Western Digital®

Ultrastar® DC SS540 TCG Enterprise SSD
FIPS 140-2 Cryptographic Module
Non-Proprietary Security Policy

Protection of Data at Rest

Document Version: 1.5
2021-06-16

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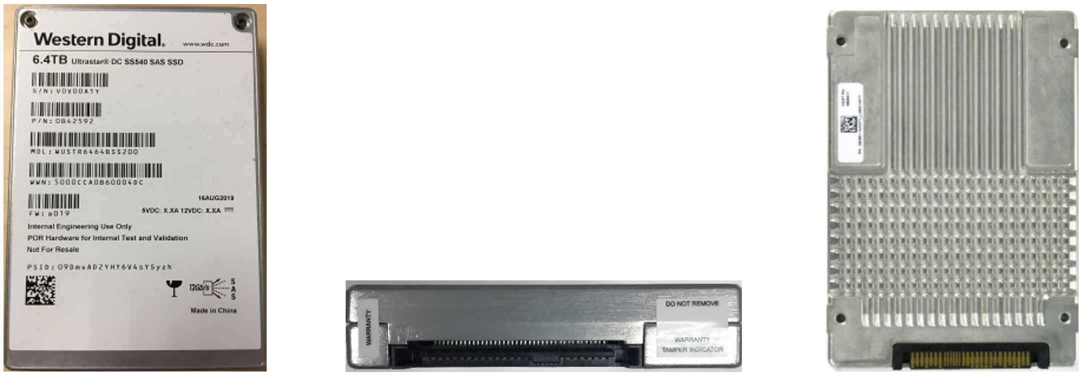
1. Cryptographic Module Overview

The self-encrypting Ultrastar® DC SS540 *TCG Enterprise SSD*, hereafter referred to as "Ultrastar DC SS540", or "Cryptographic Module", is a multiple chip embedded module that comply with FIPS 140-2 *Level 2* security. The Cryptographic Module complies with the *Trusted Computing Group (TCG) SSC: Enterprise Specification*. The drive enclosure defines the cryptographic boundary. See Figure 1: Ultrastar DC SS540 Cryptographic Boundary. All components within this boundary satisfy FIPS 140-2 requirements.

Figure 1: Ultrastar DC SS540 Cryptographic Boundary



Top View SAS Connector View Bottom View

1.1 Models

The Cryptographic Module is available in several models that vary in storage capacity and write endurance. Table 1 provides the model numbers, characteristics, and firmware versions associated with each validated module.

Table 1 Ultrastar DC SS540 TCG Enterprise SSD Models

Model Number	Firmware	Description
WUSTM3240BSS205	R088, R104, R130, R132, R134, L130, L132, L134	SSD, 2.5", 12 Gb/s SAS, TLC 3D, 400GB, ME-10DW/D
WUSTM3280BSS205	R088, R104, R130, R132, R134, L130, L132, L134	SSD, 2.5", 12 Gb/s SAS, TLC 3D 800GB ME 10DW/D
WUSTM3216BSS205	R088, R104, R130, R132, R134, L130, L132, L134	SSD, 2.5", 12 Gb/s SAS, TLC 3D 1600GB ME 10DW/D
WUSTM3232BSS205	R088, R104, R130, R132, R134, L130, L132, L134	SSD, 2.5", 12 Gb/s SAS, TLC 3D 3200GB ME 10DW/D
WUSTR6480BSS205	R088, R104, R109, R10A, R130, R132, R134, L130, L132, L134	SSD, 2.5", 12 Gb/s SAS, TLC 3D, 800GB, RI-3DW/D
WUSTR6416BSS205	R088, R104, R109, R10A, R130, R132, R134, L130, L132, L134	SSD, 2.5", 12 Gb/s SAS, TLC 3D, 1600GB RI-3DW/D
WUSTR6432BSS205	R088, R104, R109, R10A, R130, R132, R134, L130, L132, L134	SSD, 2.5", 12 Gb/s SAS, TLC 3D, 3200GB RI-3DW/D
WUSTR6464BSS205	R088, R104, R10A, R130, R132, R134, L130, L132, L134	SSD, 2.5", 12 Gb/s SAS, TLC 3D, 6400GB RI-3DW/D
WUSTVA196BSS205	R088, R104, R10A, R130, R132, R134, L130, L132, L134	SSD, 2.5", 12 Gb/s SAS, TLC 3D, 960GB RI-1DW/D
WUSTVA119BSS205	R088, R104, R10A, R130, R132, R134, L130, L132, L134	SSD, 2.5", 12 Gb/s SAS, TLC 3D, 1920GB RI-1DW/D
WUSTVA138BSS205	R088, R104, R109, R10A, R130, R132, R134, L130, L132, L134	SSD, 2.5", 12 Gb/s SAS, TLC 3D, 3840GB RI-1DW/D

Model Number	Firmware	Description
WUSTVA176BSS205	R088, R104, R109, R10A, R130, R132, R134, L130, L132, L134	SSD, 2.5", 12 Gb/s SAS, TLC 3D, 7680GB RI-1DW/D
WUSTVA1A1BSS205	R088, R104, R109, R10A, R130, R132, R134, L130, L132, L134	SSD, 2.5", 12 Gb/s SAS, TLC 3D, 15.36TB RI-1DW/D

1.2 Security Level

The Cryptographic Module meets all requirements applicable to FIPS 140-2 Level 2 Security.

Table 2 - Module Security Level Specification

FIPS 140-2 Security Requirements Section	FIPS 140-2 Security Level Achieved
Cryptographic Module Specification	2
Module Ports and Interfaces	2
Roles, Services and Authentication	2
Finite State Model	2
Physical Security	2
Operational Environment	N/A
Cryptographic Key Management	2
EMI/EMC	3
Self-Tests	2
Design Assurance	2
Mitigation of Other Attacks	N/A

2. Modes of Operation

2.1 FIPS Approved Mode of Operation

The Cryptographic Module has a single FIPS Approved mode of operation. Configuration and policy determine the Cryptographic Module's FIPS mode of operation. The Cryptographic Module enters FIPS Approved Mode after successful completion of the Initialize Cryptographic service instructions. See Section 7.2 for information on the Cryptographic Module's initialization rules. The operator can determine if the Cryptographic Module is operating in a FIPS approved mode by invoking the Get FIPS mode service[1]. The Crypto Officer shall not enable the Makers Authority after the cryptographic module enters FIPS Approved mode. The cryptographic module is in FIPS non-Approved mode whenever the Makers Authority is enabled. If the Crypto Officer enables the Makers Authority after the module enters FIPS Approved mode, the Crypto Officer must also execute the TCG Revert method to zeroize the cryptographic module. If the Crypto Officer, subsequently, executes the Initialize Cryptographic service instructions provided in Section 7.2 with the intent of placing the cryptographic module in FIPS Approved mode, the Crypto Officer must first execute the TCG Revert method to zeroize the cryptographic module.

The chapter titled FIPS 140 Crypto Officer Instructions within the Ultrastar DC SS540 Product Manual provides information on how to execute the Initialize Cryptographic service as well as the TCG Revert method.

2.2 Approved Algorithms

The Cryptographic Module supports the following FIPS Approved algorithms. All algorithms and key lengths comply with NIST SP 800-131A. All algorithms are supported in FIPS Approved mode and non-Approved mode.

[1] A return value of 1 indicates that the cryptographic module is operating in FIPS Approved mode.

Table 3 - FIPS Approved Algorithms

Algorithm	Description	Cert #
AES Firmware	[FIPS 197, SP800 38A, SP 800 38F] Functions: Encryption, decryption, and key wrapping to protect an associated MEK in data storage applications Modes: ECB, KW Key Size: 256	C1352
AES ECB Hardware[2]	[FIPS 197, SP800 38A] Functions: Encryption and decryption Mode: ECB Key Sizes: 128, 256	AES 4309
AES XTS Hardware[3]	[FIPS 197, SP800 38A, SP800 38E] Functions: Encryption and decryption in storage applications Mode: XTS • XTS-AES Key_1 does not equal XTS-AES Key_2 • The length of the XTS-AES data unit does not exceed 2^{20} blocks. Key Sizes: 128, 256	AES 4309
DRBG Firmware	[SP800 90A] Function: Deterministic random number generator that uses an AES-256 block cipher derivation function. Mode: CTR Security Strength: 256 bits (reduced to 134 bits, see NDRNG related caveat below)	C1352
HMAC Firmware	[FIPS 198-1] Function: Key encrypting key (KEK) derivation used within the PBKDF SHA size: SHA-256	C1352
RSA Firmware	[FIPS 186-4, PSS] Function: Digital signature verification with SHA-256[4] Key size: 2048	C1352
SHA Hardware/Firmware	[FIPS 180-4] Functions: Digital Signature verification SHA size: SHA-256	C1353
SHA Firmware	[FIPS 180-4] Functions: AUTH Digest and KEK generation SHA size: SHA-256	C1352

Table 4 – Approved Cryptographic Functions Tested with Vendor Affirmation

Algorithm	Description	Rationale
CKG	[SP800 133] Cryptographic Key Generation Function: Generated from the DRBG without further modification or post processing	Vendor Affirmed [FIPS140] IG D.12 [SP800 133] Sections 6.1 and 6.2.3
PBKDF	[SP 800-132] PBKDF Functions: Key Encrypting Key Modes: HMAC-SHA-256 Key Sizes: 256 bits	Vendor Affirmed [FIPS140] IG D.6 [SP 800-132] Section 5.4

[2] Tested AES ECB-128. However, the cryptographic module does not use this algorithm.

[3] Tested AES XTS-128. However, the cryptographic module does not use this algorithm.

[4] SHA-256 Cert. C1353

The Cryptographic Module supports the following non-Approved but allowed algorithm:

- A hardware NDRNG seeds the Approved [SP800-90A] DRBG. Available entropy modifies the security strength of the cryptographic keys generated by the module. Each 32-bit block contains at least 3.146 bits of min entropy. 2048 bits (64 32-bit samples) of entropy data provides at least 201.344 bits of min-entropy. This seeds the DRBG with approximately 134 bits of security strength (~134.2-bit entropy input and ~67.1 bit nonce) which meet the NIST minimum requirement of 112 bits of security strength.

3. Ports and Interfaces

The drive uses the standard 29-pin Serial Attached SCSI (SAS) connector that conforms to the mechanical requirements of SFF 8680. Table 5 identifies the Cryptographic Module's ports and interfaces. The Serial connector is a two-wire port that consists of signal and ground. Western Digital disables the serial connector at its manufacturing facility before delivering the Cryptographic Module to customers. The Cryptographic Module does not provide a maintenance access interface.

Table 5 - Ultrastar DC SS540 Pins and FIPS 140-2 Ports and Interfaces

FIPS 140-2 Interface	Cryptographic Module Port Connector Pins
Power	Power connector
Control Input	SAS connector, Serial connector(disabled)
Status Output	SAS connector, Serial connector (disabled)
Data Input	SAS connector, Serial connector (disabled)
Data Output	SAS connector, Serial connector (disabled)

4. Identification and Authentication Policy

The Cryptographic Module enforces role separation by requiring a role identifier and an authentication credential (Personal Identification Number or PIN). The Cryptographic Module enforces the following FIPS140-2 operator roles.

4.1 Crypto Officer

4.1.1 Secure ID (SID) Authority

This TCG authority initializes the Cryptographic Module. Section 11.3.1 of the TCG Storage Security Subsystem Class: Enterprise Specification defines this role.

4.1.2 EraseMaster Authority

This TCG authority can selectively zeroize bands within the cryptographic module. Section 11.4.1 of the TCG Storage Security Subsystem Class: Enterprise Specification defines this role. It may also disable User roles and erase LBA bands (user data regions).

4.2 User

4.2.1 BandMaster Authority

User roles correspond to Bandmaster Authorities. Section 11.4.1 of the TCG Storage Security Subsystem Class: Enterprise Specification provides a definition. Bandmaster authorities can lock/unlock and configure LBA bands (user data regions) and issue read/write commands to the SE Cryptographic Module. The TCG EraseMaster authority can disable a Bandmaster.

4.2.2 Anybody

The Anybody role corresponds to services that do not require authentication. With one exception, these do not disclose, modify, or substitute Critical Security Parameters, use an Approved security function, or otherwise affect the security of the Cryptographic Module. The excepted service is the Generate Random service, which provides output from an instance of the SP800-90A DRBG.

4.3 Makers

For failure analysis purposes, the vendor can enable a logical diagnostic port to perform diagnostics and gather data on the failure. A power cycle automatically disables the logical diagnostic port. An operator must authenticate to the SID authority and the Makers authority to enable the logical diagnostic port. The Cryptographic Module is in FIPS non-Approved mode whenever the Crypto Officer enables the Makers Authority. The vendor performs failure analysis within the vendor's facility. Makers authentication data shall not leave the vendor's facilities. During normal operation, the Crypto Officer disables the Makers authority when invoking the Initialize Cryptographic Module service.

The following table maps TCG authorities to FIPS 140-2 roles.

Table 6 - Roles and Required Identification and Authentication

TCG Authority	Description	Authentication Type	Authentication Data
SID Authority	The SID Authority is a Crypto Officer role that initializes the Cryptographic Module and authorizes Firmware download.	Role-based	CO Identity (TCG *SID Authority*) and PIN (TCG *SID Authority PIN*)
EraseMaster Authority	The EraseMaster Authority is a Crypto Officer role that zeroizes Media Encryption keys and disables Users.	Role-based	CO Identity (TCG *EraseMaster Authority*) and PIN (TCG *EraseMaster PIN*)
BandMaster N (N = 0 to 15)	The BandMaster Authority is a User role that controls read/write access to LBA Bands.	Role-based	User Identity (TCG *BandMaster Authority*) and PIN (TCG *BandMaster PIN*)
Anybody	Anybody is a role that does not require authentication.	Unauthenticated	N/A
Makers (Disabled)	Completion of the Initialize Cryptographic Module service disables the Makers Authority	Role-based	CO Identity (TCG SID Authority) and PIN (Makers PIN)

Table 7 - Authentication Mechanism Strengths

Authentication Mechanism	Mechanism Strength
TCG Credential (PIN)	TCG Credentials are 256 bits, which provides 2^{256} possible values. The probability that a random attempt succeeds is 1 chance in 2^{256} (approximately (8.64×10^{-78}) which is significantly less than 1/1,000,000 ($1x 10^{-6}$). Multiple, successive authentication attempts can only occur sequentially (one at a time) and only when the failed authentication *Tries* count value does not exceed the associated *TryLimit* value. Each authentication attempt consumes approximately 700 microseconds. Hence, at most, approximately 86,000 authentication attempts are possible in one minute. Thus, the probability that a false acceptance occurs within a one-minute interval is approximately 7.4×10^{-73}, which is significantly less than 1 chance in 100,000 (1×10^{-5}).

5. Access Control Policy

5.1 Roles and Services

Table 8 - Authenticated CM Services

Service	Description	Role(s)	Approved Mode	Non-Approved Mode
Initialize Cryptographic Module[5]	Crypto Officer provisions the Cryptographic Module from the organizational policies	CO (SID Authority)	X	X
Authenticate	Input a TCG Credential for authentication	CO (SID Authority, EraseMaster), User (BandMasters)	X	X
Lock/Unlock Firmware Download Control	Deny/Permit access to Firmware Download service	CO (SID Authority)	X	X
Firmware Download	Unlocking the Firmware Download Control enables firmware downloads. RSA2048 PSS and SHA-256 verify the entire firmware image. After a successful download the SED executes the new firmware object code.	CO (SID Authority)	X	
Zeroize (TCG Revert)	The TCG Revert method zeroizes a drive and returns the Cryptographic Module to its original manufactured state.	CO (SID Authority, EraseMaster), User (BandMasters)	X	X
Set	Write data structures; access control enforcement occurs per data structure field. This service can change PINs.	CO (SID Authority, EraseMaster), Users (BandMasters)	X	X
Set LBA Band	Set the starting location, size, and attributes of a set of contiguous Logical Blocks.	Users (BandMasters)	X	X
Lock/Unlock LBA Band	Deny/Permit access to an LBA Band	Users (BandMasters)	X	X
Write Data	Transform plaintext user data into ciphertext and write in an LBA band.	Users (BandMasters)	X	X
Read Data	Read ciphertext from an LBA band and output user plaintext data.	Users (BandMasters)	X	X
Set Data Store	Write a stream of bytes to unstructured storage.	Users (BandMasters)	X	X
Erase LBA Band	Band cryptographic-erasure by changing LBA band encryption keys to new values. Erasing an LBA band with EraseMaster sets the TCG Credential to the default value.	CO (EraseMaster)	X	X
Diagnostics	A Non-Approved service that is unavailable after the Initialize Cryptographic Module service completes. For failure analysis purposes, the vendor can enable a logical diagnostic port to perform diagnostics and gather data on the failure.	Makers		X

[5] See the Cryptographic Module Acceptance and Provisioning section within the Ultrastar DC SS540 Product Manual.

5.2 Unauthenticated Services

Table 9 - Unauthenticated Services lists the unauthenticated services the *C*ryptographic Module provides.

Table 9 - Unauthenticated Services

Service	Description
Reset Module	Power on Reset
Self-Test	The Cryptographic Module performs self-tests when it powers up
Status Output	TCG (IF-RECV) protocol
Get FIPS Mode	TCG 'Level 0 Discovery' method outputs the FIPS mode of the Cryptographic Module
Start Session	Start TCG session
End Session	End a TCG session by clearing all session state
Generate Random	TCG Random method generates a random number from the SP800-90A DRBG
Get	Reads data structure; access control enforcement occurs per data structure field
Get Data Store	Read a stream of bytes from unstructured storage
Zeroize (TCG Revert)	The TCG Revert method returns the Cryptographic Module to its Original Factory State; authentication data (PSID) is printed on the external label
SCSI	[SCSI Core] and [SCSI Block] commands to function as a standardized storage device. See Table 13 - SCSI Commands
FIPS 140 Compliance Descriptor[6]	This service reports the FIPS 140 revision as well as the cryptographic module's overall security level, hardware revision, firmware revision and module name.

5.3 Definition of Critical Security Parameters (CSPs)

The Cryptographic Module contains the CSPs listed in

Table 10 - CSPs and Private Keys. Zeroization of CSPs, invoking the Zeroize service, complies with the purge requirements for SCSI solid state drives within [SP800-88], Guidelines for Media Sanitization. Invoking TCG Revert causes the Cryptographic Module to revert to its Original Factory State. The side effect of this action is the regeneration of all keys and the overwriting of all PINs with a default value.

Table 10 - CSPs and Private Keys

Name	Type	Description
Crypto Officer PIN - TCG Credential (2 total)	256-bit authentication data	The PBKDF uses this PIN to authenticate the Crypto Officer's credentials.
User PIN –TCG Credential (16 total)	256-bit authentication data	The PBKDF uses this PIN to authenticate the User's credentials
MEK - Media Encryption Key[7] (16 total - 1 per LBA band)	XTS-AES-256 (512 bits)	Encrypts and decrypts LBA Bands. Each key is only associated with one LBA band. The Cryptographic Module's DRBG generates MEKs without modification.

[6] See Security Features for SCSI Commands [SFSC] for further details

[7] A concatenation of XTS-AES Key_1 (256 bits) and XTS-AES Key_2 (256 bits)

Name	Type	Description
KEK – Key Encrypting Key (16 total)	SP 800-132 PBKDF (256 bits)	Ephemeral keys derived from BandMaster PINs and 256-bit KDF salts that wrap the MEKs using an [SP 800-38F] AES-256 Key Wrap. Note: Keys protected by this [SP 800-132] PBKDF derived key shall not leave the module.
NDRNG	256-byte Entropy output	Entropy source for DRBG
DRBG Seed	256-byte Entropy input	Internal state associated with the [SP800-90A] CTR_DRBG using AES-256 Sourced from NDRNG
DRBG State: Key	256-bit value	Internal state associated with the [SP800-90A] CTR_DRBG using AES-256
DRBG State: V	128-bit value	Internal state associated with the [SP800-90A] CTR_DRBG using AES-256.
AUTH Digest	256-bit authentication data	SHA-256 digest of a PIN and a PIN salt

5.4 Definition of Public Security Parameters

The Cryptographic Module contains two public keys. The cryptographic module uses the public keys to verify the digital signature of a firmware download image. If the digital signature verification process fails when utilizing the primary public key, the cryptographic module attempts to use the secondary public key to verify the digital signature. The cryptographic module rejects the downloaded firmware image if both attempts to verify the digital signature fail.

Table 11 - Public Security Parameters

Key Name	Type	Description
RSAPublicKey[0]	RSA 2048 public key	Primary public key used to verify the digital signature of a firmware image.
RSAPublicKey[1]	RSA 2048 public key	Secondary public key used to verify the digital signature of a firmware image.
PSID	20-character alphanumeric string	A unique value generated in the factory and printed on the Cryptographic Module's label. The PSID provides authentication data and proof of physical presence for the Zeroize service.
PIN salt (16 total)	256-bit key	The Cryptographic Module's DRBG generates PIN salts without modification.
KDF Salt - Key Derivation Function Salt (16 total)	256-bit key	The Cryptographic Module's DRBG generates KDF salts without modification.
MSID	32-character alphanumeric string	The MSID is derived by concatenating the Cryptographic Module's serial number four times. For example, if the serial number is KF7B98G3 then the MSID would be KF7B98G3KF7B98G3KF7B98G3KF7B98G3.

5.5 SP800-132 Key Derivation Function Affirmations

- The Cryptographic Module utilizes a [SP800 132] Password Based Key Derivation Function (PBKDF).
- The cryptographic module complies with [SP800 132] Option 2a.
- The Cryptographic Module tracks TCG Credentials (PINs) by hashing the concatenation of a 256-bit PIN salt and TCG Credential PIN. The Cryptographic Module stores the SHA-256 AUTH Digest and associated PIN salt in the Reserved Area.

- Security Policy rules set the minimum TCG Credential PIN length at 32 bytes. The cryptographic module allows values from 0x00 to 0xFF for each byte of the User PIN.
- The upper bound for the probability of guessing a TCG Credential PIN is 2^{-256}. The difficulty of guessing the User PIN is equivalent to a brute force attack.
- KEKs ([SP800 132] Master Keys) derive from passing a TCG Credential PIN ([SP800 132] Password) and a 256-bit KDF salt though an [SP800 132] PBKDF. The cryptographic module creates a unique KEK for each LBA Band. The KEK generation process utilizes the HMAC-SHA-256 algorithm. Each KEK has a security strength of 128-bits against a collision attack.
- Each 256-bit salt is a random number generated using the [SP800 90A] DRBG.
- The sole use of a KEK is to wrap and unwrap a Media Encryption Key (MEK).

5.6 Definition of CSP Modes of Access

Table 12 defines the relationship between access to Critical Security Parameters (CSPs) or Public Security Parameters (PSP) and the listed Cryptographic Module services. The definitions shown below define the access modes listed in Table 12.

- **G** = Generate: The Cryptographic Module generates a CSP from the [SP800-90A] DRBG, derives a CSP with the Key Derivation Function or hashes authentication data with SHA-256.
- **I =** Input: The Cryptographic Module imports a CSP or PSP from outside the cryptographic boundary.
- **O =** Output: The Cryptographic Module does not support the output of CSPs outside the cryptographic boundary. The Cryptographic module outputs the value of selective PSPs.
- **E** = Execute: The module executes a service that uses the CSP or PSP.
- **S** = Store: The Cryptographic Module stores a CSP or PSP persistently on media within the cryptographic module.
- **Z** = Zeroize: The Cryptographic Module zeroizes a CSP or PSP that is stored in volatile or non-volatile memory.

Table 12 - CSP and PSP Access Rights within Roles & Services

Service	**CSP**							**PSP**				
	AUTH Digest	**CO PIN**	**DRBG**	**NDRNG**	**KEK**	**MEK**	**User PIN**	**MSID**	**RSAPublicKey[0.1]**	**PSID**	**PIN salt**	**KDF Salt**
Initialize Cryptographic Module	GS	IE	GE	GE	G	GS	IE	OIE			GS	GS
Authenticate	E	IE			GE	E	IE				E	E
Lock/Unlock Firmware Download Control												
Firmware Download									IE			
Set												
Set LBA Band												
Lock/Unlock LBA Band												
Write Data						E						
Read Data						E						
Set Data Store												

Service	CSP							PSP				
	AUTH Digest	CO PIN	DRBG	NDRNG	KEK	MEK	User PIN	MSID	RSAPublicKey[0.1]	PSID	PIN salt	KDF Salt
Diagnostics												
Erase LBA Band						GSZ						
Self-Test (KATs)												
Reset Module (Power on Reset)			GE	GE								
Status Output												
Get FIPS mode												
Start Session												
End Session												
Generate Random			GE	E								
Get Data Store												
Get												
Zeroize (TCG Revert)	Z	Z	GE	Z	G	GSZ	Z	E		I	GSZ	GSZ
SCSI												
FIPS 140 Compliance Descriptor												

6. Operational Environment

The Cryptographic Module operating environment is non-modifiable. Therefore, the FIPS 140-2 operational environment requirements are not applicable to this module. While operational, the Cryptographic Module prohibits additions, deletions, or modification of the code working set. For firmware upgrades, the Cryptographic Module uses an authenticated download service to upgrade its firmware in its entirety. If the download operation is successful, authorized, and verified, the Cryptographic Module will begin operating with the new code working set. Firmware loaded into the module that is not on the FIPS 140-2 certificate is out of the scope of this validation and requires a separate FIPS 140-2 validation.

7. Security Rules

The Cryptographic Module enforces applicable FIPS 140-2 Level 2 security requirements. This section documents the security rules that the Cryptographic Module enforces.

7.1 Invariant Rules

1. The Cryptographic Module supports two distinct types of operator roles: Crypto Officer and User. The module also supports an additional role, the Makers role. Initialization disables the Makers role.
2. Cryptographic Module power cycles clear all existing authentications.
3. After the Cryptographic Module has successfully completed all self-tests and initialized according to the instructions provided in Section 7.2, it is in FIPS Approved mode. The Crypto Officer shall not enable the Makers Authority after the cryptographic module enters FIPS Approved mode.

~~4.~~ When the Cryptographic Module is unable to authenticate TCG Credentials, operators do not have access to any cryptographic service other than the unauthenticated Generate Random service.

5. The Cryptographic Module performs the following tests. Upon failure of any test, the Cryptographic Module enters a soft error state. The Cryptographic module reports the error condition by transmitting an UEC via the [SCSI] protocol. After entering the soft error state, the cryptographic module does not process functional commands unless a power cycle occurs.

    A. Power up Self-Tests

    1) Firmware Integrity 32-bit EDC
    2) Firmware AES-ECB Encrypt KAT, Cert C1352
    3) Firmware AES-ECB Decrypt KAT, Cert C1352
    4) RSA 2048 PSS Verify KAT, Cert C1352
    5) DRBG KAT[8], Cert C1352
    6) Firmware SHA-256 KAT, Cert C1352
    7) HMAC-SHA-256 KAT, Cert C1352
    8) Hardware AES-ECB Encrypt KAT, Cert 4309
    9) Hardware AES-ECB Decrypt KAT, Cert 4309
    10) HW/FW SHA-256 KAT, Cert C1353
    11) Key Wrap KAT, KW-AE, Cert. C1352
    12) Key Wrap KAT, KW-AD, Cert. C1352

    B. Conditional Tests

    1) The Cryptographic Module performs a Continuous Random Number Generator test on the DRBG and the hardware NDRNG entropy source.
    2) The Cryptographic Module performs a key comparison test on XTS-AES Key_1 and XTS-AES Key_2 that satisfies IG A.9 XTS-AES Key Generation Requirements.
    3) Firmware Download Test, RSA 2048 PSS (Cert. C1352), SHA-256 (Cert. C1353)

6. An operator can command the Cryptographic Module to perform the power-up self-test by power cycling the device.
7. Power-up self-tests do not require operator action.
8. Data output is inhibited during key generation, self-tests, zeroization, and error states.
9. Status information does not contain CSPs or sensitive data that if misused, could compromise the Cryptographic Module.
10. The Zeroization service deletes all plaintext keys and CSPs.
11. The Cryptographic Module does not support a maintenance role.
12. The Cryptographic Module does not support manual key entry.
13. The Cryptographic Module does not have any external input/output devices used for entry/output of data.
14. The Cryptographic Module does not output plaintext CSPs.
15. The Cryptographic Module does not output intermediate key values.
16. The Cryptographic Module does not support concurrent operators.
17. The End Session service deletes the current operator's authentication. The Cryptographic Module requires operators to re-authenticate upon execution of the End Session service.
18. The host shall authenticate to LBA Bands after a power cycle.
19. The Crypto Officer shall assure that all host issued User PINs are 32-bytes in length.
20. After a Firmware Download, the CO must execute "Set 'Firmware_Dload_Port.PortLocked = True' ".

[8] The DRBG KAT is inclusive of the instantiate, generate and reseed function health tests required in [SP 800-90A]

7.2 Initialization Rules

The Crypto Officer shall follow the instructions provided in the FIPS 140 Crypto Officer Instructions section of the Ultrastar DC SS540 Product Manual and the Delivery & Operation (Crypto Officer's) Manual for acceptance and end of life procedures.

The Crypto Officer shall initialize the modules cryptographic services by executing the TCG methods listed below.

1. StartSession and SyncSession using the 'Admin SP'
2. Get MSID
3. Use the MSID to authenticate to the SID
   a. An authentication failure indicates that a tamper event has occurred for the Cryptographic Module
4. Set 'SID PIN' to an organizational value
5. Set 'Makers.Enabled = FALSE'
6. Set 'Firmware_Dload_Port.PortLocked = True'
7. Set 'Firmware_Dload_Port.LockOnReset = PowerCycle'
8. EndSession
9. StartSession and SyncSession using the 'Locking SP'
10. Use the MSID to authenticate to the EraseMaster
    a. An authentication failure indicates that a tamper event has occurred for the Cryptographic Module
11. Set 'EraseMaster PIN' to a new value
12. Erase Band0
13. Use the MSID to authenticate to the BandMaster0
    a. An authentication failure indicates that a tamper event has occurred for the Cryptographic Module.
14. Set 'BandMaster0 PIN' to a new value
15. As required by organizational policy, repeat steps 13 to 14 for each LBA band
16. EndSession
17. Power cycle or reset the Cryptographic Module

The instructions provided above accomplish the following:

- Establish authentication data for the TCG Authorities by replacing the MSID (default PIN value).
- Erase the LBA Bands. When the Cryptographic Module erases the LBA bands it also erases the Media Encryption Keys.
- Establish the LBA Bands. When the Cryptographic Module establishes LBA bands it also generates Media Encryption Keys.
- Disable the Makers Authority.
- Lock the Firmware Download service and set the Firmware Download service to lock automatically after a power cycle.

At the end of the initialization process, the cryptographic module will be in a FIPS Approved Mode of operation. While in FIPS Approved mode, only an authenticated Crypto Officer can change the state of the firmware download service.

7.3 Zeroization Rules

The Crypto Officer shall use the TCG Revert method to perform the zeroize service. After successfully executing TCG Revert the Crypto Officer shall power cycle the module. Power cycling the module assures that all CSPs stored in volatile memory are erased. TCG Reverting and power cycling the cryptographic module zeroizes all Critical Security Parameters.

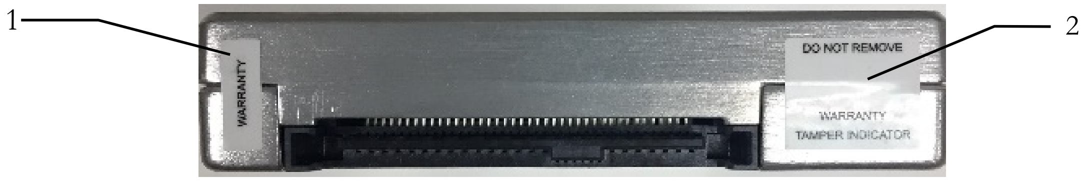
8. Physical Security Policy

8.1 Mechanisms

The Cryptographic Module does not make claims in the Physical Security area beyond FIPS 140-2 Security Level 2.

- All components are production-grade materials with standard passivation.
- The enclosure is opaque.
- Engineering design supports opacity requirements.
- Western Digital applies two (2) tamper-evident security seals during manufacturing (see Figure 2 and Figure 3).
- The tamper-evident security seals cannot be penetrated or removed and reapplied without evidence of tampering. In addition, it is difficult to replicate the of tamper-evident security seals.

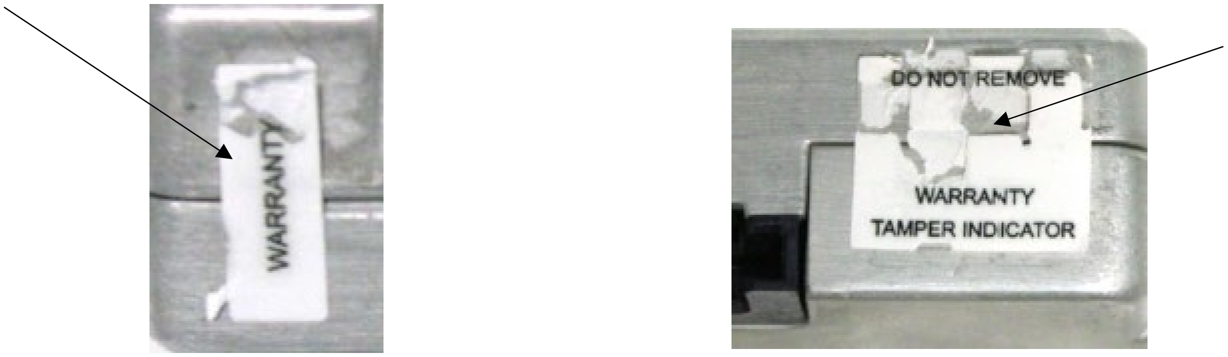
Figure 2: Tamper-Evident Seals



8.2 Operator Responsibility

The Crypto Officer and/or User shall inspect the Cryptographic Module enclosure for evidence of tampering at least once a year. If the inspection reveals evidence of tampering, the Crypto Officer should return the module to Western Digital.

Figure 3: Tamper Evidence on Tamper Seals



9. Mitigation of Other Attacks Policy

The Cryptographic Module lacks features to mitigate any specific attacks beyond the scope of the requirements within FIPS 140-2.

10. Definitions

- **Allowed**: NIST approved, i.e., recommended in a NIST Special Publication, or acceptable, i.e., no known security risk as opposed to deprecated, restricted and legacy-use. [SP800-131A]
- **Anybody**: A formal TCG term for an unauthenticated role. [TCG Core]
- **Approved mode of operation**: A mode of the cryptographic module that employs only approved security functions. [FIPS140]

- **Approved**: [FIPS140] approved or recommended in a NIST Special Publication.
- **Authenticate**: Prove the identity of an Operator or the integrity of an object.
- **Authorize**: Grant an authenticated Operator access to a service or an object.
- **Ciphertext**: Encrypted data transformed by an Approved security function.
- **Confidentiality**: A cryptographic property that sensitive information is not disclosed to unauthorized parties.
- **Credential**: A formal TCG term for data used to authenticate an Operator. [TCG Core]
- **Critical Security Parameter (CSP)**: Security-related information (e.g., secret and private cryptographic keys, and authentication data such as credentials and PINs) whose disclosure or modification can compromise the security of a cryptographic module. [FIPS140]
- **Cryptographic Boundar**y: An explicitly defined continuous perimeter that establishes the physical bounds of a cryptographic module and contains all the hardware, software, and/or firmware components of a cryptographic module. [FIPS140]
- **Cryptographic key (Key)**: An input parameter to an Approved cryptographic algorithm
- **Cryptographic Module**: The set of hardware, software, and/or firmware used to implement approved security functions contained within the cryptographic boundary. [FIPS140]
- **Crypto Officer**: An Operator performing cryptographic initialization and management functions. [FIPS140]
- **Data at Rest**: User data residing on the storage device media when the storage device is powered off.
- **Discovery**: A TCG method that provides the properties of the TCG device. [TCG Enterprise]
- **Drive Writes per Day (DWPD):** Drive Writes per Day defines how many times the entire capacity of the SSD can be overwrite every single day of its usable life without failure during the warranty period.
- **Integrity**: A cryptographic property to assure sensitive data has not been modified or deleted in an unauthorized and undetected manner.
- **Interface**: A logical entry or exit point of a cryptographic module that provides access to the cryptographic module for logical information flows. [FIPS140]
- **Key Derivation Function (KDF)**: An Approved cryptographic algorithm by which one or more keys are derived from a shared secret and other information.
- **Key Encrypting Key (KEK)**: A cryptographic key used to encrypt or decrypt other keys.
- **Key management**: The activities involving the handling of cryptographic keys and other related security parameters during the entire life cycle of the Cryptographic Module. The handling of authentication data is representative of a key management activity.
- **Key Wrap**: An Approved cryptographic algorithm that uses a KEK to provide Confidentiality and Integrity.
- **LBA Band**: A formal [TCG Core] term that defines a contiguous logical block range (sequential LBAs) to store encrypted User Data; bands do not overlap, and each has its own unique encryption key and other settable properties.
- **Manufactured SID (MSID)**: A unique default value assigned to a SED during manufacturing. An externally visible MSID value is not required if the user can derive the MSID from other information printed on the drive. The MSID is readable with the TCG protocol. It is the initial and default value for all TCG credentials. [TCG Core]
- **Method**: A TCG command or message. [TCG Core]
- **Operator**: A consumer, either human or automation, of cryptographic services that is external to the Cryptographic Module. [FIPS140]

- **Personal Identification Number (PIN)**: A formal TCG term designating a string of octets used to authenticate an identity. [TCG Core]
- **Plaintext**: Unencrypted data.
- **Port**: A physical entry or exit point of a cryptographic module that. A port provides access to the Cryptographic Module's physical signals. [FIPS140]
- **PSID (Physical Security Identifier)**: A SED unique value printed on the Cryptographic Module's label used as authentication data and proof of physical presence for the Zeroize service.
- **Public Security Parameters (PSP)**: Public information, that if modified can compromise the security of the cryptographic module (e.g., a public key).
- **Read Data**: An external request to transfer User Data from the SED. [SCSI Block]
- **Reserved Area**: Private data on the Storage Medium that is not accessible outside the Cryptographic Boundary.
- **Security Identifier (SID)**: A TCG authority used by the Crypto Officer. [TCG Core]
- **Self-Encrypting Drive (SED)**: A storage device that provides data storage services, which automatically encrypts all user data written to the device and automatically decrypts all user data read from the device.
- **Session**: A formal TCG term that envelops the lifetime of an Operator's authentication. [TCG Core]
- **Small Form Factor (SFF):** Small form factor is a computer form factor designed to minimize the volume and footprint of a desktop computer
- **Storage Medium**: The non-volatile, persistent storage location of a SED; it is partitioned into two disjoint sets, a User Data area and a Reserved Area.
- **Triple Level Cell (TLC)**: Triple level cells refer to NAND flash devices that store three bits of information per cell, with eight total voltage states.
- **User Data**: Data transferred from/to a SED using the Read Data and Write Data commands. [SCSI Block]
- **User**: An Operator that consumes cryptographic services. [FIPS140]
- **Write Data**: An external request to transfer User Data to a SED. [SCSI Block]
- **Zeroize**: Invalidate a Critical Security Parameter. [FIPS140]

11. Acronyms

- **CO**: Crypto Officer [FIPS140]
- **CRC**: Cyclic Redundancy Check
- **CSP**: Critical Security Parameter [FIPS140]
- **DRAM**: Dynamic Random Access Memory
- **DRBG**: Deterministic Random Bit Generator
- **DW/D:** Drive Writes per Day
- **EDC:** Error Detection Code
- **EMI**: Electromagnetic Interference
- **FSEC:** Flash Security Data
- **FID:** Flash Internal Data
- **FIPS**: Federal Information Processing Standard

- **KAT**: Known Answer Test
- **KDF**: Key Derivation Function
- **LBA**: Logical Block Address
- **MEK**: Media Encryption Key
- **MSID**: Manufactured Security Identifier
- **NAND: N**egative AND, Flash Memory technology
- **NOR: N**egative OR, Flash Memory technology
- **NDRNG**: Non-deterministic Random Number Generator
- **NIST**: National Institute of Standards and Technology
- **PIN**: Personal Identification Number
- **PSID**: Physical Security Identifier
- **PSP**: Public Security Parameter
- **RID:** Reserved Area Internal Data
- **SAS**: Serial Attached SCSI
- **SECD:** Security Data
- **SCSI**: Small Computer System Interface
- **SED**: Self Encrypting Drive
- **SFF:** SSD Form Factor or Small Form Factor
- **SID**: TCG Security Identifier, the authority representing the Cryptographic Module owner
- **SSD**: Solid-state Drive
- **TCG**: Trusted Computing Group
- **TLC:** Triple Level Cell
- **UEC:** Universal Error Code
- **XTS**: A mode of AES that utilizes "Tweakable" block ciphers

12. References

12.1 NIST Specifications

- [AES] Advanced Encryption Standard, FIPS PUB 197, NIST, November 2001
- [DSS] Digital Signature Standard, FIPS PUB 186-4, NIST, July 2013
- [FIPS140] Security Requirements for Cryptographic Modules, FIPS PUB 140-2, NIST, December 2002
- [HMAC] The Keyed-Hash Message Authentication Code, FIPS PUB 198-1, July 2008
- [SHA] Secure Hash Standard (SHS), FIPS PUB 180-4, NIST, August 2015
- [SP800 38A] Recommendation for Block Cipher Modes of Operation: Methods and Techniques, NIST, December 2001
- [SP800 38E] Recommendation for Block Cipher Modes of Operation: The XTS-AES Mode for Confidentiality on Storage Devices, SP800-38E, NIST, January 2010

- [SP800 38F] Recommendation for Block Cipher Modes of Operation: Methods for Key Wrapping, NIST, December 2012
- [SP800 57] Recommendation for Key Management – Part I General (Revision 4), NIST, January 2016
- [SP800 90A] Recommendation for Random Number Generation Using Deterministic Random Bit Generators (Revision 1), NIST, June 2015
- [SP800 90B] Recommendation for the Entropy Sources Used for Random Bit Generation, NIST, January 2018
- [SP800 131A] Transitions: Recommendation for Transitioning the Use of Cryptographic Algorithms and Key Lengths (Revision 1), NIST, November 2015
- [SP800 132] Recommendation for Password-Based Key Derivation, NIST, December 2010
- [SP800 133] Recommendation for Cryptographic Key Generation (Revision 2), NIST, June 2020

12.2 Trusted Computing Group Specifications

- [TCG Core] *TCG Storage Architecture Core Specification,* Version 2.0 Revision 1.0 (April 20, 2009)
- [Enterprise] *TCG Storage Security Subsystem Class: Enterprise Specification,* Version 1.00 Revision 3.00 (January 10, 2011)
- [TCG App Note] *TCG Storage Application Note: Encrypting Storage Devices Compliant with SSC: Enterprise,* Version 1.00 Revision 1.00 Final
- [TCG Opal] *TCG Storage Security Subsystem Class: Opal Specification,* Version 2.00 Final Revision 1.00 (February 24, 2012)
- TCG Storage Interface Interactions Specification (SIIS), Version 1.02, (2011)

12.3 International Committee on Information Technology Standards T10 Technical Committee Standards

- [SCSI Core] SCSI Primary Commands (SPC-5)
- [SCSI Block] SCSI Block Commands (SBC-3)
- [SAS] Serial Attached SCSI (SAS-4)
- [SFSC] Security Features for SCSI Commands

12.4 Corporate Documents

- [Product Manual] Ultrastar DC SS540 2.5-inch Serial Attached SCSI (SAS) Solid-State Drive Product Manual, Version 1.0 (March 2020), https://www.westerndigital.com/support
- [Datasheet] Ultrastar DC SS540 Product Brief, 02-05-WW-04-00171_v1.1 (February 2020), https://www.westerndigital.com/products/data-center-drives/ultrastar-sas-series-ssd

12.5 SCSI Commands

Table 13 - SCSI Commands

Description	Code	Description	Code
FORMAT UNIT	04h	RESERVE	16h
INQUIRY	12h	RESERVE	56h
LOG SELECT	4Ch	REZERO UNIT	01h
LOG SENSE	4Dh	SANITIZE	48h
MODE SELECT	15h	SEEK (6)	0Bh
MODE SELECT	55h	SEEK (10)	2Bh
MODE SENSE	1Ah	SEND DIAGNOSTIC	1Dh
MODE SENSE	5Ah	SET DEVICE IDENTIFIER	A4h/06h
PERSISTENT RESERVE IN	5Eh	START STOP UNIT	1Bh
PERSISTENT RESERVE OUT	5Fh	SYNCHRONIZE CACHE (10)	35h
PRE-FETCH (16)	90h	SYNCHRONIZE CACHE (16)	91h
PRE-FETCH (10)	34h	TEST UNIT READY	00h
READ (6)	08h	UNMAP	42h
READ (10)	28h	VERIFY (10)	2Fh
READ (12)	A8h	VERIFY (12)	AFh
READ (16)	88h	VERIFY (16)	8Fh
READ (32)	7Fh/09h	VERIFY (32)	7Fh/0Ah
READ BUFFER	3Ch	WRITE (6)	0Ah
READ CAPACITY (10)	25h	WRITE (10)	2Ah
READ CAPACITY (16)	9Eh/10h	WRITE (12)	AAh
READ DEFECT DATA	37h	WRITE (16)	8Ah
READ DEFECT DATA	B7h	WRITE (32)	7Fh/0Bh
READ LONG (16)	9Eh/11h	WRITE AND VERIFY (10)	2Eh
READ LONG	3Eh	WRITE AND VERIFY (12)	AEh
REASSIGN BLOCKS	07h	WRITE AND VERIFY (16)	8Eh
RECEIVE DIAGNOSTICS RESULTS	1Ch	WRITE AND VERIFY (32)	7Fh/0Ch
RELEASE	17h	WRITE BUFFER	3Bh
RELEASE	57h	WRITE LONG (10)	3Fh
REPORT DEVICE IDENTIFIER	A3h/05h	WRITE LONG (16)	9Fh/11h
REPORT LUNS	A0h	WRITE SAME (10)	41h
REPORT SUPPORTED OPERATION CODES	A3h/0Ch	WRITE SAME (16)	93h
REPORT SUPPORTED TASK MANAGEMENT FUNCTIONS	A3h/0Dh	WRITE SAME (32)	7Fh/0Dh
REQUEST SENSE	03h		