



# Testing for PCIe SSD Compatibility and Performance

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**TELEDYNE LECROY**  
Everywhereyoulook™

# Teledyne LeCroy



- Teledyne LeCroy Corporation is the leader in Serial Data Test solutions
  - Founded in 1964
  - Headquarters in Chestnut Ridge, NY
- Teledyne LeCroy's Protocol Solutions Group (PSG) was formed in October 2004 with the acquisition of CATC Corporation
  - PSG Headquarters in Santa Clara, CA
  - Part of the Serial Data Division of LeCroy
  - Catalyst was acquired & added to PSG in 2006
- PSG specializes in providing complete protocol solutions for a wide range of serial data standards
  - Products range from production tools to full protocol analysis systems with intuitive user interfaces and complete traffic generation



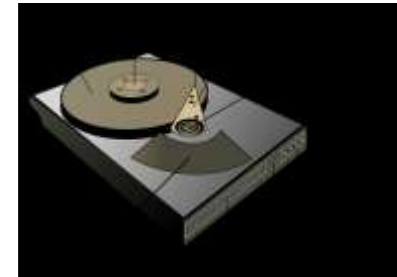
# Agenda

- Brief overview of new SSD types
- Testing SSD Devices
- NVMe Express
- SCSI Express
- SATA Express



# Storage Devices

- Hard disk drive(HDD) technology
  - Uses mechanical moving parts to store data
- Solid State Drive(SSD) technology
  - Emulates a hard disk drive by using NAND Flash components and controller
- Hybrid Hard Drive (HHD),
  - Combines high performance SSD technology with high capacity SATA drives



HDD

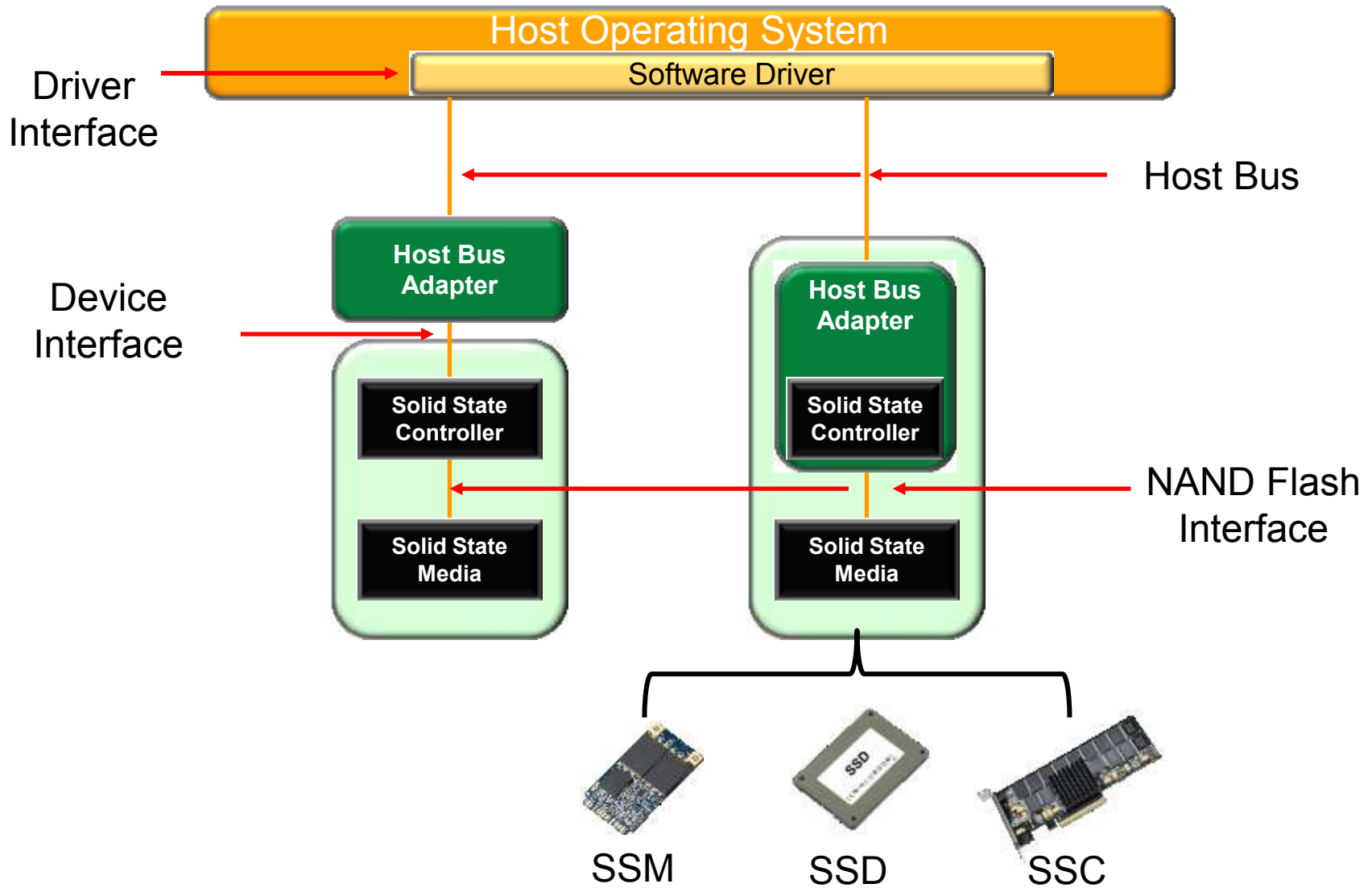


SSD



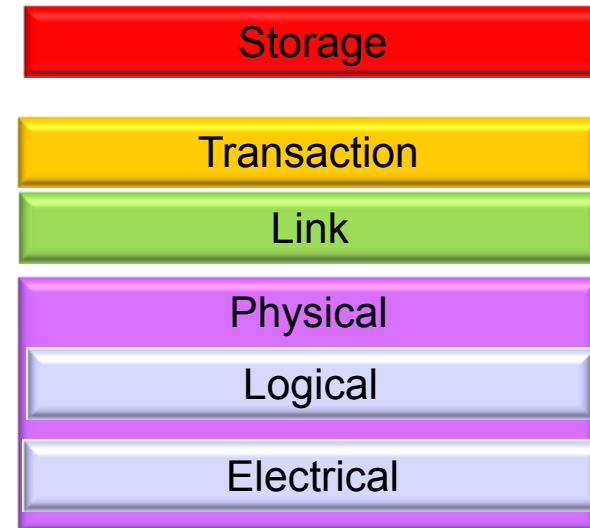
HHD

# SSD Devices



# PCIe SSDs Require New Testing Methodologies

- PCIe SSDs combine various storage protocol layers on top of the PCI Express electrical, link and transaction layers.
- New tools and testing methodologies are required to meet the challenges of high performance SSDs.



# SSD Test Setup

## SSD Device Controller Test

Exerciser



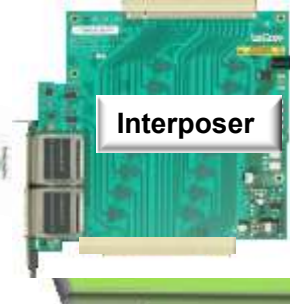
## SSD Driver Host Test



Protocol Analyzer



Exerciser Device Emulator



Interposer

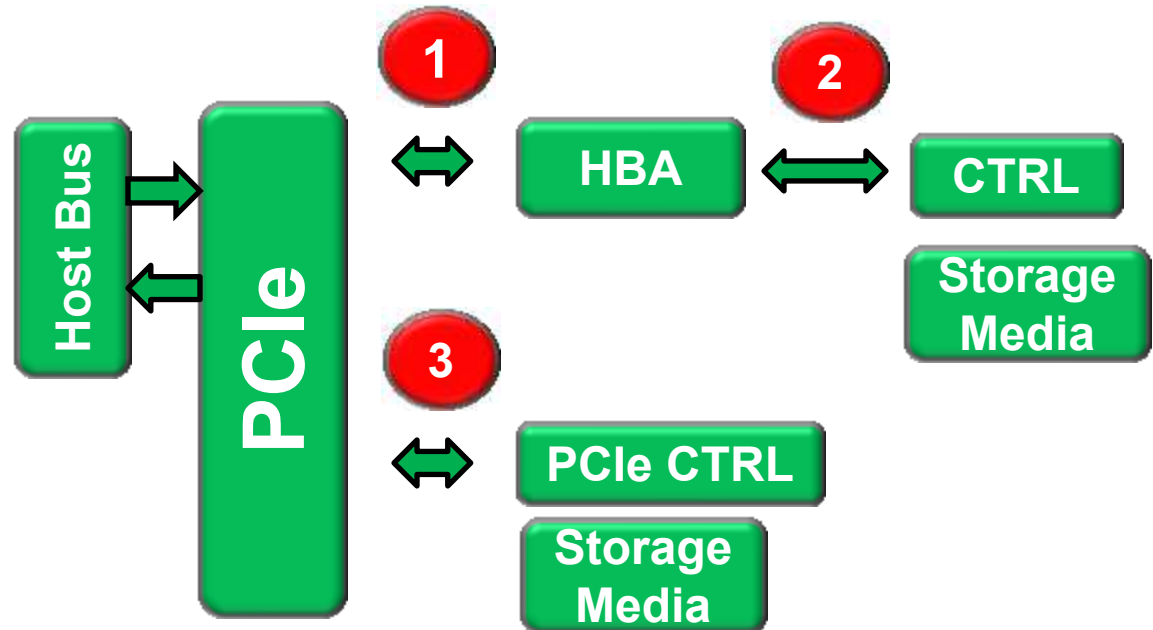
System Board(DUT)



# Testing Storage Interfaces

## Test Points of Interest

1. System board and HBA
2. HBA and Storage Media
3. System board and PCIe Storage Media





# PCI Express Performance Tools



## ■ Measure and monitor PCIe SSD performance details

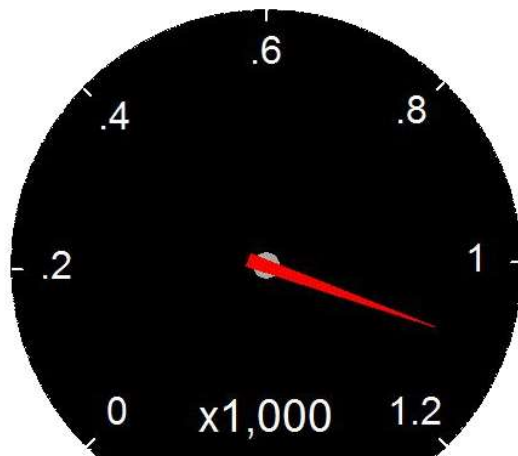
- PCIe Packet Metrics
- Timing Calculator- Bandwidth, Link Utilization
- Post Capture Bus Utilization Graph Tool
  - Latency, Throughput Views
- Real Time Statistics Graph Tool



## ■ Understand link behaviors and improve SSD performance

- Flow Control View
- Link Tracker
- LTSSM State View

Bus Utilization		
	Upstream	Downstream
Link Utilization	45.127 %	44.546 %
Time Coverage	45.072 %	44.493 %
Bandwidth	9025.43 Mb/s	8909.10 Mb/s
Data Throughput	592.29 MB/s	598.72 MB/s
Packets/second	19696168.45	24833612.81

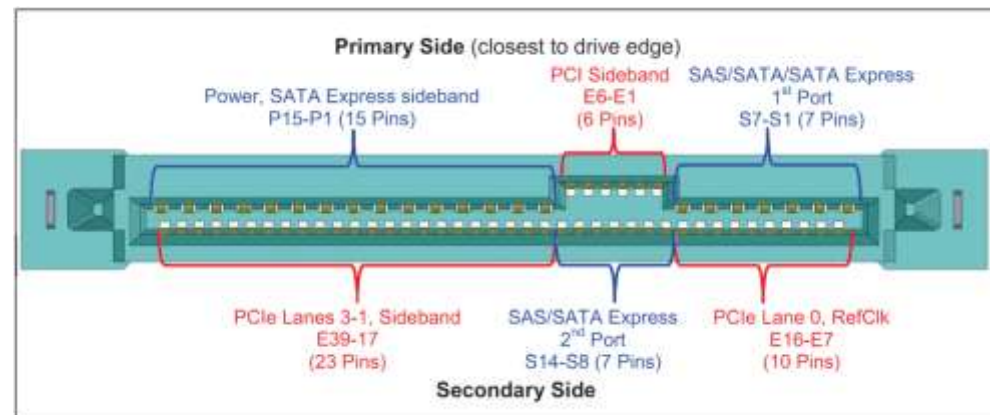


# Tests That Are Interesting to Developers

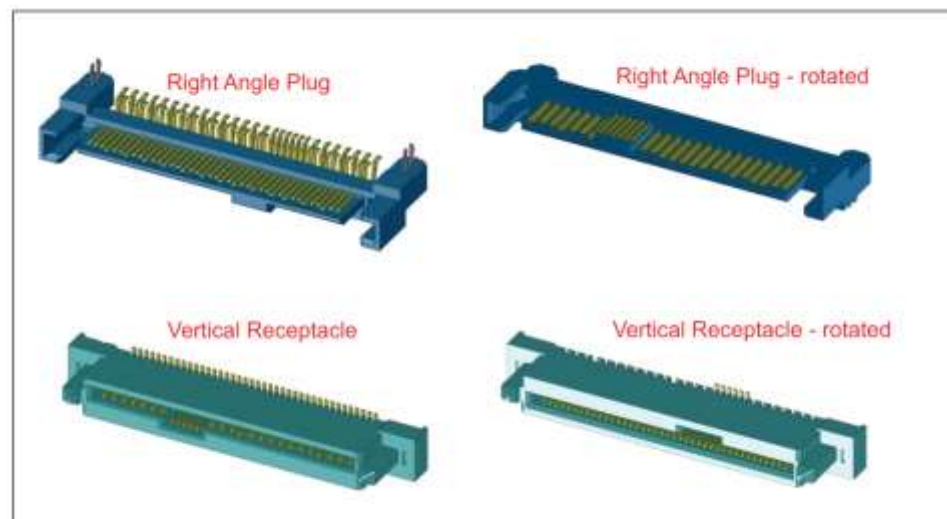
- Correct operation of storage devices
  - Check for each Admin and NVM command if the device fetches the correct number of commands for each SQ(Submission Queue) tail register write and from the correct SQBR.
  - Check if PRP(Physical Region Page) is accessed based on correct pointer supplied by the command.
  - Check if the completion is issued with correct identifiers and written to correct memory location and head pointer updated correctly.
  - Check if interrupt is issued and if the host did not consume all the completions if the device does not overwrite unconsumed completions.
- Compliance Tests for SSD Devices

# SFF 8639 Connector

- The SFF Committee has developed the specification.
- Intended for PCIe connections to SSDs (Solid State Drives) for the enterprise market of servers and storage systems
- Supports
  - Single port SATA
  - Dual port SCSI Express
  - Dual port SAS
  - Multilane SAS(12 Gb/s, 4 lanes)
  - PCIe Gen3x4 (8 GT/s, 4 lanes)

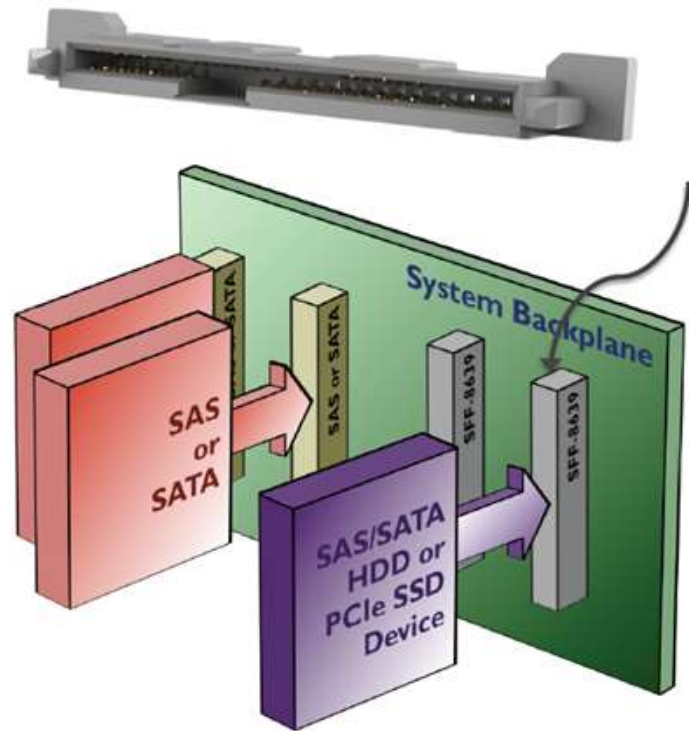


**SFF 8639 Connector**



# Express Bay- Multi- Function Bay

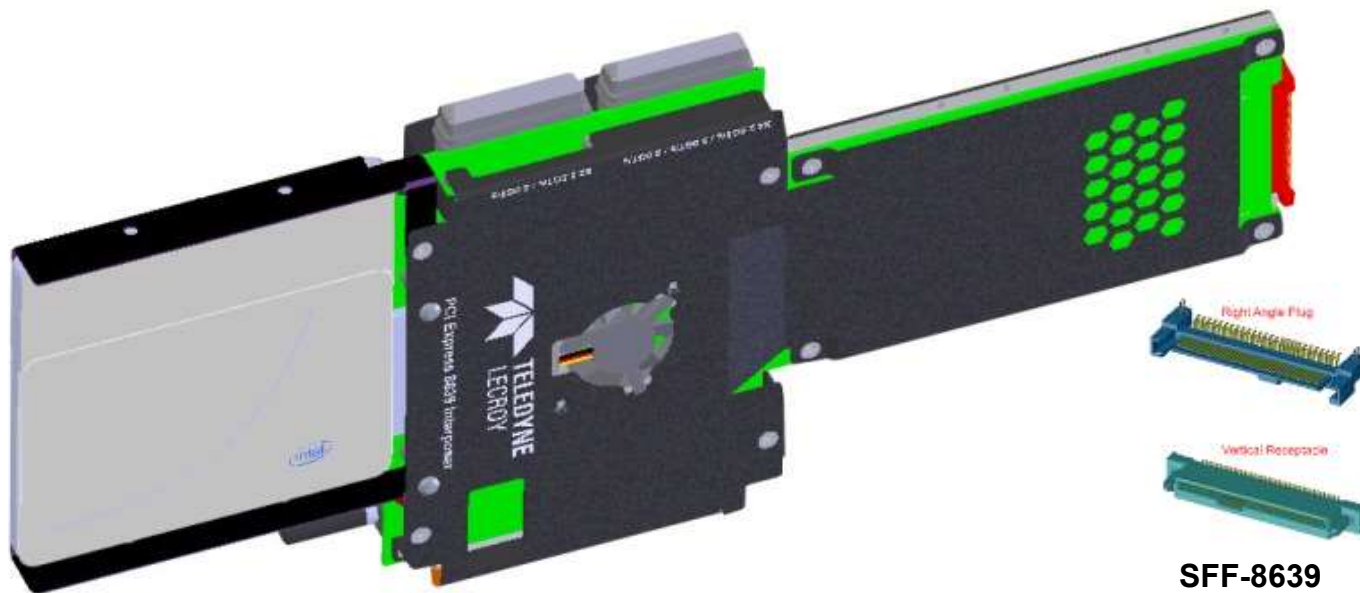
- Multi-function SAS/PCIe bay
  - Uses SFF-8639 Multi-function connector
  - Supports a range of devices
    - 12Gb/s SAS
    - PCIe SSD
      - NVMe, SOP-PQI, Proprietary
      - 6Gb/s SATA
      - Multilink SAS (4 SAS Ports)
      - SATA Express



SNIA 2012

# Protocol Analysis with the SFF-8639 Interposer

New



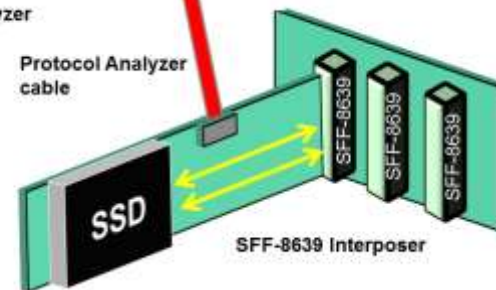
## Supports

- NVM Express x4
- SATA Express x2
- SCSI Express x4



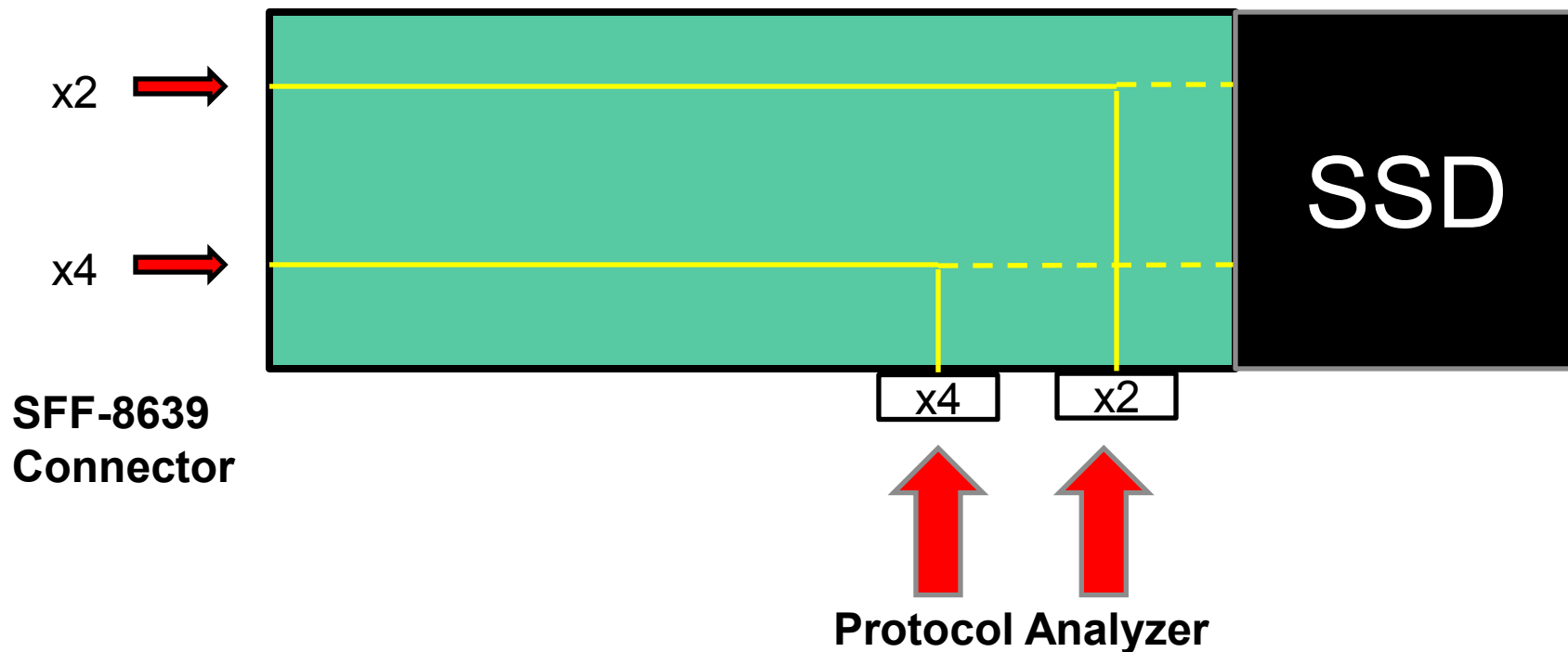
PCIe Protocol Analyzer

Protocol Analyzer cable



SFF-8639 Interposer

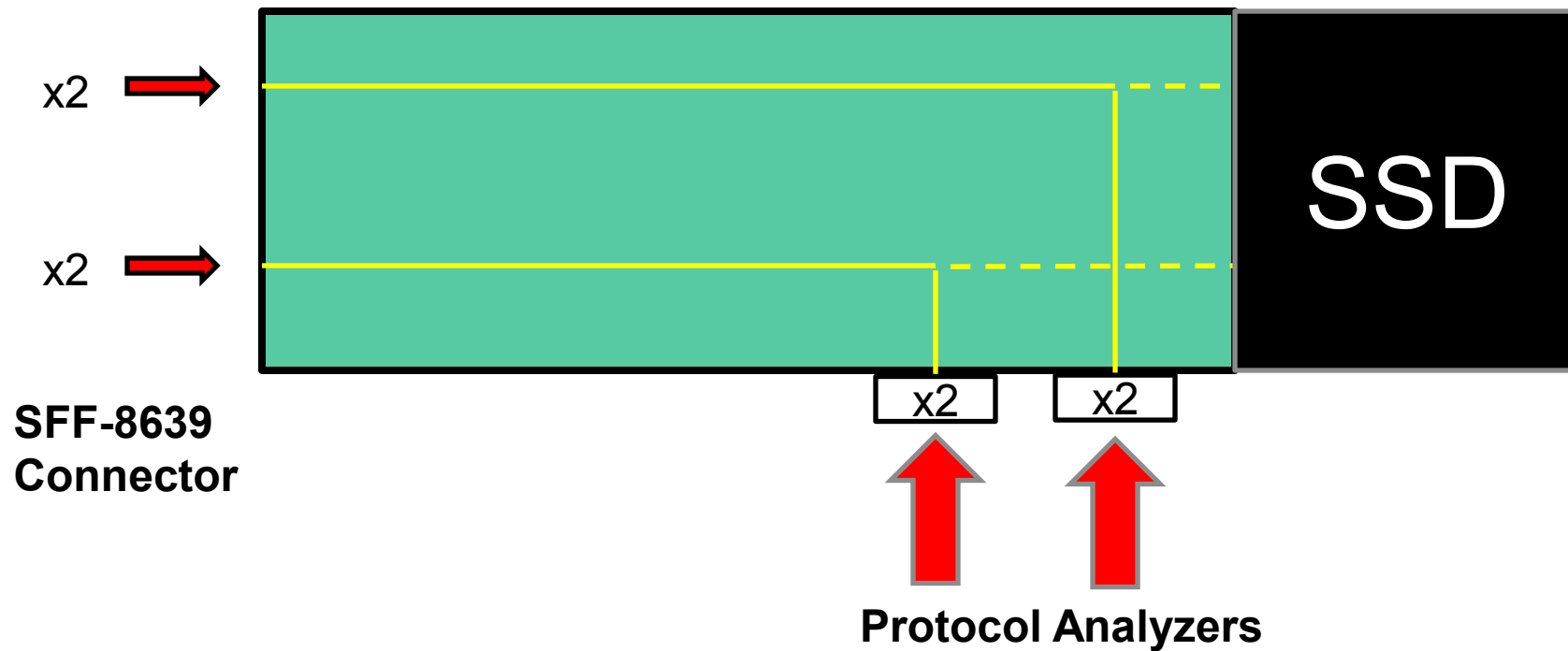
# SFF 8639 Interposer(Single Port)



Supports	
NVM Express	x4
SATA Express	x2
SCSI Express	x4



# SFF 8639 Interposer(Dual Port)



**Supports**  
NVM Express Dual Port  
SCSI Express Dual Port

Requires two Protocol Analyzers

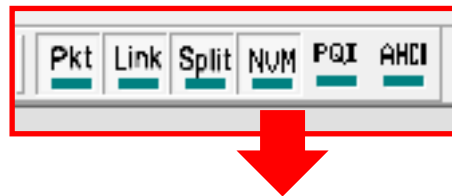


# NVM Express 1.0c Analysis Decode



IO Transfer

Completion



NVM	ReqID	CompleterID	IO Cmd	OPC	FUSE	CID	NSID	MPTR Hi	MPTR Low	PRP1 Hi	PRP1 Low	PRP2 Hi	PRP2 Low	SLBA	LR	FUA	PRINFO
195	R- 2.5	008:00:0	000:00:0	Read	b00	0x0000	0x00000001	0x00000000	0x00000000	0x00000001	0xEED31000	0x00000000	0x00000000	0x00000000:00000000	0	0	0x0

NLM	DSM	Incompressible	SR	AF	EILBRT	ELBAT	ELBATM	Time Delta	Time Stamp
0x0000		0	0	None	0x00000000	0x0000	0x0000	163.968 µs	0079.553228928 s

NVM	ReqID	CompleterID	CMD PRP	Addr Hi	Addr Lo	Data Len	Data	Time Delta	Time Stamp
196	R- 2.5	008:00:0	0x00000001	0xEED31000	0x00000200	127 quadlets		313.872 µs	0079.553392896 s

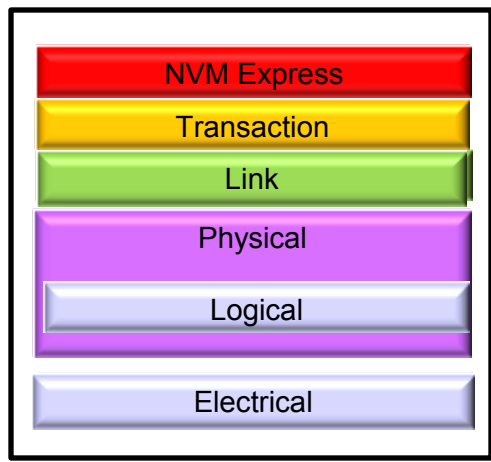
NVM	ReqID	CompleterID	Command Completion	QID	SQID	CID	P	ST	SC	SCT	M	MR	Time Delta	Time Stamp
197	R- 2.5	008:00:0	0x00000000	0x0001	0x0010	0x0000	1		0x0000	0x00	0	0	26.720 µs	0079.553706768 s

Physical Region Page

Commands or Data

Courtesy SanDisk 2012

- NVMe is a standardized high performance queuing interface and command set optimized for PCIe SSDs
- NVMe is scalable from client to enterprise applications



# Testing PCIe SSD and Systems

- Supports the Windows 7 NVMe Driver
- Emulates all NVMe Registers
- Admin Commands
- NVM Commands
  - Write
  - Read
  - Compare
  - Extensible for Vendor Specific Commands
- Queue Management
- Come up in Device Manager
- Extensible Vendor Specific Features (for Get/Set Features)
- Complete commands via fused Commands (i.e. Compare & Write)



Summit Z3-16 Protocol Exerciser

# NVMe Compliance and Interoperability Testing



University of New Hampshire  
**InterOperability  
Laboratory**

- UNH-IOL (University Of New Hampshire IOL) and the NVM Express Promoters Group are collaborating to create an interop and conformance test program centered at UNH-IOL.
- They will be creating a multi-vendor test bed to help products prove interoperability, and conformance test services to prove that products follow the NVMe specification correctly.
- Targeting Jan 2013.

## NVMe SSD Compliance Tester

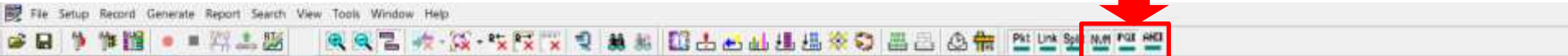
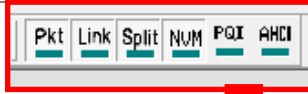
**Exerciser**  
Running Compliance Tests



# SCSI Express SOP Analysis Decode



Advancing Producer in Inbound Queue



PQI	Req	Len	RequesterID	Index	Time Delta	Time Stamp
55	R+	x1	000:00:0	0x0001	21.304 µs	0140 . 113 039 492 s
56	R-	x1	010:00:0	000:00:0		

SOP IU	IT	CF	IU LEN	ROQID	WA	Req ID	Data Dir	PARTIAL	DATA LEN	SCSI CDB	OP Code	SA	CDB Info	LBA	CDB Info	LEN	CDB Info	CONTROL
0x10	0x00	0x003C	0x0003	0x0000	0x0007	3	0	0x00000010		0xA0	0x0	0x0	0x00000000	0x00001000	0x00000000	0x00	0x00000000	

Advancing Consumer in Inbound Queue

PQI	Req	Len	RequesterID	Index	Time Delta	Time Stamp
57	R-	x1	010:00:0	0x0001	90.879 ms	0140 . 113 162 956 s

Link Tra	Req	Len	TLP	Msg	MsgID	Msg Routing	Length	RequesterID	Tag	Message Code	VID	Data	VC ID	Explicit ACK	Metrics	# Packets	Time Delta	Time Stamp
9610	R-	x1	851	Msg	011:10011	Broadcast	1	000:00:0	0	Vendor Defined Type1	0x8086	1 demand	0	Packet #18600		2	135.073 ms	0140 . 604 041 748 s

Advancing Producer in Outbound Queue

PQI	Req	Len	RequesterID	SOP IU	IT	CF	IU LEN	ROQID	WA	Req ID	NEXUS ID	Time Delta	Time Stamp
58	R-	x1	010:00:0	0x90	0x00	0x000C	0x0003	0x0000	0x0007	0x0007		23.096 µs	0140 . 919 210 444 s

Advancing Consumer in Outbound Queue

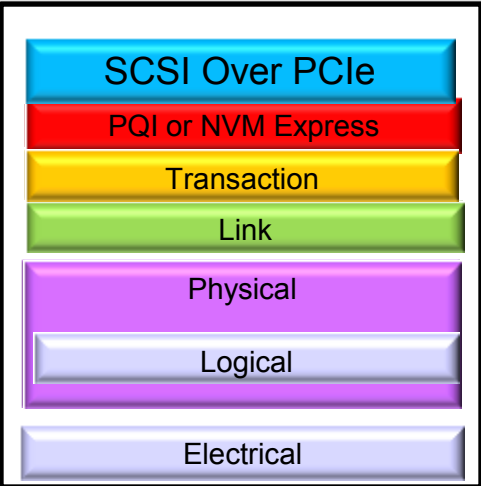
PQI	Req	Len	RequesterID	Index	Time Delta	Time Stamp
59	R-	x1	010:00:0	0x0001	10.6 µs	

Link Tra	Req	Len	TLP	Mem	MWrr(32)	Len	Time Delta	Time Stamp
9614	R-	x1	571	Mem	010:00000		5.640 µs	0140 . 919 244 204 s

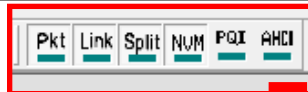
Courtesy SanDisk 2012

- SCSI Express is based on the SCSI over PCIe (SOP) host interface specification which enables SCSI initiators communicating to SCSI targets over PCIe through the PQI transfer layer





# SATA Express Analysis Decode

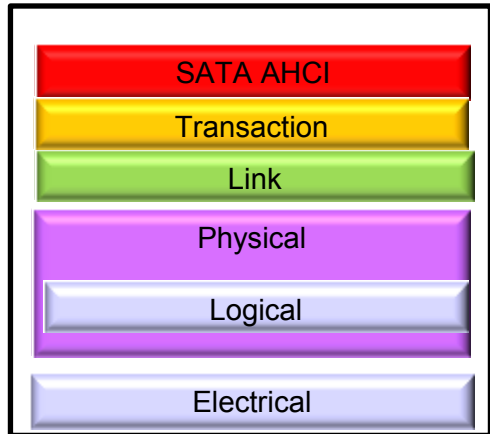


RequesterID	CompleterID	PxCMD	ICC	ASP	ALPE	DLAE	ATAPI	APSTE	FBSCP	ESP	CPD	MPSP	HPCP	PMA	CPS	CR	FR	MPSS	CCS	FRE	CLO	POD	SUD	ST	Time Delta	Time Stamp
AHCI 203	x1	No-Op / Idle	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1,520 µs	0010_002 648 088 s
AHCI 204	x1	No-Op / Idle	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	812,776 µs	0010_002 649 608 s
AHCI 205	x1	No-Op / Idle	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1,688 µs	0010_003 462 384 s
AHCI 206	x1	No-Op / Idle	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	8,113 ms	0010_003 464 072 s
AHCI 207	x1	PxCLBU	CLBU	0x00000000	1,788 µs	0010_011 577 456 s																				
AHCI 208	x1	PxCLB	CLB	0x00000100	1,496 µs	0010_011 579 224 s																				
AHCI 209	x1	PxCLB	CLB	0x0009D100	2,326 µs	0010_011 580 720 s																				
AHCI 210	x1	PxFBU	FB	0x00000000	1,648 µs	0010_011 583 048 s																				
AHCI 211	x1	PxFB	FB	0x0009D140	1,712 µs	0010_011 584 696 s																				
AHCI 212	x1	PxFB	FB	0x0009D140	2,304 µs	0010_011 586 408 s																				

Port control setup address of Command list

Port control setup address of FIS

- SATA Express enables new devices to be developed that utilize the faster PCIe interface and maintain compatibility with a broad base of existing SATA applications.



# Tools for PCIe SSD Technologies



SSD Protocols	Analyzer	Exerciser
PCI Express	Summit T3-16 Summit T3-8 Summit T28	Summit Z3-16 <i>Host/Device Emulation</i>
NVM Express	Summit T3-16/ T3-8/ T28 <i>SSD Decoding</i>	Summit Z3-16 <i>NVMe Host/Device Emulation</i>
SCSI Express(SOP/PQI)	Summit T3-16/ T3-8/ T28 <i>SSD Decoding</i>	Summit Z3-16 <i>SCSI Express Host Emulation</i>
SATA Express (AHCI/PCIe)	Summit T3-16/ T3-8/ T28 <i>SSD Decoding</i>	Summit Z3-16 <i>SATA Express Host Emulation</i>



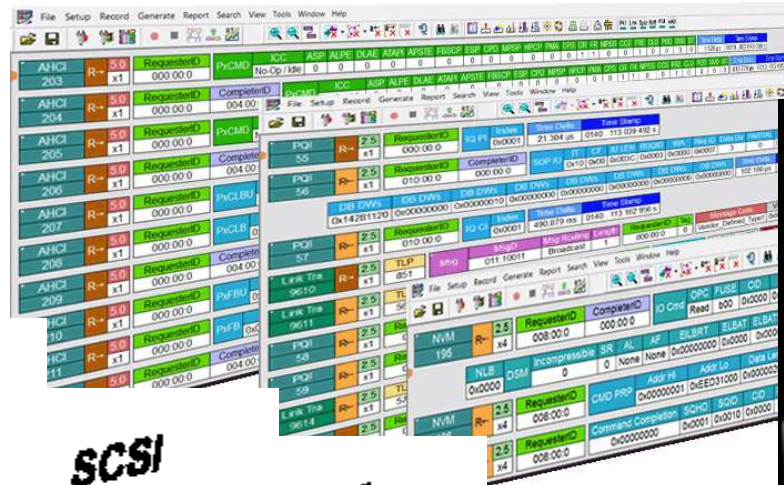
**SCSI Express**



**SATA Express**

# Conclusion

- New testing methodologies are needed for NVM Express, SCSI Express and SATA
- Protocol analysis tools can show developers useful details about PCIe SSD transactions between the storage host and controller.
- Host and device emulation can discover performance, error handling and protocol issues that affect the quality of products.



**Sata  
Express**

**SCSI  
Express**

**NVM  
Express**





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