Coverage Metrics for Device Level Validation of SATA and SAS Devices - An Approach

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Abstract - This paper highlights the significance of Coverage analysis with respect to the functionality and adherence to the standard specification of SATA, SAS, NVME & eMMC Devices (SSD’s, HDD’s). Coverage analysis aims at achieving an effective way of testing the intrinsic functionality of the storage devices. Commands are issued to the Device under test to validate the attributes such as methods of transfer, latest technology involved to structure the storage device functionality, performance and the adherence to the protocol (SATA protocol). Validation environment of the storage device will include innumerable test cases which lead to redundancy of test scenarios and may cause gaps in the whole validation procedure rendering the goal to achieve a thorough validation output.

Keywords: Functional Coverage, Command Coverage, HDD, SSD, SATA, SAS, NVME, eMMC, Coverage, Coverage Analysis

I. INTRODUCTION

The non-linear growth of the SSD market has led to a significant influx of new SSD-Solid State Drive vendors into the market. In 2002 there were less than 10 SSD vendors; today there are over 100 vendors, and this number is growing exponentially. The product attributes of the given SSD product alone cannot be considered as a differentiating factor to distinguish which of the three emerging SSD categories the product belongs to: Consumer, Commercial or Industrial Grade. Consumer Grade SSDs are the most visible in the market since they are optimized for the high-volume, low-cost per gigabyte applications such as laptop computing. The distinction between Commercial and Industrial Grade drives is far less clear since SSD vendors can deliver very similar market outputs. An efficient way to understand whether an SSD is truly Industrial Grade is by comparing the design, testing and manufacturing processes used by the vendors being evaluated. SSD has no moving parts and is essentially an HDD-Hard Disk Drive emulator. It is basically comprised of a printed circuit board, a set of NAND flash memory chips, SDRAM cache, a memory controller, an interface controller and an interface connector such as IDE or SATA or SAS or even fiber channel. Thorough design verification on operational devices, extensive burn-in testing during manufacturing on every single device (vs. lot sampling), and comprehensive quality assurance procedures will lead to the highest quality solid state drive possible. Coverage is quantitative test metrics and can be utilized for the mentioned cause and can play a significant role in determining the superiority of the particular storage device. Coverage is a statistical representation of the number of scenarios or test cases or the various combinations the parameter under coverage has attained. Coverage Analysis is used as a benchmark for validating whether the device under test is completely adhering to the functionality described as per the standard specification.

During the course of research the following were utilized for obtaining the results and updating the Coverage Validation of each Target Connected device.

Validating Tool: MSDV 2013 Pro SATA, SAS, NVME & eMMC in-house proprietary tool by TechMahindra, Inc.

Protocal Analyser: SerialTek BusXpert 4.0.883 by Agilent Technologies, Inc.
engineer the accurate measure of efficiency of the validation environment used by them since it clearly feedbacks the amount of different scenarios required to achieve the complete coverage.

III. COVERAGE SETUP

In Device Level testing, our main focus is to test the actual performance and protocol testing of target connected SATA-Serial Advanced Technology Attachment is a protocol Disk i.e. SSD, so target device SSD should be connected to the native HBA-Host Bus Adaptor on the motherboard. The following steps were followed for Device Level Testing.

Steps:-
1. Change the BIOS setting configuration to SATA AHCI and enable HOT PLUG for all the SATA motherboard inbuilt ports.
2. For SAS validation, connect SAS Controller HBA and connect the SAS & SATA through SAS Expander (65536 Devices possible)
3. Restart the system & install the MSDV

A. Mass Storage Device Validator (MSDV)

Task File interface is used for the command delivery and data transfer. SATA-Serial Advanced Technology Attachment, interface is built on the foundation of this Task File architecture. SATA uses NCQ which allows systems to take advantage of a queuing structure in the SATA interface. It lets device to reorder multiple commands in order to minimize the rotational latency and track access overhead. AHCI is a host system interface designed for this purpose: to support NCQ and to provide a platform for hardware and software vendors to use. Intel has leaded the industry to define a NEW TASK FILE: AHCI for the next generation storage interface. It prepares a command base for hardware vendors and software drivers to build a higher performance storage interface. The mentioned Tool provides the features required for device level testing.

MSDV provided the feature of calculating the command coverage and the parameter coverage. It calculated the number of commands which were executed on the device and the various possible input combinations of the parameters as the parameter coverage.

B. BusXpert Protocol Analyzer

It is used to determine whether the command has passed to the device through HBA and the corresponding response is received by the host. It is connected between the host and the device to capture the trace of the request-response between the host and the device.

IV. COVERAGE METRICS CLASSIFICATION

Coverage analysis is based on the set of variables defined for coverage. Variables defined are utilized to differentiate between coverage scenarios and can be merged to get a complete coverage analysis. The different types of coverage depend upon each other and may sometimes be mutually exclusive to their own context. These Coverage metrics provides the validation engineer more pipelined and more accurate results to improve test scenarios. The coverage metrics are broadly classified as follow:

A. Specification coverage
B. Functional coverage
C. Command coverage
D. Parameter coverage
E. Test scenario Coverage

A. Specification Coverage

This Coverage analysis signifies the measure up to which the device under test is adhering to the standard specification. This coverage is calculated with respect to the scenarios mentioned in the specifications. The standard specifications imply the protocols to be followed and specification coverage is aimed at determining whether the
device is following those protocols and is giving expected results.

B. Functional Coverage

Functional Coverage aims at providing the measure up to which the the functions or the features provided in the device adheres to those present in the standard specification. Whether the features mentioned in the specifications are enabled or supported is determined by the device vendors and through this coverage we can analyze the coverage of these features. This coverage is purely dependent on the device manual and on the device. The validation engineer should ensure that functional coverage should be achieved maximum since this truly determines the adherence of the vendor devices to the standard protocol.

C. Command Coverage

Command Coverage depicts the number of command run or tested on the device against the total number of commands supported by the device. This coverage type can be utilized to determine the number of command the device actually processed and the number of commands which failed to execute and can provide an accurate and more efficient test case and test scenarios. The total number of command may differ in various protocols and hence the parameter to obtain this coverage has to be fixed after thorough understanding of the specification and the device under test.

D. Parameter Coverage

Parameter Coverage is calculated for commands having parameters. Device commands are tested on the device which may have arguments in this case parameters and these parameters can achieve various input combinations and it becomes mandatory to check the behavior of the device when each command is executed with all the possible input combinations to ensure that there are no holes in the verification environment. Parameter coverage works in tandem with Command Coverage.

E. Test Scenario Coverage

Test Scenario Coverage plays a significant role in the whole validation of storage device process. Test scenario depends upon the user specified test scenarios. Many real-world scenarios are tested on the device using scripts which emulate the real-time situations. Test scenario coverage is divided further into three more sub-categories:

i. Code Coverage- Code Coverage is merged coverage of line, expression and state coverage. It gives the number of lines covered in the test script currently running on the device.

ii. Test Pass/Fail Coverage- this coverage statistically represents the number of test scenarios which have passed or failed. Test scenarios would be provided such that both the conditions are achieved and thus covering the error injected test cases more effective.

V. COVERAGE METRICS FOR SATA DEVICES.

SATA is used to transfer information between host and target connected device and vice-versa. This section describes the coverage metrics defined or validated for all devices which follows SATA protocol. The coverage defined for all ATA Commands, Interface commands, SATA Specification, Functionality, Test cases, etc.

A. Specification Coverage:

The Specification Coverage structures are:

i. ATA Commands

ii. Transfer Lengths

iii. Corner LBA (Logical Block Addressing)

iv. Security Feature Set

v. General Purpose Feature Set

vi. Software Setting Preservation

vii. SMART (Self-Monitoring, Analysis, and Reporting Technology)

viii. Resets

ix. Simulation Tests

x. Multiple Threads

xi. NCQ Queue Depth

xii. NCQ Error Injection

xiii. General Error

Achieving high specification coverage depends upon the extent to which the device vendor has followed the standard specifications and which features the vendors have eliminated or coined them as obsolete set of features. The device under test has to be completely tested against every feature and then the calculation of the specific coverage is done with respect to the features actually present against the features which the vendor has claimed to be present in their device. Specification coverage was calculated by writing number of scripts which emulated the scenarios which were required to test the features supported in the device under test. Specification Coverage may vary from vendor to vendor.

![SATA - Specification Coverage](image)

Fig.4 Coverage percentage with respect to SATA – Specification

Fig.4 illustrates how SATA specification areas were plotted against the percentage of coverage covered.

B. Functional Coverage:
Fig. 5 Coverage percentage with respect to SATA – Functional

Fig. 5 illustrates how SATA Functional coverage is calculated over the SATA Specification with respect to the specification supported by the target connected device. The X axis shows the SATA Specification and Y axis shows the percentage of specification supported by the device. Functional Coverage can be increased by identifying the boundary cases and error response cases. The accuracy of the device behavior will be determined if we achieve high functional coverage.

C. Command Coverage

Command coverage aims at running test cases which will cover all the 140 SATA commands along with their respective sub-commands, Interface commands, NCQ Commands, etc. If the test case on commands increasing more and more, the coverage will increase and it’s maximum when all 140 commands executed.

Parameters Set (Fig. 6, Fig. 7, and Fig. 8):
Device Settings       Stop Mode          : Trigger
                      Trigger Position: 30%
                      Buffer Size         : 100% (2.25 GB)
                      Speed                     - Up to 3.0 Gbps
                      Trigger                 - IDFY, Read Sector, Write Sector, Check
                      Power mode, Read FPDMA (first part DMA) Queued and Enable Smart

Fig. 6 BusXpert-Spreadsheet \View Shows Commands trigger point

The Spreadsheet views of BusXpert shows the commands which were used for the generation of the command coverage for SATA Devices.

Fig. 7 BusXpert-Transaction View Shows trigger point (256 GB SSD)

The Transactional view of BusXpert shows all the 5 commands how it is transferred from host (SATA Controller HBA) to the target connected SATA Device. These were the basic commands used for the generation of the command coverage for SATA Devices and other commands could be leveraged to increase the coverage.

Fig. 8 MSDV window Shows Coverage for 5 SATA Commands

In this section, MSDV window shows the percentage of command coverage achieved for 5 SATA Commands. Commands used for the above coverage generation were IDFY (Identify Commands), Read sector Command, Write Sector Command, Power Management command (Check Power Mode). Command Coverage was calculated by executing the 140 SATA commands and their sub-command which varied to the Features and Length field. These commands are mentioned in the standard specification.

D. Parameter Coverage

Parameter coverage is calculated with respect to the commands having parameters, supported by the SATA device. For example, Read multiple command have parameters such as LBA, sector number.

\textbf{e.g.} \texttt{READ MULTIPLE 10, 10}

LBA count varies from 0 to 250045779 and sector count varies from 0 to 65535 for 48 bit 128 GB Device. Parameter coverage defines the coverage for all the LBA ranges.
Bus Analyser Trace Window showing the Trigger point and Views is displayed in Fig. 9, Fig. 10 and Fig. 11. The Capture window shows all the setup of BusXpert and also it shows the triggering point.

BusXpert Settings:
- Device Settings
  - Stop Mode: Trigger
  - Trigger Position: 30%
  - Buffer Size: 100% (2.25 GB)
- Speed: Up to 3.0 Gbps
- Trigger: Read Multiple, Write Multiple, Set Feature Command, TRIM Command, Read DMAEXT Command

The Transactional view of BusXpert shows all the 5 commands have parameters for coverage. These were the basic commands used for the generation of the parameter coverage for SATA Devices and other parameter ranges could be leveraged to increase the coverage and the above trace gives a clear idea of how many commands are sent from the host to the target.

The Spreadsheet views of BusXpert shows the commands which were used for the generation of the parameter coverage for SATA Devices. Parameter coverage was calculated using the MSDV tool feature.

E. Test Scenarios Coverage

During this test Scenario coverage only read/write variants are issued continuously in a loop for a given time and verified if the response to a given command is same independent of the number of times we run the commands. An attempt to simulate the Real world data centre scenario will be made here.

VI. COVERAGE METRIC FOR SAS DEVICES.

SAS stands for Serial Attached SCSI (Small Computer System Interface). SAS combines the intelligence of SCSI with the physical transport layer of Serial ATA. SAS provides for full duplex operation, at 300 MB/sec. This section describes the coverage metrics of all SAS Specification and SAS commands that should be run to validate the performance of the device under test either SAS or SATA Device because SAS supports SATA devices also.

A. SAS Specification Coverage

The specification coverage of SAS structure was constituted as follows:

1. SSP Frame Coverage
2. SMP Frame Coverage
3. STP Frame Coverage
4. Address Coverage
5. Error Injection Coverage

Fig. 12 Coverage percentage with respect to SAS – Specification

Fig. 12 illustrates how SAS specification areas were plotted against the percentage of coverage covered.

B. SAS Command Coverage
SAS Command Coverage aims at identifying and calculating how much the SAS commands were covered with respect to the Validation Environment. The SAS Commands are broadly classified as:
1. Multimedia commands
2. SCSI Block Commands
3. SCSI Controller Commands
4. SCSI Media Commands
5. SCSI Primary Commands
6. SCSI Stream Commands

Fig. 13 illustrates how SAS Commands were plotted against the percentage of coverage covered.

VII. FUTURE ENHANCEMENT OF COVERAGE METRICS OVER eMMC and NVME

A. eMMC Technology
The coverage metrics for device level validation of eMMC (embedded Multi Media Card) are:
1. Command Level
2. eMMC specification Level
3. Interface level
4. Device (Card) Functionality level
5. Test case coverage

eMMC describes an architecture consisting of an embedded storage solution with MMC interface (version 4.1/4.2, MMCplus), flash memory and controller, all in a small ball grid array (BGA) package. MMCs are available in sizes up to and including 128 GB. They are used in almost every context in which memory cards are used, like cellular phones, digital audio players, digital cameras and PDAs.

B. NVME
NVM Express is architected from the ground up for Non-Volatile Memory (NVM). NVM Express significantly improves both random and sequential performance by reducing latency, enabling high levels of parallelism, and streamlining the command set while providing support for security, end-to-end data protection, and other Client and Enterprise features users need. The above coverage metrics explained for SATA and SAS can be leveraged to NVME to improve the validation process in efficient way.

VIII. HARDWARE REQUIREMENT
Below is the system configuration requirement for SSD testing and validation.

<table>
<thead>
<tr>
<th>PROPERTY</th>
<th>REQUIRED</th>
<th>USED</th>
</tr>
</thead>
<tbody>
<tr>
<td>CPU</td>
<td>Duo Core or above, hyper-threading is recommended.</td>
<td>Intel® Core i3</td>
</tr>
<tr>
<td>RAM</td>
<td>1 GB or above.</td>
<td>4 GB</td>
</tr>
<tr>
<td>Motherboard</td>
<td>With on board SATA Controller based on the Intel ICHx(R) chipset or equivalent (e.g. HP with AMD chipset or VIA system).</td>
<td>SATA Controller based on the Intel 6 series chipset.</td>
</tr>
<tr>
<td>Add On Card For OS Boot Up</td>
<td>One PCI/PCI-E to ATA or SATA add-on card (e.g. Promise TX2 plus or equivalent). Please do NOT use Marvell HBA as the Test HBA.</td>
<td>JMicron SATA Add on card. As per SNIA standard, we need to use LSI HBA for our testing purpose.</td>
</tr>
</tbody>
</table>

IX. CONCLUSION
The Coverage metrics for device level testing provides a platform to test 100 % functionalities of SATA & SAS HDD and Solid State Drive’s NAND Flash Design, protocol Violation testing, performance and reliability of the SDD without the involvement of the presiding OS and the validation can be performed over a wide range of Enterprises and consumer markets. Coverage analysis plays a significant role in improving the validation process efficiency and more effective test scenarios are designed. Coverage analysis including all the classifications mentioned in the paper provides more accurate and optimum results to the validation engineers.

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