	2	see below	Rd only
Vendor specific	1		Rd only
Off-line data collection capability	1	see below	Rd only
S.M.A.R.T. capability	2	see below	Rd only
Reserved (00h)	16		Rd/Wrt
Vendor specific	125		Rd only
Data structure checksum	1		Rd only
Total bytes	512		

The data structure revision number identifies which version of this data structure is implemented by a device. The data structure revision number for this revision of the specification shall be set to 0005h. Later revisions, if any, shall increment the revision number by one for each new revision. The revision number shall be the same for both the device attributes data structure and the device attribute thresholds structures.

The following defines the twelve bytes that make up the information for each individual attribute entry in the device attributes data structure. Individual attribute entries in the device attributes data structure shall be in the same order and correspond to the individual attribute threshold entries in the device attribute thresholds data structure.

Table 6 - Individual attribute data structure

Description	Bytes	Format	Type
Attribute ID number (01h to FFh)	1	binary	Rd only

Status flag
    Bit 0 (pre-failure/advisory bit)
    Bit 1 (on-line data collection bit)
    Bits 2-5 (vendor specific)
    Bits 6-15 (Reserved)
	2	bit flags	Rd only

Attribute value (valid values are from 01h through FDh)
    00h = invalid for attribute value -- not to be used
    01h = minimum value
    64h = initial value for all attributes prior to any data collection
    FDh = maximum value
    FEh = invalid for attribute value -- not to be used
    FFh = invalid for attribute value -- not to be used
	1	binary	Rd only

Vendor specific	8	binary	Rd only
Total bytes	12		

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 01h through Ffh.

Status flags

The following describes the definitions for the bits in the status flag bits:

- Bit 0 (pre-failure/advisory bit) - If the value of this bit equals zero, 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 equals one, 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.

- Bit 1 (on-line data collection bit) - If the value of this bit equals zero, then the attribute value is updated only during off-line data collection activities. If the value of this bit equals one, then the attribute value is updated during normal operation of the device or during both normal operation and off-line testing.

- Bits 2-5 (vendor specific bits) - The values of these bits are vendor specific.

- Bits 6-15 (reserved bits) - All bits other not defined in this section are reserved for future use.

The range and meaning of the attribute values is defined in Table 6. Prior to the monitoring and saving of attribute values, all values shall be set to 64h. The attribute values of 00h and FFh are reserved and shall not be used by the device.

The value of the off-line data collection status byte defines the current status of the off-line activities of the device. The values and their respective definitions are listed in Table 7.

Table 7 - Off-line data collection status byte values

Value	Definition
00h	Off-line data collection activity was never started.
01h	Reserved
02h	Off-line data collection activity was completed without error.
03h	Reserved
04h	Off-line data collection activity was suspended by an interrupting command from host.
05h	Off-line data collection activity was aborted by an interrupting command from host.
06h	Off-line data collection activity was aborted by the device with a fatal error.
07h thru 3Fh	Reserved
40h thru 7Fh	Vendor specific
80h	Off-line data collection activity was never started. The auto-off-line feature is enabled.
81h	Reserved
82h	Off-line data collection activity was completed without error. The auto-off-line feature is enabled.
83h	Reserved
84h	Off-line data collection activity was suspended by an interrupting command from host. The auto-off-line feature is enabled.
85h	Off-line data collection activity was aborted by an interrupting command from host. The auto-off-line feature is enabled.
86h	Off-line data collection activity was aborted by the device with a fatal error. The auto-off-line feature is enabled.
87h thru BFh	Reserved
C0h thru FFh	Vendor specific

The total time in seconds to complete off-line data collection activity word specifies how many seconds the device requires to complete its sequence of off-line data collection activity. Valid values for this word are from 0001h to FFFFh.

Off-line data collection capability

The following describes the definition for the off-line data collection capability bits. If the value of all of these bits is equal to zero, then no off-line data collection is implemented by this device.

- Bit 0 (EXECUTE OFF-LINE IMMEDIATE implemented bit) - If the value of this bit equals one, then the S.M.A.R.T. EXECUTE OFF-LINE IMMEDIATE subcommand is implemented by this device. If the value of this bit equals zero, then the S.M.A.R.T. EXECUTE OFF-LINE IMMEDIATE subcommand is not implemented by this device.

- Bit 1 (ENABLE/DISABLE AUTOMATIC OFF-LINE implemented bit) - If the value of this bit equals one, then the S.M.A.R.T. ENABLE/DISABLE AUTOMATIC OFF-LINE subcommand is implemented by this device. If the value of this bit equals zero, then the S.M.A.R.T. ENABLE/DISABLE AUTOMATIC OFF-LINE subcommand is not implemented by this device.

- Bit 2 (abort/restart off-line by host bit) - If the value of this bit equals one, then the device shall abort all off-line data collection activity initiated by an S.M.A.R.T. EXECUTE OFF-LINE IMMEDIATE command upon receipt of a new command. Off-line data collection activity must be restarted by a new S.M.A.R.T. EXECUTE OFF-LINE IMMEDIATE subcommand from the host. If the value of this bit equals zero, the device shall suspend off-line data collection activity after an interrupting command and resume off-line data collection activity after some vendor-specified event.

- Bits 3-7 (reserved bits) - All bits other not defined in this section are reserved for future use.

S.M.A.R.T. capability

The following describes the definition for the S.M.A.R.T. capabilities bits. If the value of all of these bits is equal to zero, then off-line data collection is not implemented by this device.

- Bit 0 (power mode attribute saving capability bit) - If the value of this bit equals one, the device shall save its attribute values prior to going into a power saving mode (idle, standby or sleep) or immediately upon return to active or idle power saving mode from a standby power saving mode. If the value of this bit equals zero, the device shall not save its attribute values prior to going into a power saving mode (idle, standby or sleep) or immediately upon return to active or idle power saving mode from a standby power saving mode.

- Bit 1 (attribute autosave after event capability bit) - If the value of this bit equals one, the device supports the S.M.A.R.T. ENABLE/DISABLE ATTRIBUTE AUTOSAVE subcommand. If the value of this bit equals zero, the device does not support the S.M.A.R.T. ENABLE/DISABLE ATTRIBUTE AUTOSAVE subcommand.

- Bits 2-15 (reserved bits) - All bits other not defined in this section are reserved for future use.

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.

Implementation of this feature is optional and vendor specific.

2.8. S.M.A.R.T. RETURN STATUS

COMMAND CODE - B0h

PROTOCOL - Non-data subcommand

INPUTS - The Features register shall be set to DAh. The Cylinder Low register shall be set to 4Fh. The Cylinder High register shall be set to C2h.

Register	7	6	5	4	3	2	1	0
Features	DAh							
Sector Count								
Sector Number								
Cylinder Low	4Fh							
Cylinder High	C2h							
Device/Head	1		1	D				
Command	B0h							
Note: No entry indicates register or bit not used by the device. If the register is written by the host, bits with no entry shall be written to zero.								

NORMAL OUTPUTS - If the device has not detected a threshold exceeded condition, the device sets the Cylinder Low register to 4Fh and the Cylinder High register to C2h. If the device has detected a threshold exceeded condition, the device sets the Cylinder Low register to F4h and the Cylinder High register to 2Ch.

ERROR OUTPUTS - If the device does not support the S.M.A.R.T. feature set, if S.M.A.R.T. is disabled or if the values in the Features, Cylinder Low or Cylinder High registers are invalid, an Aborted command error is posted.

Status register				Error register				
DRDY	DF	CORR	ERR	UNC	IDNF	ABRT	TK0NF	AMNF
V			V			V		
Note: No entry indicates register or bit not required. V indicates bit is valid.								

PREREQUISITES - DRDY set equal to one. S.M.A.R.T. enabled.

DESCRIPTION - This subcommand is used to communicate the reliability status of the device to the host at the host's request.

Upon receipt of this subcommand the device shall set BSY to one; save any updated attribute values to non-volatile memory and compare the updated attribute values to the attribute thresholds.

If a threshold exceeded condition is not detected by the device, the device shall set the Cylinder Low register to 4Fh and the Cylinder High register to C2h.

If a threshold exceeded condition is detected by the device, the device shall set the Cylinder Low register to F4h and the Cylinder High register to 2Ch.

After setting the Cylinder Low and Cylinder High registers the device shall clear BSY to zero and assert INTRQ.

2.9. S.M.A.R.T. SAVE ATTRIBUTE VALUES (optional)

COMMAND CODE - B0h

PROTOCOL - Non-data subcommand

INPUTS - The Features register shall be set to D3h. The Cylinder Low register shall be set to 4Fh. The Cylinder High register shall be set to C2h.

Register	7	6	5	4	3	2	1	0
Features				D3h				
Sector Count								
Sector Number								
Cylinder Low				4Fh				
Cylinder High				C2h				
Device/Head	1		1	D				
Command				B0h				
Note: No entry indicates register or bit not used by the device. If the register is written by the host, bits with no entry shall be written to zero.								

NORMAL OUTPUTS - None

ERROR OUTPUTS - If the device does not support this subcommand, if S.M.A.R.T. is disabled or if the values in the Features, Cylinder Low or Cylinder High registers are invalid, an Aborted command error is posted.

Status register				Error register				
DRDY	DF	CORR	ERR	UNC	IDNF	ABRT	TK0NF	AMNF
V			V			V		
Note: No entry indicates register or bit not required. V indicates bit is valid.								

PREREQUISITES - DRDY set equal to one. S.M.A.R.T. enabled.

DESCRIPTION - 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 shall set BSY to one, write any updated attribute values to non-volatile memory, clear BSY to zero and assert INTRQ.

Implementation of this feature is optional and vendor specific.

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

When used in a system that is utilizing the ATA Power Management Feature set, it is recommended that a S.M.A.R.T. enabled device automatically save its attribute values upon receipt of an IDLE IMMEDIATE, STANDBY IMMEDIATE or SLEEP command or upon return to an active or idle power saving mode from a standby power saving mode (see the S.M.A.R.T. capability bytes in the device attribute data structure in Section 2.7).

If a S.M.A.R.T. enabled device has been set to utilize its Standby timer, it is recommended that the device automatically perform a S.M.A.R.T. SAVE ATTRIBUTE VALUES function prior to going from an idle power saving mode to the standby power saving mode or upon return to an active or idle power saving mode from a standby power saving mode (see the S.M.A.R.T. capability bytes in the device attribute data structure in Section 2.7).

If a S.M.A.R.T. enabled device has been set to utilize its Standby timer and the device has its automatic off-line data collection feature enabled, the device may automatically perform a set of S.M.A.R.T. off-line data collection activities prior to going from an idle power saving mode to a standby power saving mode.

A device shall not execute either an attribute autosave routine or an automatic off-line data collection routine while in a standby or sleep power saving mode.

4. 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 8 - S.M.A.R.T. error codes

Error condition	Status register	Error register
A S.M.A.R.T. subcommand was received by the device without the required key being loaded into the Cylinder High and Cylinder Low registers.	51h or 53h	04h
A S.M.A.R.T. subcommand was received by the device with a subcommand value in the Features register that is either invalid or not supported by this device.	51h or 53h	04h
A S.M.A.R.T. subcommand other than ENABLE S.M.A.R.T. OPERATIONS was received by the device while the device was in a "S.M.A.R.T. disabled" state.	51h or 53h	04h
The device is unable to read its attribute values or attribute thresholds data structure.	51h or 53h	10h or 40h
The device is unable to write to its attribute values data structure.	71h or 73h 51h or 53h	04h 10h or 01h
The data structure revision number in the device's attribute values data structure does not match the data structure revision number in the device's attribute thresholds data structure.	51h or 53h	01h
A mismatch has occurred between the entries in the device's attribute values data structure and attribute thresholds data structure.	51h or 53h	01h
The device has detected a checksum error in its attribute threshold data structure.	51h or 53h	10h