Storage over PCIe protocol analysis and traffic generation techniques

Isaac Livny

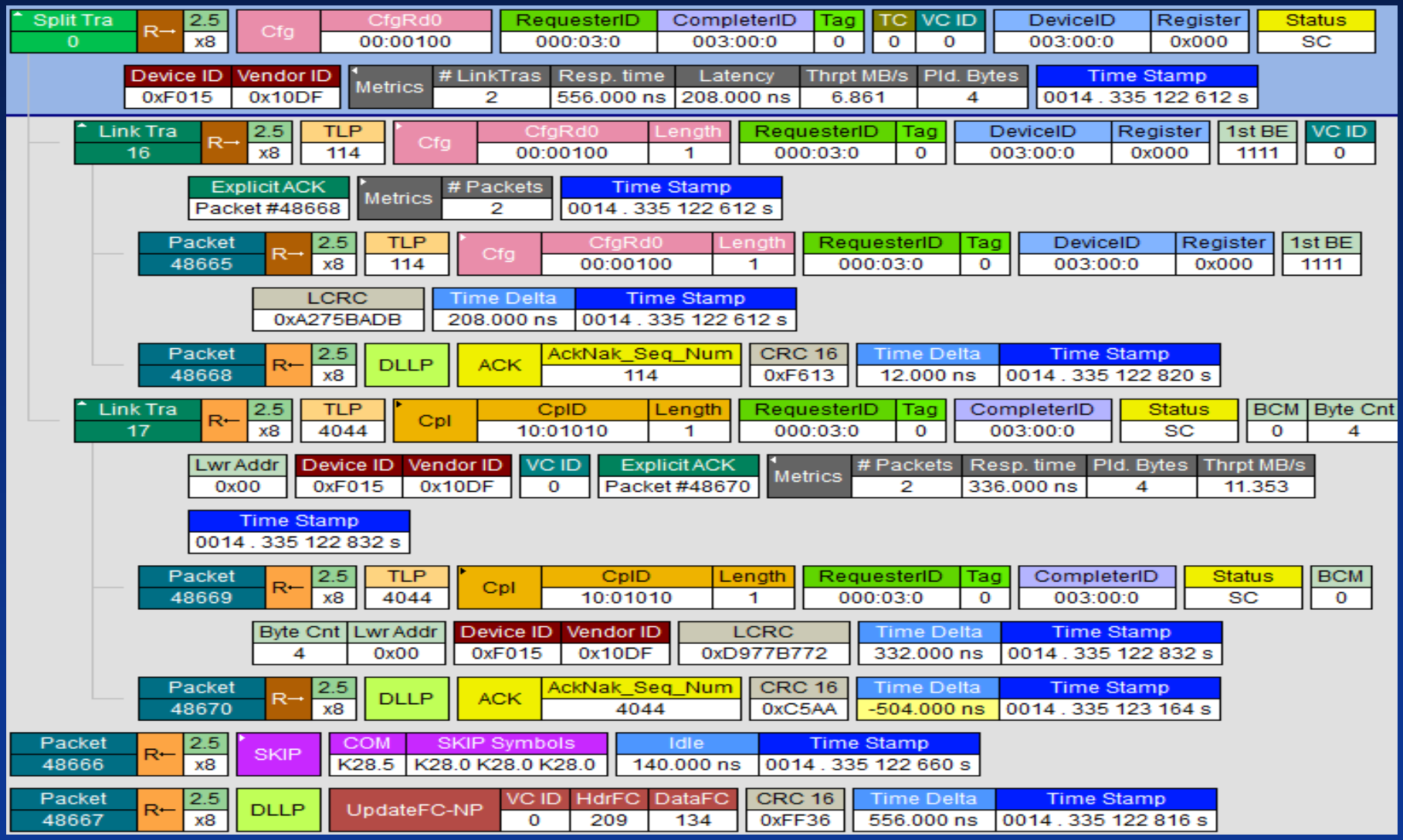
Field Applications Engineer

Teledyne LeCroy Corporation

Agenda

- Storage over PCI Express® architecture
  - SATA Express / AHCI
  - SCSI Express / SOP – PQI
  - NVM Express
- Command queue generation example
- Emulating an SSD controller
- Emulating an SSD host
- Command Validation

Layered protocols analysis over PCIe as transport mechanism



Layered Protocols Support in Analysis Tools

- Hierarchical view display capability with multi layer expansion into sub-layers
- Multi-view capabilities
- Processing capability of upper layer through scripting to adopt to specification changes
- Tooltip feature to highlight specification details
- Performance and statistical analysis per instruction, by segment and overall trace
- Compacting of repetitive traffic
- Compacting of multiple 32 bit transactions into 64 bit upper layer commands

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SATA Express

SATA Express

ATA command over Serial ATA Read DMA

I2	ATA Cmd.	1.5 G	Command	Input (H)	Normal Output (H)	ATA Command Data , 2560 Bytes	PM Port (H)	Protocol	Status	Metrics
5.002.537.866 (s)	2		0xC8 : Read DMA	C8000500000040	00000400004050	00 01 02 03 04 05 06 07 08 09 0A 0B >>	0	0x07 : DMA	0x01 : Normal Output	

I2	Transport	1.5 G	FIS Type	PM Port (H)	C (H)	Command (H)	Features (H)	LBA Low (H)	LBA Mid (H)	LBA High (H)	Device (H)	LBA Low (exp) (H)	LBA Mid (exp) (H)
5.002.537.866 (s)	3		0x27 : Register Host to Device	0	1	C8	00	00	00	00	40	00	00

LBA High (exp) (H)	Features (exp) (H)	Sector Count (H)	Sector Count (exp) (H)	Control (H)	CRC (H)	Duration
00	00	05	00	00	E0EA7CCB	4.426 (us)

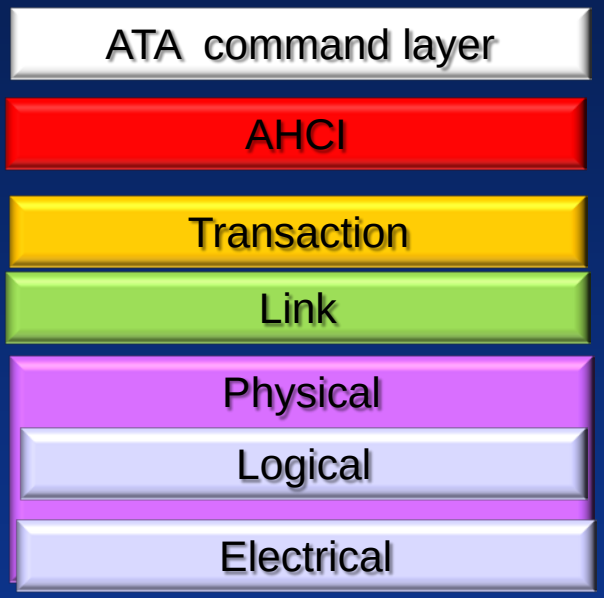
T2	Transport	1.5 G	FIS Type	PM Port (H)	Data , 2560 Bytes	CRC (H)	Duration
5.015.078.960 (s)	4		0x46 : Data	0	00 01 02 03 04 05 06 07 08 09 0A 0B >>	89E129F5	32.666 (us)

T2	Transport	1.5 G	FIS Type	PM Port (H)	I (H)	Status (H)	Error (H)	LBA Low (H)	LBA Mid (H)	LBA High (H)	Device (H)	LBA Low (exp) (H)	LBA Mid (exp) (H)
5.015.111.626 (s)	6		0x34 : Register Device to Host	0	1	50	00	04	00	00	40	00	00

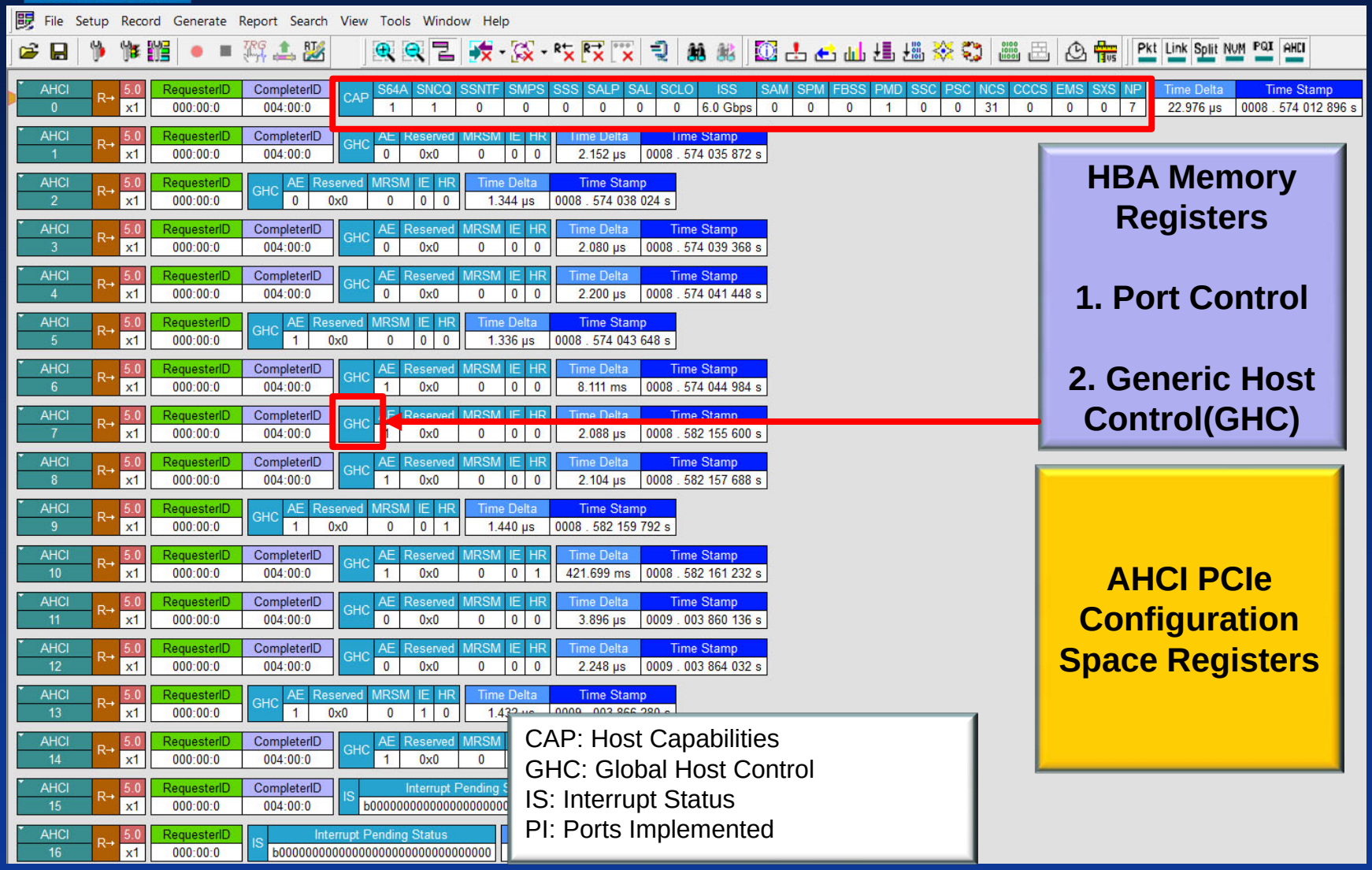
LBA High (exp) (H)	Sector Count (H)	Sector Count (exp) (H)	CRC (H)	Duration
00	00	00	47CA0EE1	40.373 (us)

SATA Express

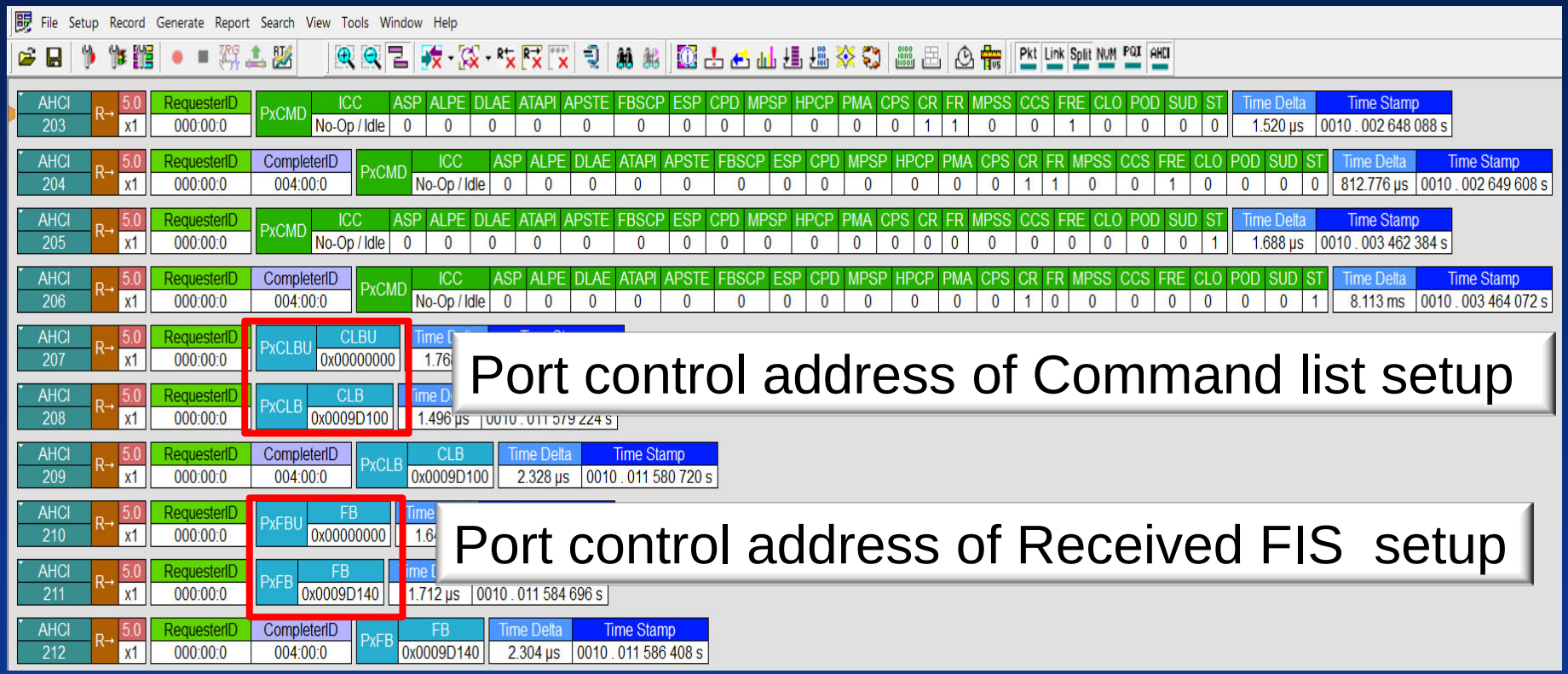
- The Serial ATA International Organization (SATA-IO) developed the specification
- This protocol combines the SATA AHCI software specification with the PCIe host interface
- SATA Express enables new devices to be developed that utilize the faster PCIe interface and maintain compatibility with a broad base of existing SATA applications
- Data Rate Support
  - PCIe 2.x at x2 link for 8GT/s data rate
  - PCIe 3.0 at x2 link for a 16GT/s data rate



AHCI HBA Registers



SATA Express
Port Control Setup



AHCI System Memory

Host System Memory

Port 0-31 Control Registers

Port 0

Each Port CTL Register points to two sections of System Memory

PxCLB: Cmd List Base Address

PxCLBU: CLB Addr Up32b

PxFB: FIS Base Addr

PxFBU: FIS Base Addr Up32b

AHCI 207	R→	5.0 x1	RequesterID 000:00:0	PxCLBU	CLBU 0x00000000	Time Delta 1.768 µs	Time Stamp 0010 . 011 577 456 s		
AHCI 208	R→	5.0 x1	RequesterID 000:00:0	PxCLB	CLB 0x0009D100	Time Delta 1.496 µs	Time Stamp 0010 . 011 579 224 s		

AHCI 210	R→	5.0 x1	RequesterID 000:00:0	PxFBU	FB 0x00000000	Time Delta 1.648 µs	Time Stamp 0010 . 011 583 048 s		
AHCI 211	R→	5.0 x1	RequesterID 000:00:0	PxFB	FB 0x0009D140	Time Delta 1.71	Time Stamp 0010 . 011 584 696 s		

Command 0
Command 1
Command 2
Command 31

Command Table Address

uesterID 04:00:1	CompleterID 000:00:0	CTBAU 0x00000000	CTBA 0x0009D280	Time Stamp 0010 . 146 471 378 s					
Mem	MRd(32) 000:00000	RequesterID 004:00:1	CompleterID 000:00:0	Tag 3	TC 0	VC ID 0	Address 0009D108	Status SC	Data 0009D280 00000000

Received FIS Structure

Physical Region Descriptor(PRD) Table Address

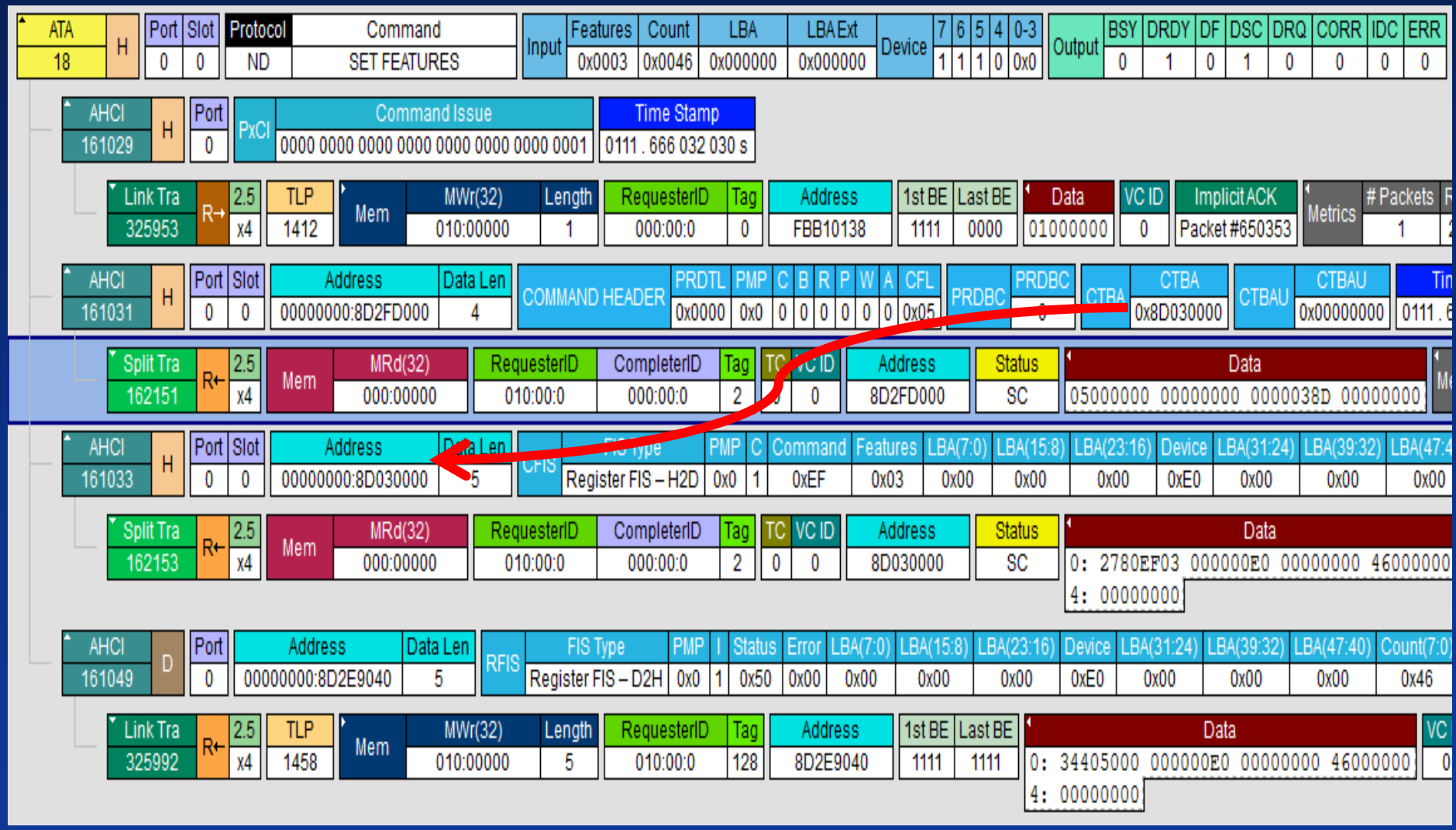
AHCI 282	R←	5.0 x1	RequesterID 004:00:1	CompleterID 000:00:0	PRDT	DBAU 0x00000000	DBA 0x0009D748	Reserved 0x00000000	I 0	DBC 0x000001FF	Time Stamp 0010 . 146 479 946 s		
Split Tra 8072	R←	5.0 x1	Mem	MRd(32) 000:00000	RequesterID 004:00:1	CompleterID 000:00:0	Tag 5	TC 0	VC ID 0	Address 0009D300	Status SC	Data 0009D748 00000000 00000000 000001FF	

DBA	Addr Hi 0x00000000	Addr Lo 0x0009D748	Data Len 0x00000200	Data 127 quadlets

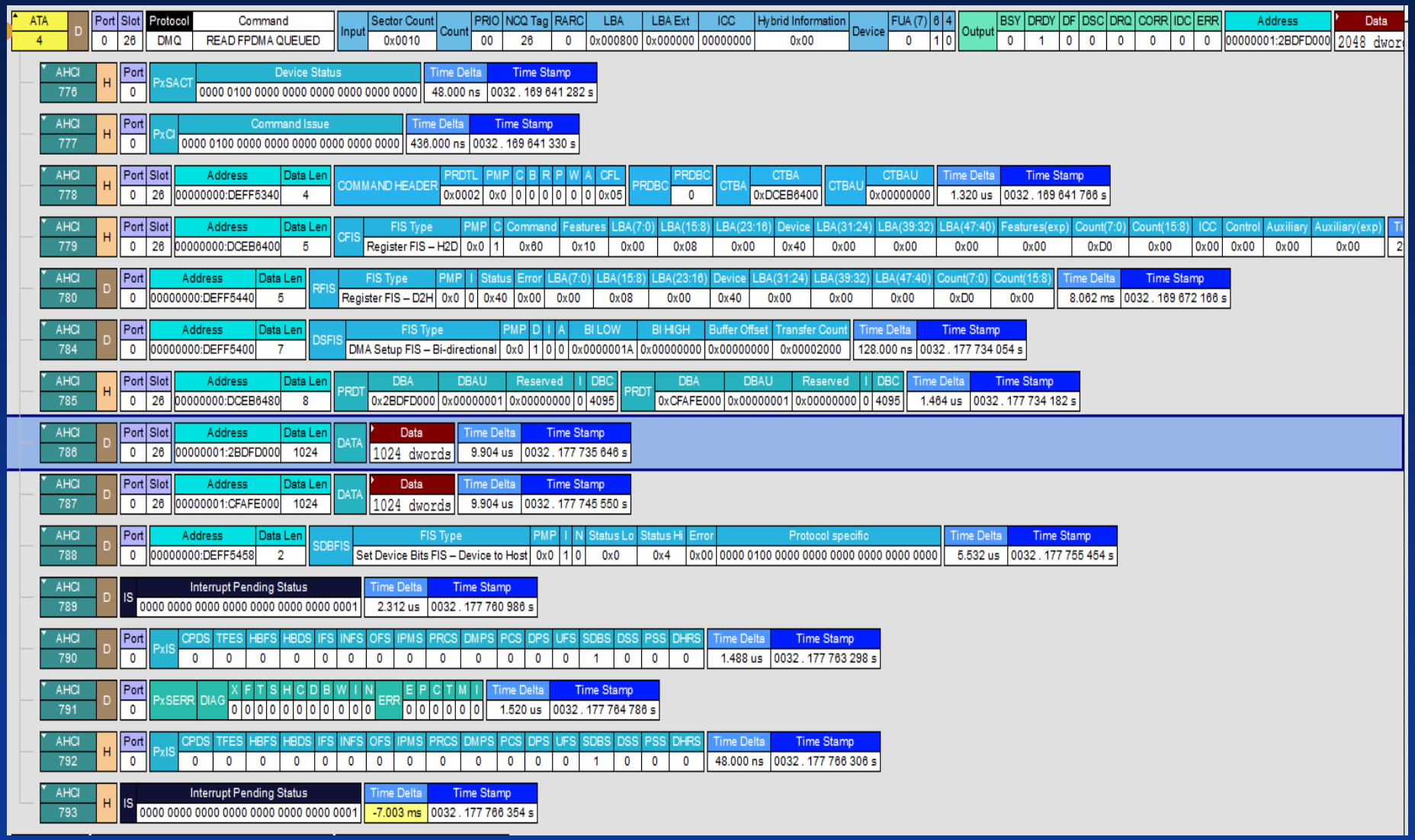
Command List Structure

Data payload is sent and received through the PRDT (Physical Region Descriptor Table) in Command List

ATA command: Set Features



READ FPDMA QUEUED



ATA	D	Port	Slot	Protocol	Command	Input	Sector Count	Count	PRIO	NCQ Tag	RARC	LBA	LBA Ext	ICC	Hybrid Information	Device	FUA (7)	6	4	Output	BSY	DRDY	DF	DSC	DRQ	CORR	IDC	ERR	Address	Data
4		0	26	DMQ	READ FPDMA QUEUED		0x0010		00	26	0	0x000800	0x000000	00000000	0x00		0	1	0		0	1	0	0	0	0	0	0	00000001:2BDFD000	2048 dwor

AHCI	H	Port	PxSACT	Device Status	Time Delta	Time Stamp
776		0		0000 0100 0000 0000 0000 0000 0000 0000	48.000 ns	0032 . 169 641 282 s

AHCI	H	Port	PxCI	Command Issue	Time Delta	Time Stamp
777		0		0000 0100 0000 0000 0000 0000 0000 0000	436.000 ns	0032 . 169 641 330 s

AHCI	H	Port	Slot	Address	Data Len	COMMAND HEADER	PRDTL	PMP	C	B	R	P	W	A	CFL	PRDBC	PRDBC	CTBA	CTBA	CTBAU	CTBAU	Time Delta	Time Stamp
778		0	26	00000000:DEFF5340	4		0x0002	0x0	0	0	0	0	0	0	0x05		0		0xDCEB6400		0x00000000	1.320 us	0032 . 169 641 766 s

AHCI	H	Port	Slot	Address	Data Len	CFIS	FIS Type	PMP	C	Command	Features	LBA(7:0)	LBA(15:8)	LBA(23:16)	Device	LBA(31:24)	LBA(39:32)	LBA(47:40)	Features(exp)	Count(7:0)	Count(15:8)	ICC	Control	Auxiliary	Auxiliary(exp)	Ti
779		0	26	00000000:DCEB6400	5		Register FIS – H2D	0x0	1	0x60	0x10	0x00	0x08	0x00	0x40	0x00	0x00	0x00	0x00	0xD0	0x00	0x00	0x00	0x00	0x00	2

AHCI	D	Port	Address	Data Len	RFIS	FIS Type	PMP	I	Status	Error	LBA(7:0)	LBA(15:8)	LBA(23:16)	Device	LBA(31:24)	LBA(39:32)	LBA(47:40)	Count(7:0)	Count(15:8)	Time Delta	Time Stamp
780		0	00000000:DEFF5440	5		Register FIS – D2H	0x0	0	0x40	0x00	0x00	0x08	0x00	0x40	0x00	0x00	0x00	0xD0	0x00	8.062 ms	0032 . 169 672 166 s

AHCI	D	Port	Address	Data Len	DSFIS	FIS Type	PMP	D	I	A	BI LOW	BI HIGH	Buffer Offset	Transfer Count	Time Delta	Time Stamp
784		0	00000000:DEFF5400	7		DMA Setup FIS – Bi-directional	0x0	1	0	0	0x0000001A	0x00000000	0x00000000	0x00002000	128.000 ns	0032 . 177 734 054 s

AHCI	H	Port	Slot	Address	Data Len	PRDT	DBA	DBAU	Reserved	I	DBC	PRDT	DBA	DBAU	Reserved	I	DBC	Time Delta	Time Stamp
785		0	26	00000000:DCEB6480	8		0x2BDFD000	0x00000001	0x00000000	0	4095		0xCFAFE000	0x00000001	0x00000000	0	4095	1.464 us	0032 . 177 734 182 s

AHCI	D	Port	Slot	Address	Data Len	DATA	Data	Time Delta	Time Stamp
786		0	26	00000001:2BDFD000	1024		1024 dwords	9.904 us	0032 . 177 735 646 s

AHCI	D	Port	Slot	Address	Data Len	DATA	Data	Time Delta	Time Stamp
787		0	26	00000001:CFAFE000	1024		1024 dwords	9.904 us	0032 . 177 745 550 s

AHCI	D	Port	Address	Data Len	SDBFIS	FIS Type	PMP	I	N	Status Lo	Status Hi	Error	Protocol specific	Time Delta	Time Stamp
788		0	00000000:DEFF5458	2		Set Device Bits FIS – Device to Host	0x0	1	0	0x0	0x4	0x00	0000 0100 0000 0000 0000 0000 0000 0000	5.532 us	0032 . 177 755 454 s

AHCI	D	IS	Interrupt Pending Status	Time Delta	Time Stamp
789			0000 0000 0000 0000 0000 0000 0000 0001	2.312 us	0032 . 177 760 988 s

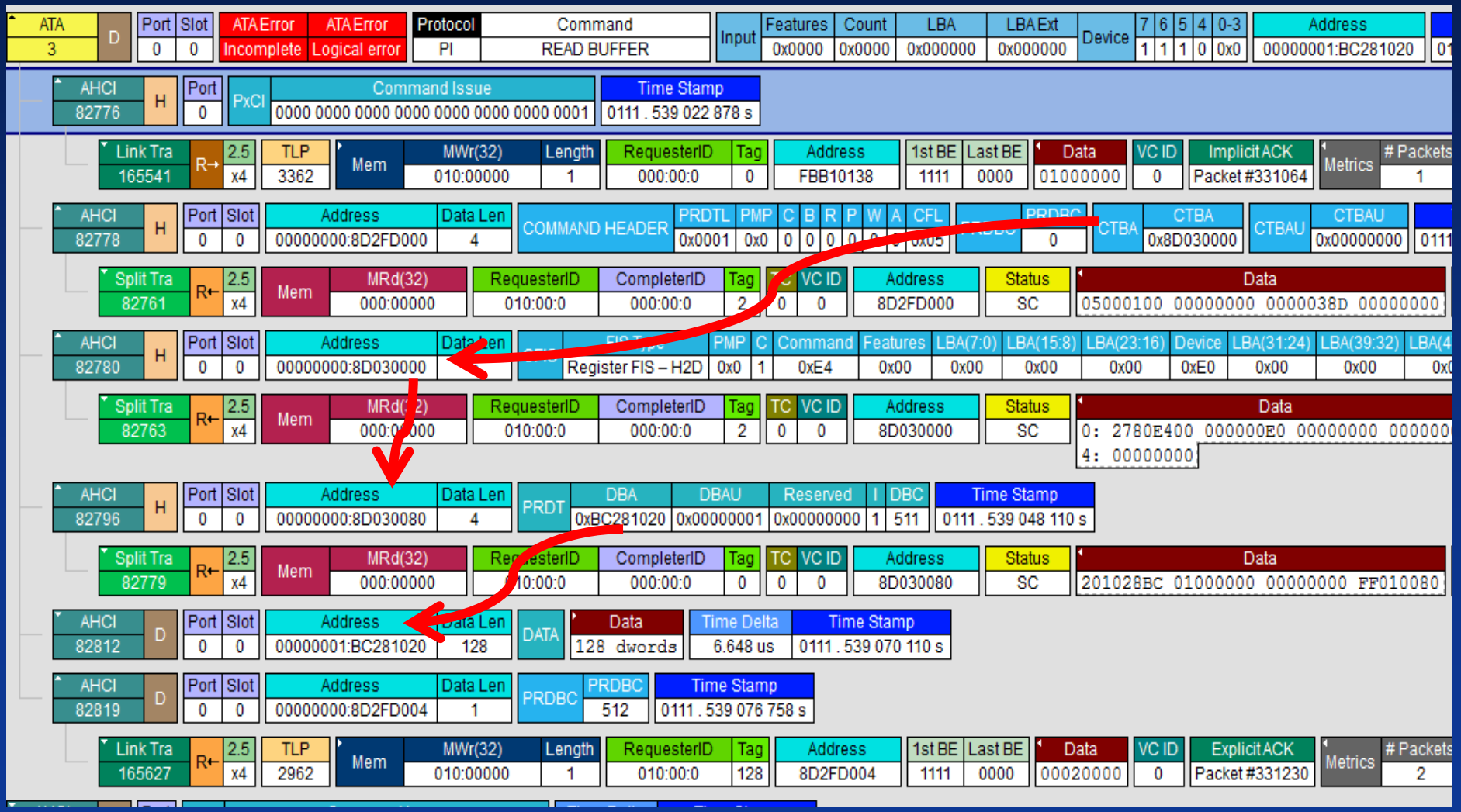
AHCI	D	Port	PxIS	CPDS	TFES	HBFS	HBDS	IFS	INFS	OFS	IPMS	PRCS	DMPS	PCS	DPS	UFS	SDBS	DSS	PSS	DHRS	Time Delta	Time Stamp
790		0		0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	1.488 us	0032 . 177 763 298 s

AHCI	D	Port	PxSERR	DIAG	X	F	T	S	H	C	D	B	W	I	N	ERR	E	P	C	T	M	I	Time Delta	Time Stamp
791		0			0	0	0	0	0	0	0	0	0	0	0		0	0	0	0	0	0	1.520 us	0032 . 177 764 786 s

AHCI	H	Port	PxIS	CPDS	TFES	HBFS	HBDS	IFS	INFS	OFS	IPMS	PRCS	DMPS	PCS	DPS	UFS	SDBS	DSS	PSS	DHRS	Time Delta	Time Stamp
792		0		0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	48.000 ns	0032 . 177 766 306 s

AHCI	H	IS	Interrupt Pending Status	Time Delta	Time Stamp
793			0000 0000 0000 0000 0000 0000 0000 0001	-7.003 ms	0032 . 177 766 354 s

ATA Command: READ BUFFER



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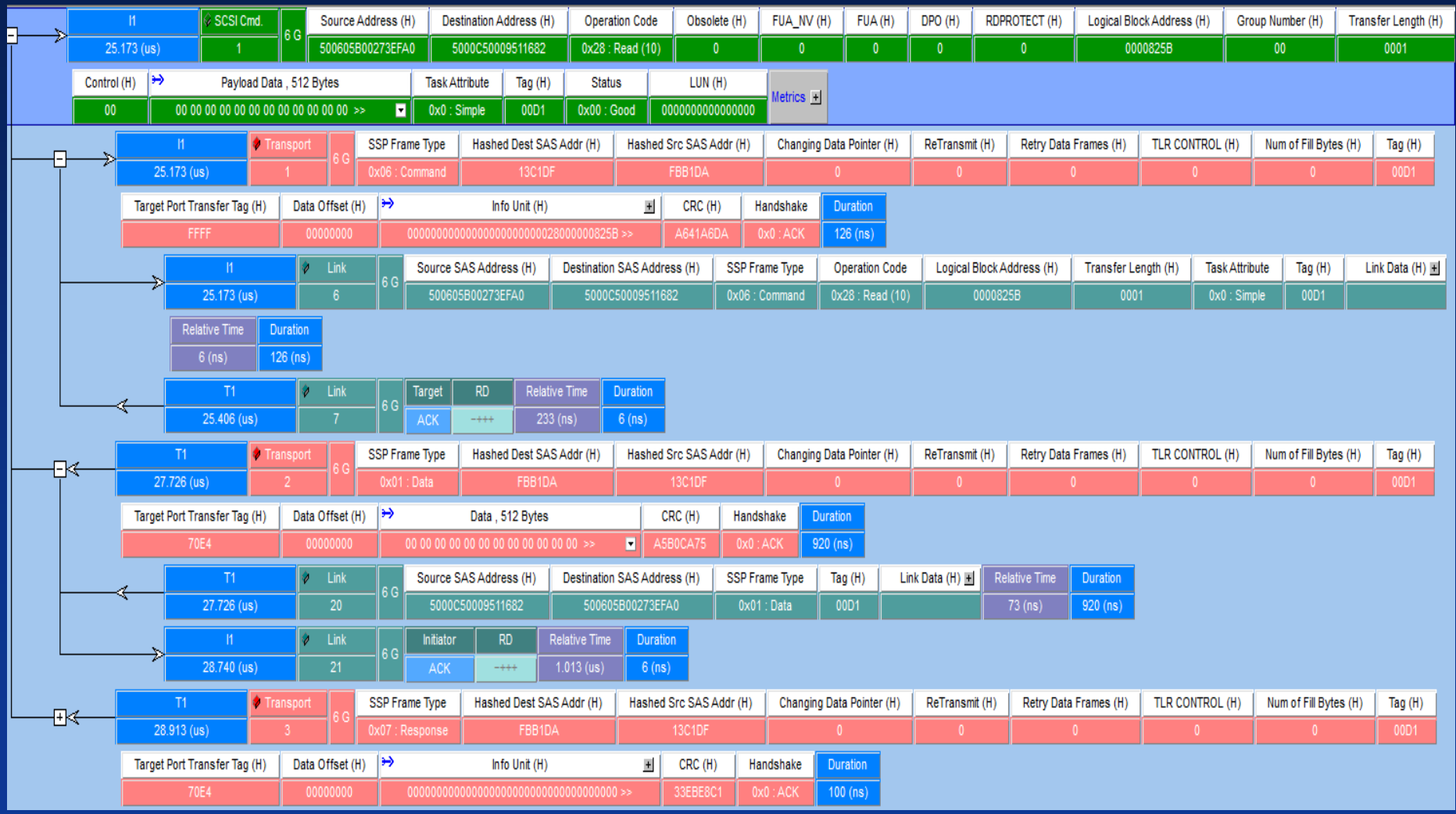
PCIe Architecture Queuing Interface (PQI)

SCSI Express

SAS Hierarchical View
SCSI Command Decode



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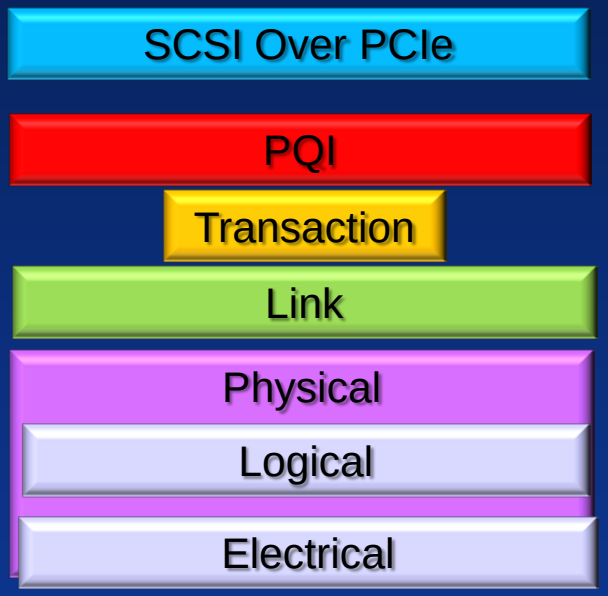
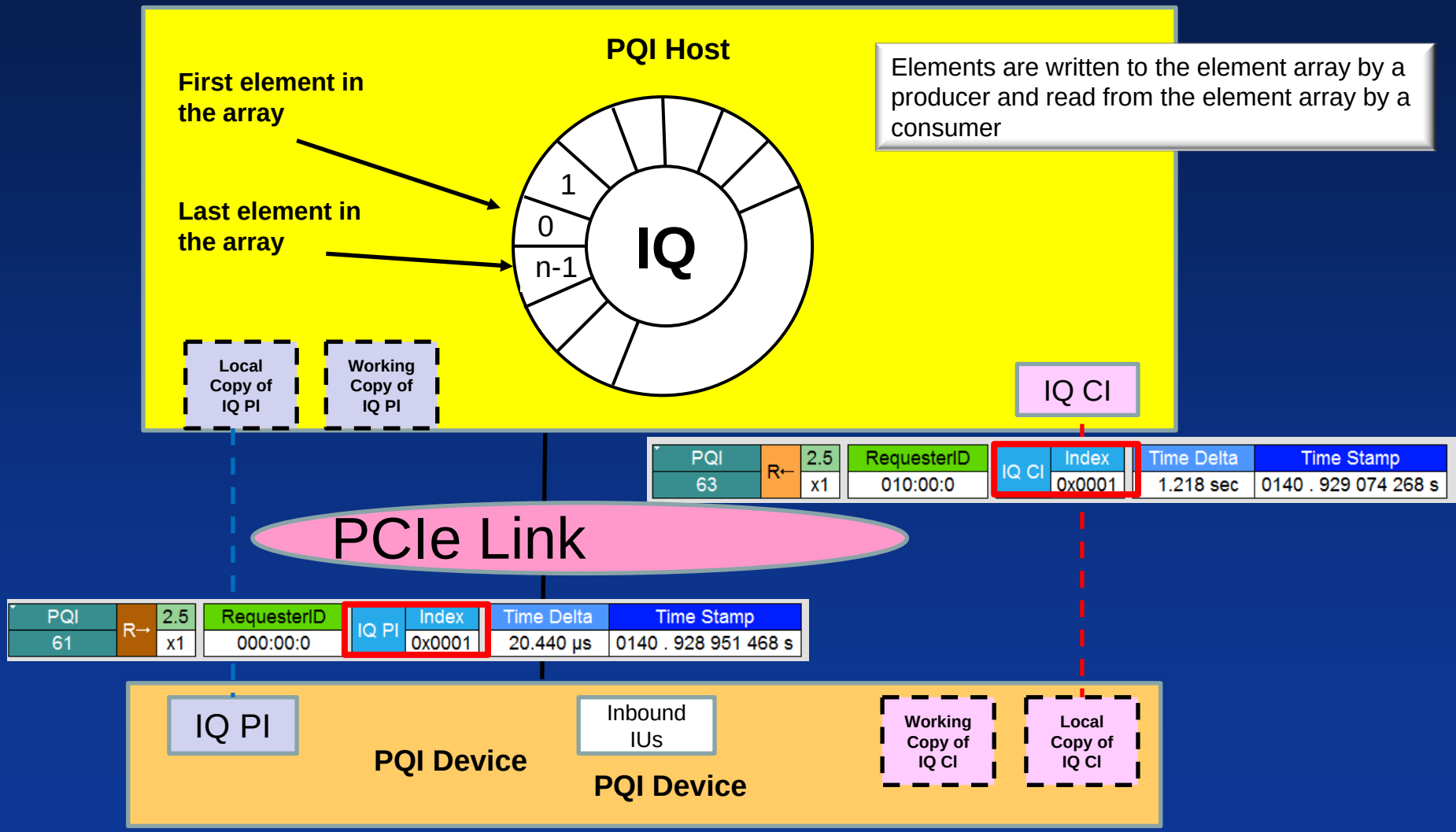
SCSI Over PCI Express(SOP/SOX)

- Developed by T10 Committee
- Compliance with SCSI Architectural Model
- Proposed support for SOP target ports interfacing to flash devices, RAID controllers, and other SCSI peripheral device types
- Targeting PCIe 3.0

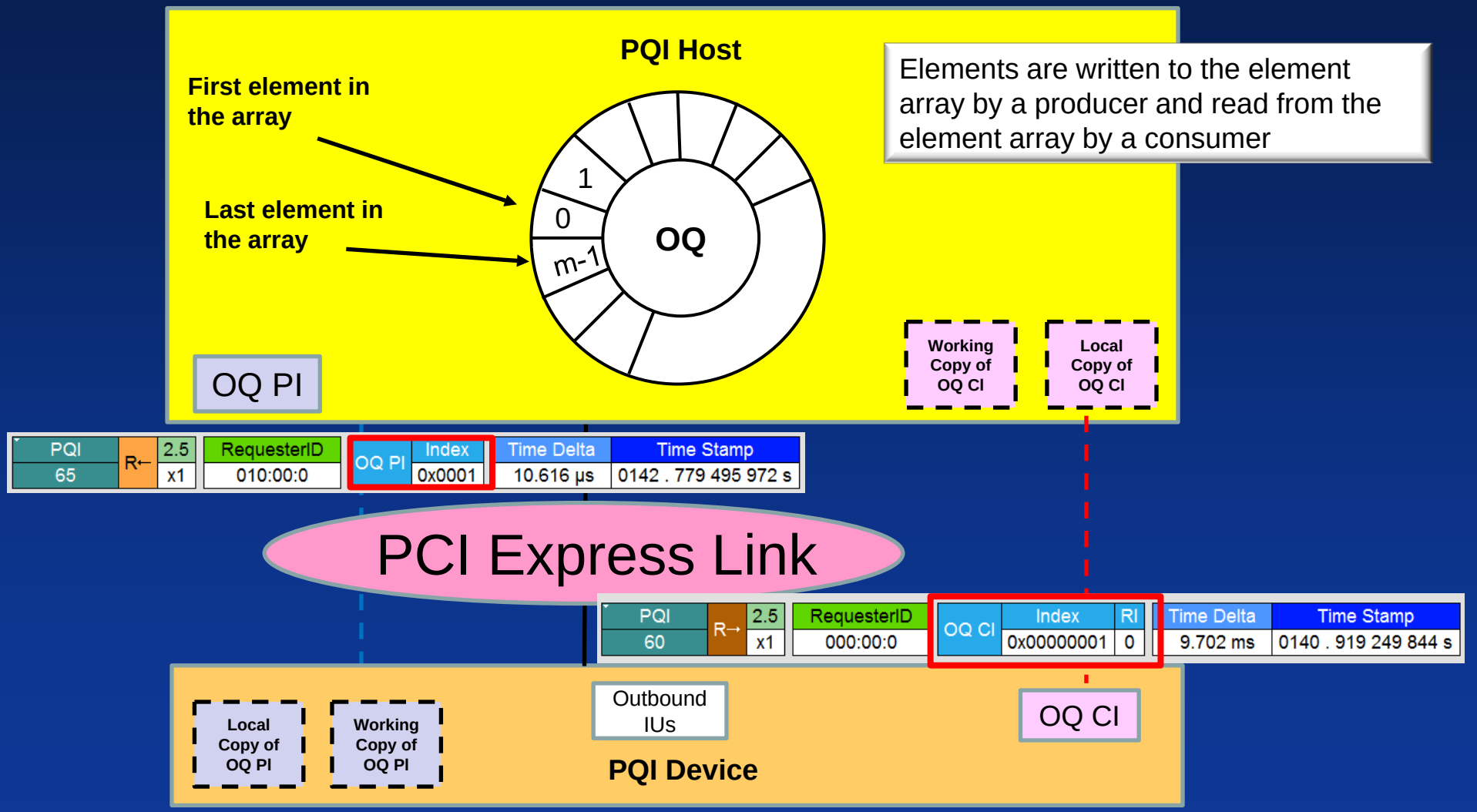


Preliminary Protocol Stack

SCSI Express SOP/PQI IQ(Inbound Queue)

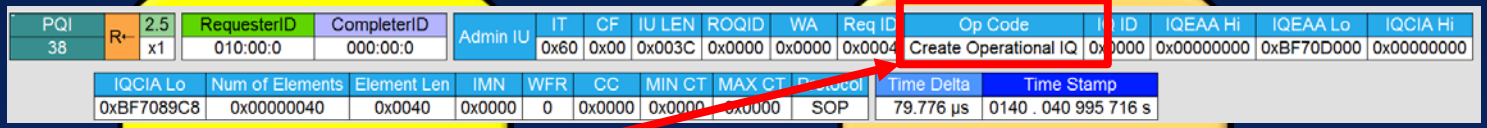


SCSI Express SOP/PQI OQ(Outbound Queue)



Creating Administrative and Operational Queues

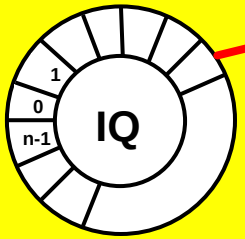
Creating an Operational Inbound Queue

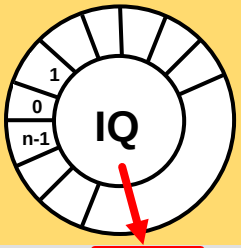


PQI	R←	2.5	RequesterID	CompleterID
38		x1	010:00:0	000:00:0

Admin IU	IT	CF	IU LEN	ROQID	WA	Req ID	Op Code	IQ ID	IQEAA Hi	IQEAA Lo	IQCIA Hi
	0x60	0x00	0x003C	0x0000	0x0000	0x0004	Create Operational IQ	0x0000	0x00000000	0xBF70D000	0x00000000

IQCIA Lo	Num of Elements	Element Len	IMN	WFR	CC	MIN CT	MAX CT	Protocol	Time Delta	Time Stamp
0xBF7089C8	0x00000040	0x0040	0x0000	0	0x0000	0x0000	0x0000	SOP	79.776 µs	0140 . 040 995 716 s

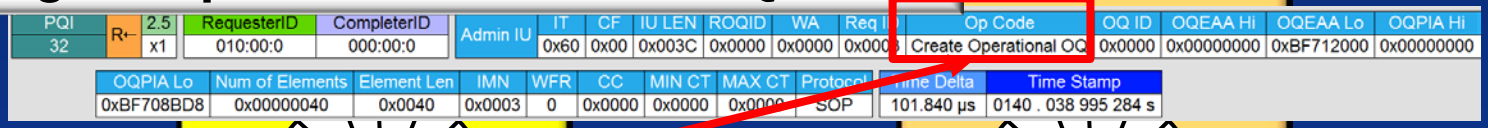




Response

PQI	R←	2.5	RequesterID	Admin OU	IT	CF	IU LEN	Reserved	WA	Req ID	OP Code	Status	QPI Offset Hi	IQPI offset Lo	Time Delta
39		x1	010:00:0		0xE0	0x00	0x003C	0x0000	0x0000	0x0004	Create Operational IQ	Success	0x00000000	0x00001010	22.792 µs

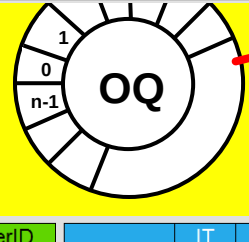
Creating an Operational Outbound Queue

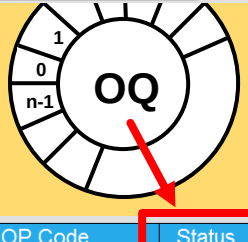


PQI	R←	2.5	RequesterID	CompleterID
32		x1	010:00:0	000:00:0

Admin IU	IT	CF	IU LEN	ROQID	WA	Req ID	Op Code	OQ ID	OQEAA Hi	OQEAA Lo	OQPIA Hi
	0x60	0x00	0x003C	0x0000	0x0000	0x0000	Create Operational OQ	0x0000	0x00000000	0xBF712000	0x00000000

OQPIA Lo	Num of Elements	Element Len	IMN	WFR	CC	MIN CT	MAX CT	Protocol	Time Delta	Time Stamp
0xBF708BD8	0x00000040	0x0040	0x0003	0	0x0000	0x0000	0x0000	SOP	101.840 µs	0140 . 038 995 284 s



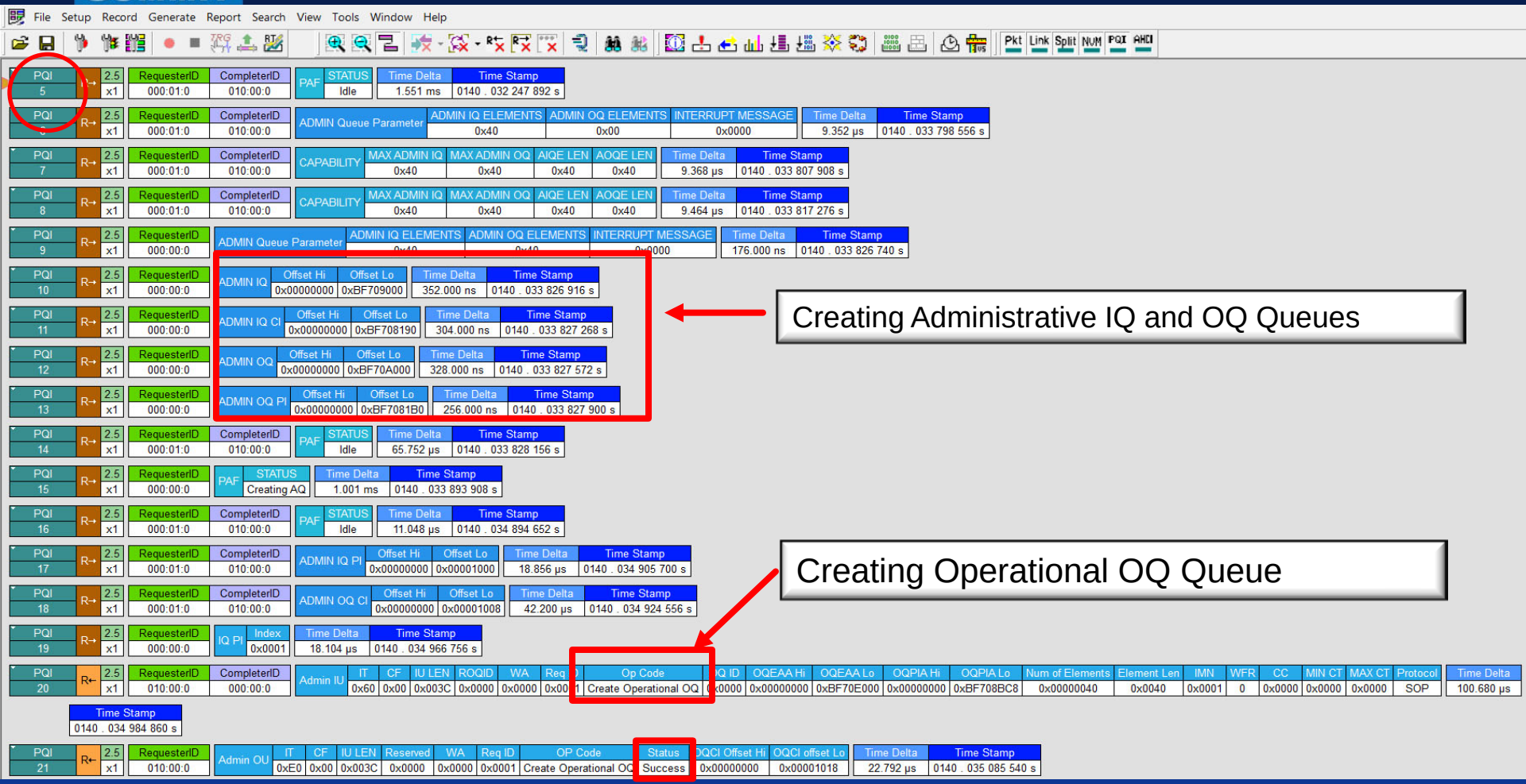


Response

PQI	R←	2.5	RequesterID	Admin OU	IT	CF	IU LEN	Reserved	WA	Req ID	OP Code	Status	OQCI Offset Hi	OQCI offset Lo	Time Delta
33		x1	010:00:0		0xE0	0x00	0x003C	0x0000	0x0000	0x0003	Create Operational OQ	Success	0x00000000	0x00001038	22.816 µs

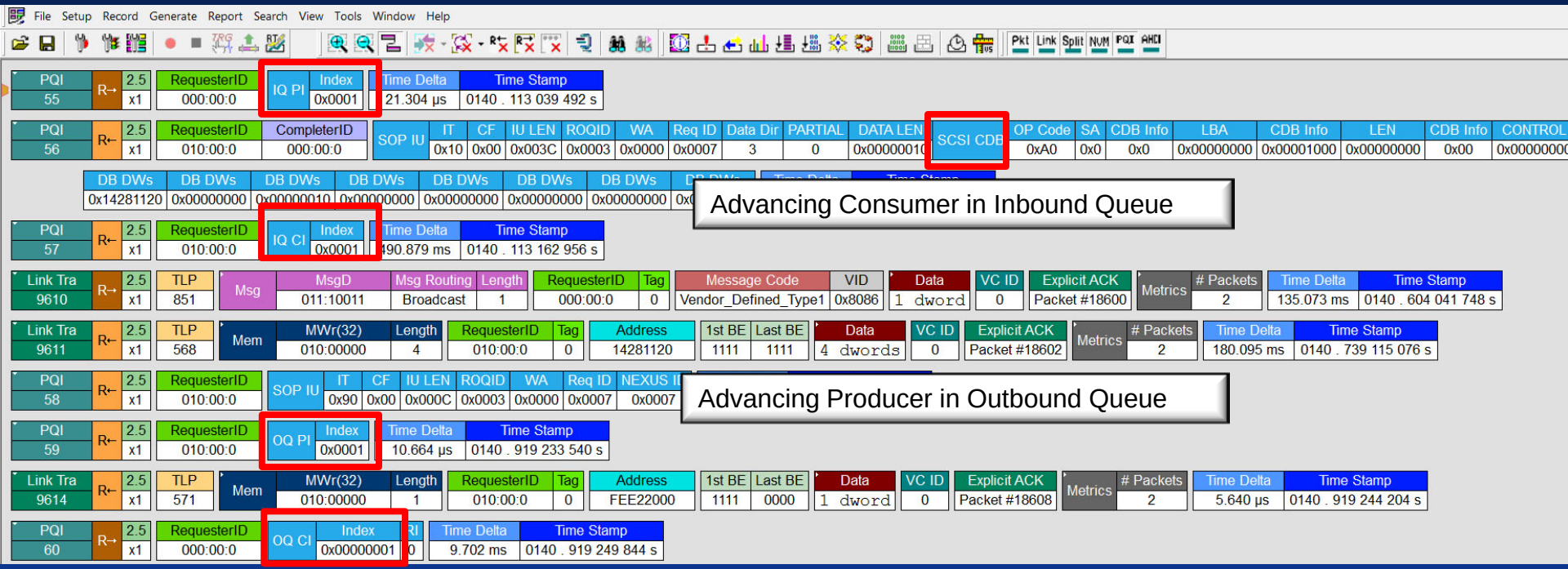
Admin Queue **Operational Queue**

SCSI Express Initialization



SCSI Express SOP Transfer Packet

Advancing Producer in Inbound Queue



Courtesy SanDIsk 2012

Advancing Consumer in Outbound Queue

PQI initialization

PQI		Admin Queue Parameter	ADMIN IQ ELEMENTS	ADMIN OQ ELEMENTS	INTERRUPT MESSAGE
6	H		64	64	0

PQI		Admin IQ Mem Addr	Address
7	H		00000000:BF709000

PQI		Admin IQ CI Mem Addr	Address
8	H		00000000:BF708190

PQI		Admin OQ Mem Addr	Address
9	H		00000000:BF70A000

PQI		Admin OQ PI Mem Addr	Address
10	H		00000000:BF7081B0

PQI		AQ Config Function	Function and status
11	D		IDLE

PQI		AQ Config Function	Function and status
12	H		Create AQ Pair

PQI		AQ Config Function	Function and status
13	D		IDLE

PQI		Admin IQ PI Offset	Offset
14	D		00000000:00001000

PQI		Admin OQ CI Offset	Offset
15	D		00000000:00001008

PQI: Create Operational Queues

PQI					
16	H	AIQ	Admin IQ PI	Index	0x0001

PQI													
17	H	AIQ	Elem	Adm IQ IU	Type	Rsv	Cmp	Len	WA	RQ ID	OP	Queue ID	Queue Element Array Address
			0x0000		Adm RQ	0x0	0x0	0x003C	0x0000	1	Create OP OQ	0x0001	00000000:BF70E000

OQ PI Address	OQ Number of Elements	OQ Element Length	IMN	WFR	CC	Min CT	Max CT	Op Queue Protocol
00000000:BF708BC8	64	64 (1024 bytes)	1	0	0	0	0	SOP

PQI													
18	D	AOQ	Elem	Adm OQ IU	Type	Rsv	Cmp	Len	WA	RQ ID	OP	Status	OQ CI Offset
			0x0000		Adm RSP	0x0	0x0	0x003C	0x0000	1	Create OP OQ	Good	00000000:00001018

PQI				
19	D	AOQ	Admin OQ PI	Index 0x0001

Link Tra		2.5	TLP		MWr(32)	Length	RequesterID	Tag	Address	1st BE	Last BE	Data	VC ID
9563	R←	x1	539	Mem	010:00000	1	010:00:0	0	FEE00000	1111	0000	B0400000	0

Explicit ACK		
Packet #18511	Metrics	# Packets 2

PQI				
20	D	AIQ	Admin IQ CI	Index 0x0001

PQI				
21	H	AOQ	Admin OQ CI	Index 0x0001 RI 0

PQI				
22	H	AIQ	Admin IQ PI	Index 0x0002

PQI													
23	H	AIQ	Elem	Adm IQ IU	Type	Rsv	Cmp	Len	WA	RQ ID	OP	Queue ID	Queue Element Array Address
			0x0001		Adm RQ	0x0	0x0	0x003C	0x0000	2	Create OP OQ	0x0002	00000000:BF710000

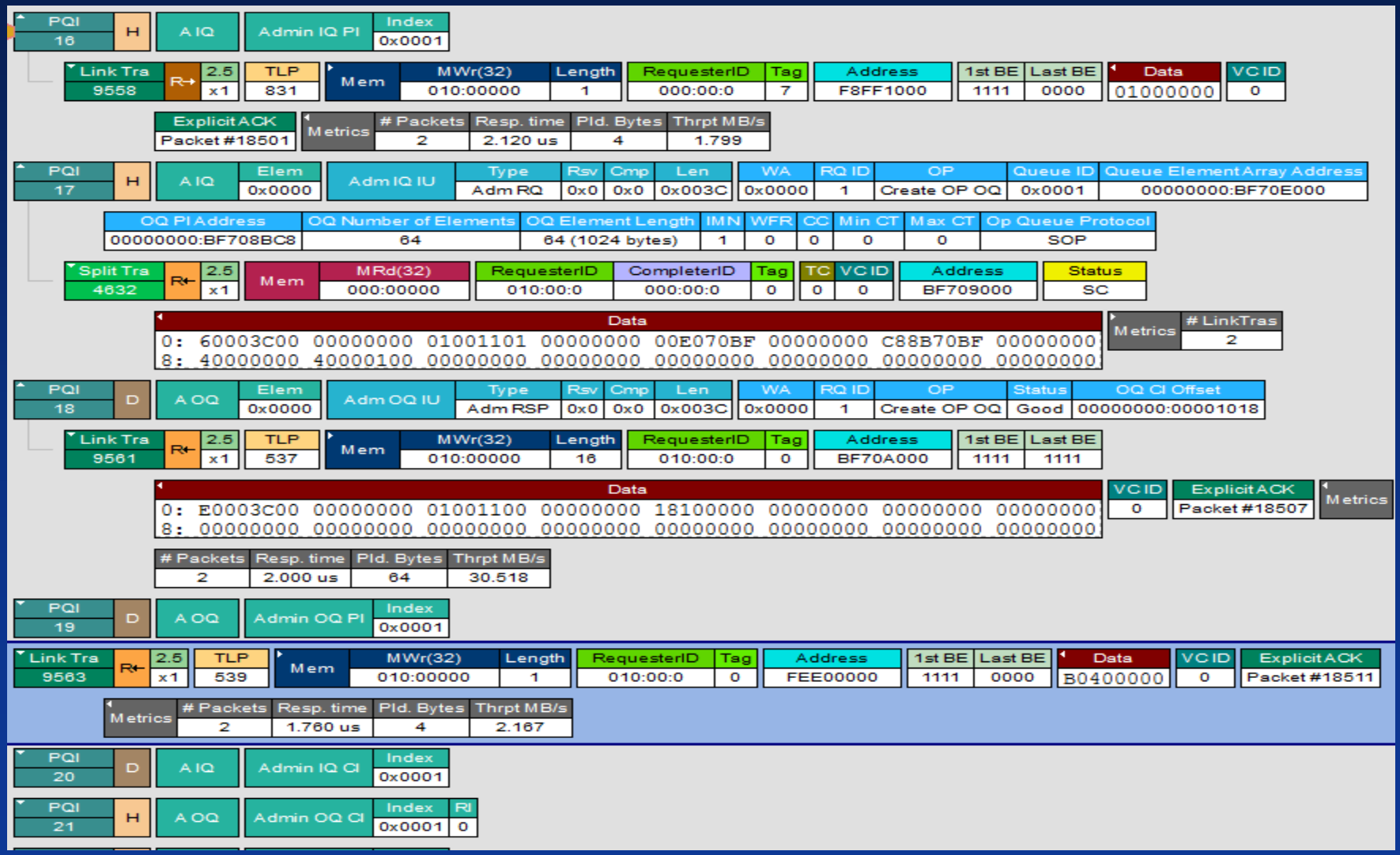
OQ PI Address	OQ Number of Elements	OQ Element Length	IMN	WFR	CC	Min CT	Max CT	Op Queue Protocol
00000000:BF708BD0	64	64 (1024 bytes)	2	0	0	0	0	SOP

PQI													
24	D	AOQ	Elem	Adm OQ IU	Type	Rsv	Cmp	Len	WA	RQ ID	OP	Status	OQ CI Offset
			0x0001		Adm RSP	0x0	0x0	0x003C	0x0000	2	Create OP OQ	Good	00000000:00001028

PQI				
25	D	AOQ	Admin OQ PI	Index 0x0002

Link Tra		2.5	TLP		MWr(32)	Length	RequesterID	Tag	Address	1st BE	Last BE	Data	VC ID
9571	R←	x1	544	Mem	010:00000	1	010:00:0	0	FEE00000	1111	0000	B0400000	0

PQI: Create Op Queue detailed



PQI				
16	H	A IQ	Admin IQ PI	Index
				0x0001

Link Tra			TLP										
9558	R→	2.5 x1	831	Mem	MWr(32)	Length	RequesterID	Tag	Address	1st BE	Last BE	Data	VC ID
					010:00000	1	000:00:0	7	F8FF1000	1111	0000	01000000	0

Explicit ACK	Metrics	# Packets	Resp. time	Pld. Bytes	Thrpt MB/s
Packet #18501		2	2.120 us	4	1.799

PQI												
17	H	A IQ	Elem	Adm IQ IU	Type	Rsv	Cmp	Len	WA	RQ ID	OP	Queue ID	Queue Element Array Address
			0x0000		Adm RQ	0x0	0x0	0x003C	0x0000	1	Create OP OQ	0x0001	00000000:BF70E000

OQ PI Address	OQ Number of Elements	OQ Element Length	IMN	WFR	CC	Min CT	Max CT	Op Queue Protocol
00000000:BF708BC8	64	64 (1024 bytes)	1	0	0	0	0	SOP

Split Tra												
4632	R←	2.5 x1	Mem	MRd(32)	RequesterID	CompleterID	Tag	TC	VC ID	Address	Status	
				000:00000	010:00:0	000:00:0	0	0	0	BF709000	SC	

Data	Metrics	# LinkTras
0: 60003C00 00000000 01001101 00000000 00E070BF 00000000 C88B70BF 00000000 8: 40000000 40000100 00000000 00000000 00000000 00000000 00000000 00000000		2

PQI												
18	D	A OQ	Elem	Adm OQ IU	Type	Rsv	Cmp	Len	WA	RQ ID	OP	Status	OQ CI Offset
			0x0000		Adm RSP	0x0	0x0	0x003C	0x0000	1	Create OP OQ	Good	00000000:00001018

Link Tra			TLP								
9561	R←	2.5 x1	537	Mem	MWr(32)	Length	RequesterID	Tag	Address	1st BE	Last BE
					010:00000	16	010:00:0	0	BF70A000	1111	1111

Data	VC ID	Explicit ACK	Metrics
0: E0003C00 00000000 01001100 00000000 18100000 00000000 00000000 00000000 8: 00000000 00000000 00000000 00000000 00000000 00000000 00000000 00000000	0	Packet #18507	

# Packets	Resp. time	Pld. Bytes	Thrpt MB/s
2	2.000 us	64	30.518

PQI				
19	D	A OQ	Admin OQ PI	Index
				0x0001

Link Tra			TLP											
9563	R←	2.5 x1	539	Mem	MWr(32)	Length	RequesterID	Tag	Address	1st BE	Last BE	Data	VC ID	Explicit ACK
					010:00000	1	010:00:0	0	FEE00000	1111	0000	B0400000	0	Packet #18511

Metrics	# Packets	Resp. time	Pld. Bytes	Thrpt MB/s
	2	1.760 us	4	2.167

PQI				
20	D	A IQ	Admin IQ CI	Index
				0x0001

PQI					
21	H	A OQ	Admin OQ CI	Index	RI
				0x0001	0

SCSI command: WRITE (10)

SCSI	SCSI Error
5	Error in SOP Sub-Tra

SCSI CDB	OpCode	WRPROTECT	DPO	FUA	FUA_NV	Obsolete	Logical Block Addr	GROUP NUMBER	Transfer Len	CONTROL
WRITE(10)	0x2A	0x0	Not set	Not set	Not set	Not set	0x000007B0	0x00	8	0x00

Status	LUN
GOOD	0x0

Data

```
  0: 5FC70167 A383C49B 56BF8AE4 D53BC84A BA9D2D50 752FA850 4CF46AFA B336393F B4685E8D 39D8398C 9CBA37A1 15905BF9
 12: BD5CE0AA 785454A1 25115B61 C6AB18A0 154382B3 8D121353 5EF26D40 68ACEED5 AB3F388D 54CE4363 D7226551 51023715
 24: 9FB2D796 C99AA193 A2A920D1 0693C359 5E6B1F7F DD683329 9A45448E ABB3A5C3 61E136CB 3D25496D CB06BE92 FB4DB47B
 36: BA5DA111 A9D34ABA 42338E0B 60251EE2 26D23FB0 711F011A 2F49399C 9B00F80E 8DD8F2B5 CCE3C1D6 BF092162 EC82A733
 48: D89BEE65 B873C6B5 325643B1 7E7F8DDC 9060E7DE 1F36201C 2E6608B2 845A8019 AE4E9E28 6D5EDB62 DADC095C 024F5C0E
 60: C161CB8A 72358C10 253817CD 4A94F037 C5917CF7 ACD60339 DA9CDC14 43FD009C 9A15F979 0B43EE8A 68146E27 9097CE92
 72: 1F1E39D8 1A657C39 8D18EC3C AC169C3B E17E6EAB F27F3C17 17BFED93 BCD79552 EB980A6A 8CD499A9 4EDA3633 2E96B20D
 84: D65FBD76 6B261EC6 8CE33D10 4516CA0C 3C4FC1B5 0224089E 9A07187A EE004BD5 691F88B3 D0EAAAF5 1656BC3B 09AF3E6D
 96: E05ACA0F 5488DE83 359DE82A 2375F906 06035814 9B25574D 5280030A DC39738B 1E4D2D25 5EF67E7E 4E20BB61 083F6D29
108: 20B35970 1B92A508 CBBCF789 AA63E9E4 7798ACB4 1EECE65A 37A17066 BD3B13AD 385DEB4F 79C549EA CE2BB1F8 F3D18355
120: 38010398 5E7DF680 A6669660 CC5474BF 8F124B54 5A068508 F5A763AD AB198A9F ...
```

Metrics	# SOP IUs
	3

SOP	H
15	

Type	Cmp	Rstr	Len	Rsp QID	WA	RQ ID	Data Dir	Partial	Fence	Size	CDB	SGL	Address	Length
Lim Cmd	0x0	0x0	0x003C	0x0001	0x0000	0x002A	Data-Out	0	0	0x00001000	16 bytes		00000000:447CD000	0x00001000

Zero	Type	Address	Length	Zero	Type
0x0	Data Block	00000000:00000000	0x00000000	0x0	Data Block

PQI	H
331	

IQ ID	Elem	Op IQ IU	Rstr	Rstr	Cmp	Len	Data
0x0001	0x0000		0x10	0x0	0x0	0x003C	60 bytes

SOP	H
16	

Tra	Address	Length	Data
15	00000000:447CD000	0x00001000	1024 dwords

SOP	D
17	

1 error(s)	Rsvd not zero	Type	Cmp	Rstr	Len	WA	RQ ID	Nexus ID
Rsvd not zero	Field: Rsvd	Success	0x0	0x0	0x000C	0x0000	0x002A	0x0000

SCSI command: Report LUNS

SCSI	SCSI Error	SCSI CDB	OpCode	SELECT REPORT	AllocLen	CONTROL	Data	Status	LUN	Metrics	# SOP IUs
0	Error in SOP Sub-Tra	REPORT LUNS	0xA0	0x0000	16	0x00	4 dwords	GOOD	0x0		3

SOP	H	Type	Cmp	Rstr	Len	Rsp QID	WA	RQ ID	Data Dir	Partial	Fence	Size	CDB	SGL	Address	Length	Zero
0		Lim Cmd	0x0	0x0	0x003C	0x0003	0x0000	0x0007	Data-Out	0	0	0x00000010	16 bytes		00000000:14281120	0x00000010	0x0

Type	Address	Length	Zero	Type
Data Block	00000000:00000000	0x00000000	0x0	Data Block

PQI	H	IQ ID	Elem	Op IQ IU	Rstr	Rstr	Cmp	Len	Data
53		0x0001	0x0010		0x10	0x0	0x0	0x003C	60 bytes

Split Tra	R←	2.5 x1	Mem	MRd(32)	RequesterID	CompleterID	Tag	TC	VC ID	Address	Status	Data	Metrics	# LinkTras
4638				000:00000	010:00:0	000:00:0	2	0	0	BF711000	SC	16 dwords		2
4643				000:00000	010:00:0	000:00:0	3	0	0	BF711040	SC	16 dwords		2
4919				000:00000	010:00:0	000:00:0	3	0	0	BF711080	SC	16 dwords		2
6950				000:00000	010:00:0	000:00:0	1	0	0	BF7110C0	SC	16 dwords		2
6951				000:00000	010:00:0	000:00:0	2	0	0	BF711100	SC	16 dwords		2
6952				000:00000	010:00:0	000:00:0	3	0	0	BF711140	SC	16 dwords		2
6953				000:00000	010:00:0	000:00:0	0	0	0	BF711180	SC	16 dwords		2
6956				000:00000	010:00:0	000:00:0	2	0	0	BF7111C0	SC	16 dwords		2
6963				000:00000	010:00:0	000:00:0	3	0	0	BF711200	SC	16 dwords		2
6966				000:00000	010:00:0	000:00:0	1	0	0	BF711240	SC	16 dwords		2
6973				000:00000	010:00:0	000:00:0	2	0	0	BF711280	SC	16 dwords		2

SOP	D	Tra	Address	Length	Data
1		0	00000000:14281120	0x00000010	4 dwords

SOP	D	1 error(s)	Rsvd not zero	Type	Cmp	Rstr	Len	WA	RQ ID	Nexus ID
2		Rsvd not zero	Field: Rsvd	Success	0x0	0x0	0x000C	0x0000	0x0007	0x0000

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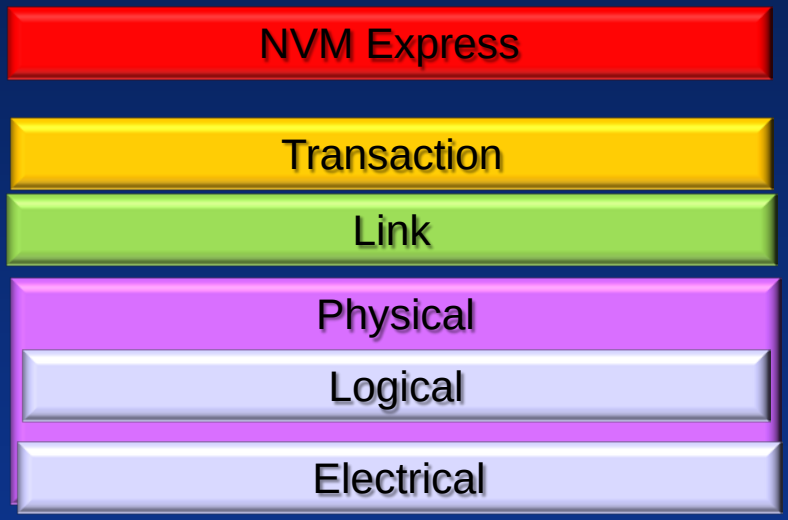
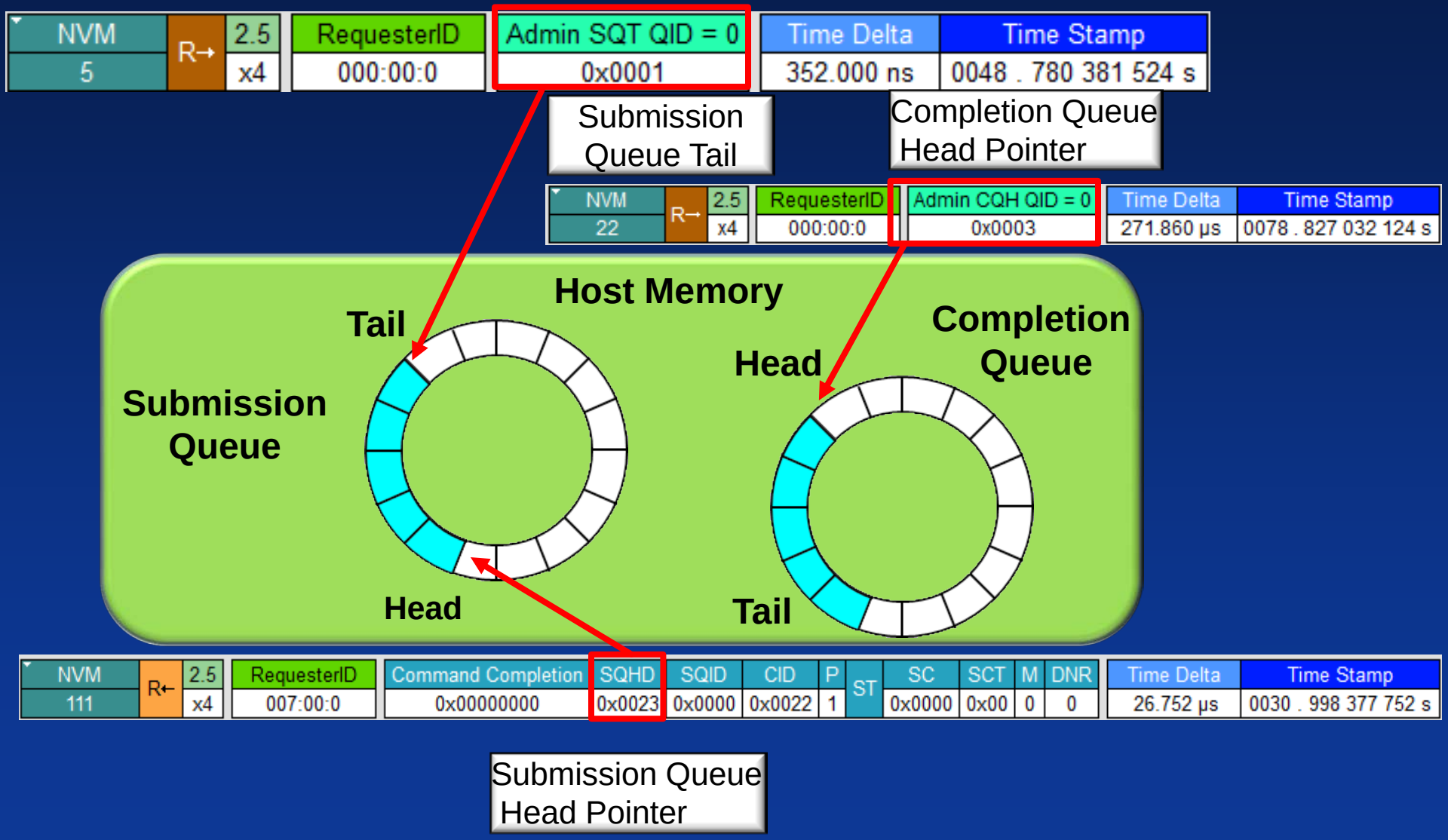
NVM Express

NVM Express

- The NVMHCI Workgroup released the NVM Express 1.0 specification on March 1, 2011 and is available at www.nvmexpress.org
- NVMe is a standardized high performance queuing interface and command set optimized for PCIe SSDs
- NVMe is scalable from client to enterprise applications

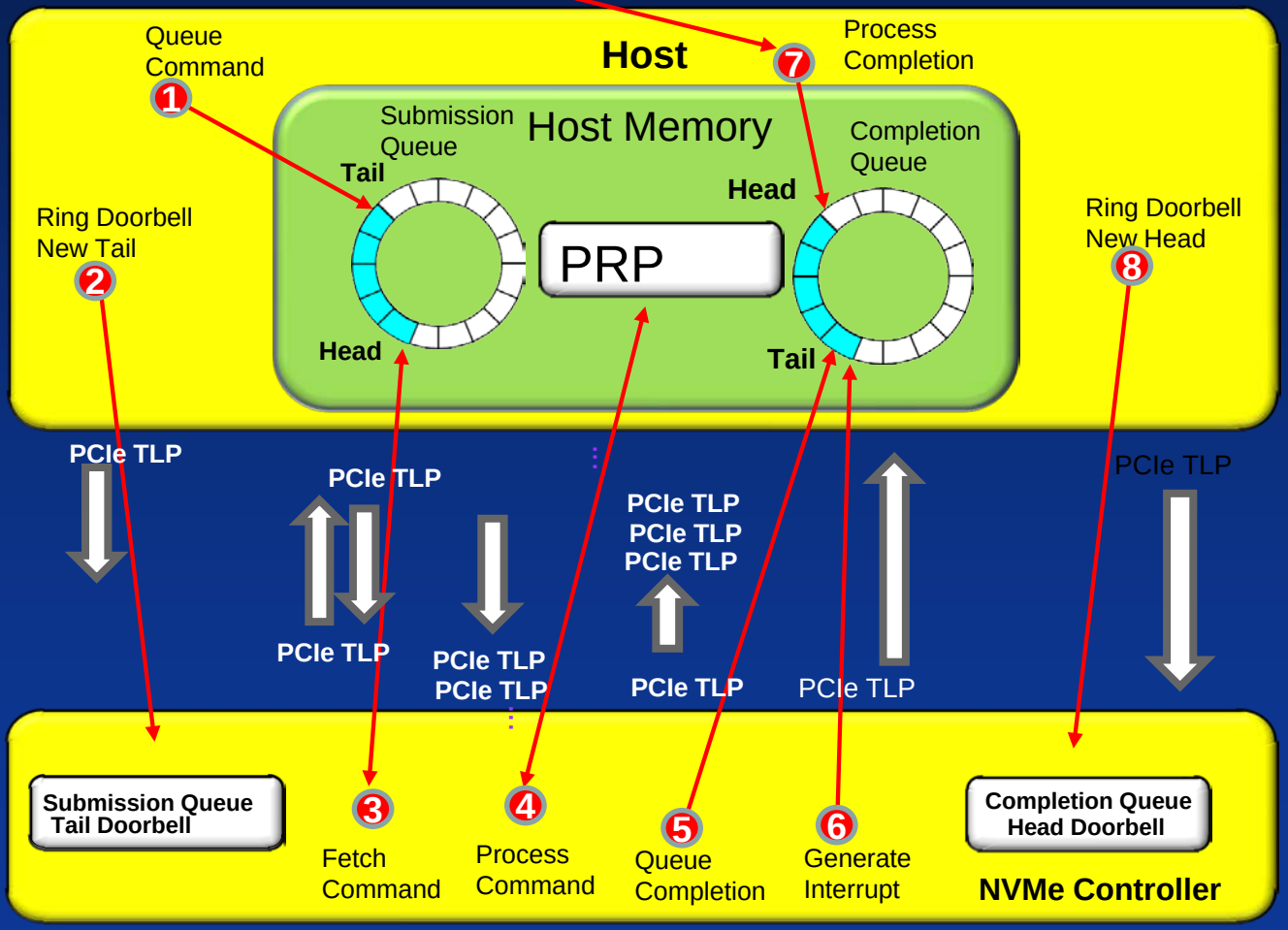


Submission and Completion Queues

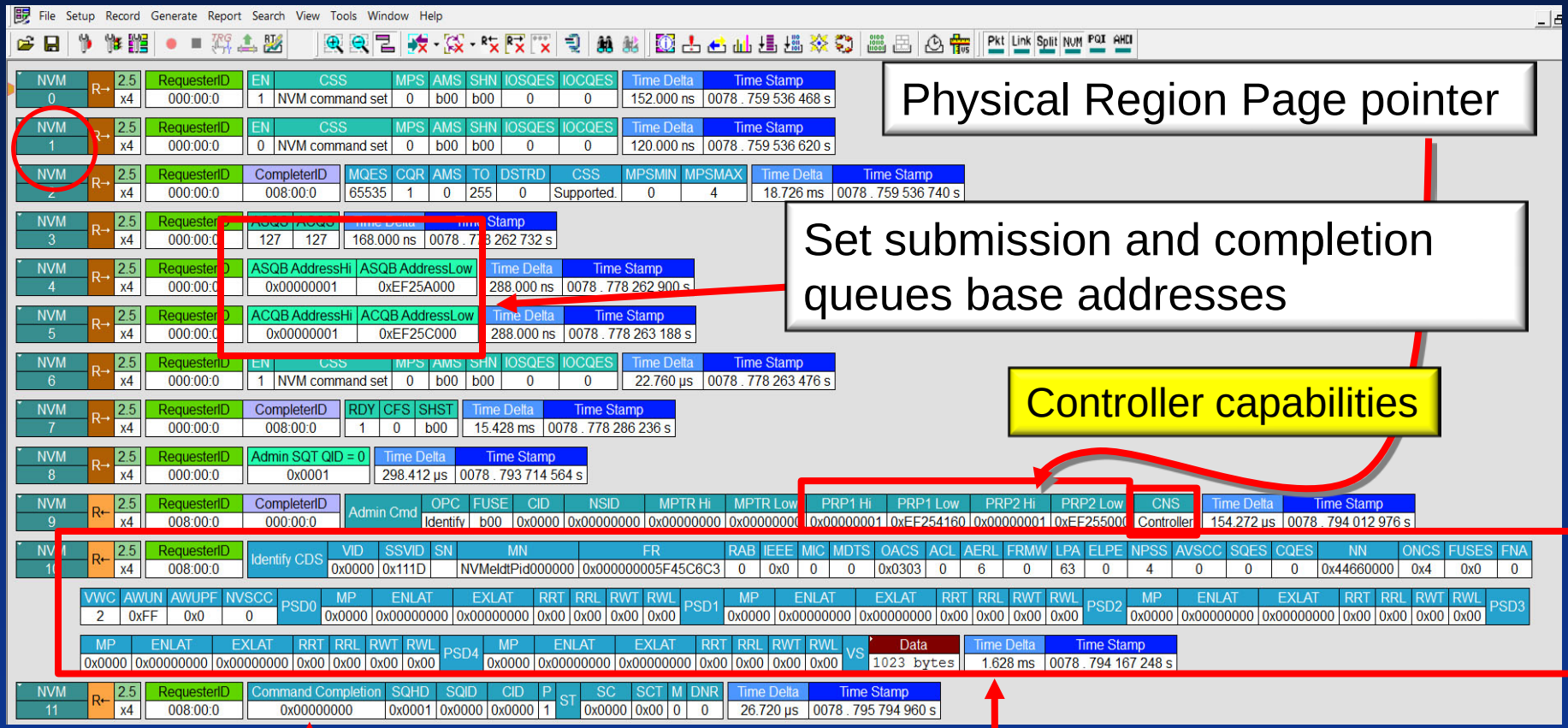


Circular Queuing Interface

NVM			RequesterID	Command Completion	SQHD	SQID	CID	P	ST	SC	SCT	M	DNR	Time Delta	Time Stamp
111	R←	2.5 x4	007:00:0	0x00000000	0x0023	0x0000	0x0022	1		0x0000	0x00	0	0	26.752 µs	0030 . 998 377 752 s



Viewing the NVM Express 1.0c Initialization Phase

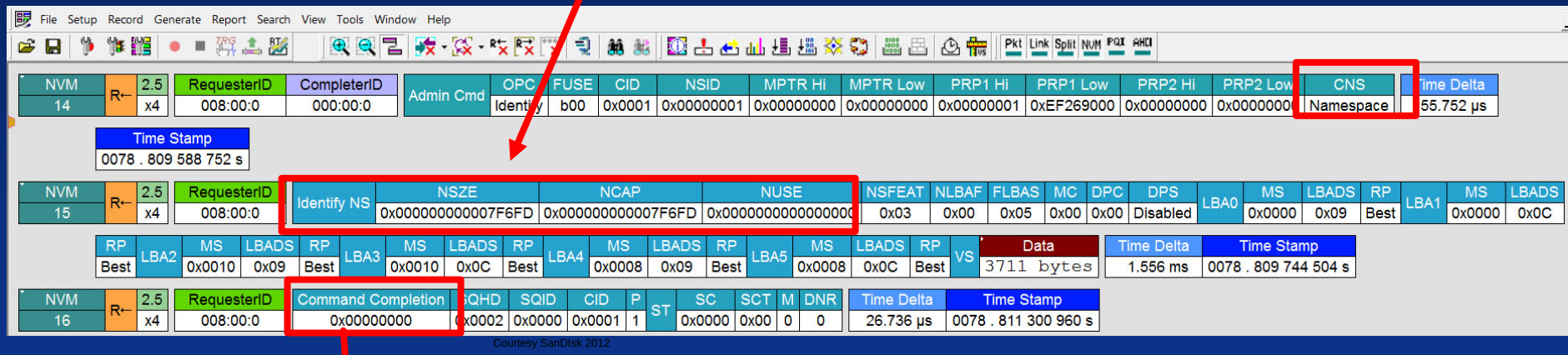


Courtesy SanDisk 2012

Viewing the NVM Express 1.0c

Identify Namespace Capabilities command

Namespace capabilities



Courtesy SanDisk 2012

Command Completion

Viewing the NVM Express 1.0c

Creating an I/O queue and Read command example

Create IO Submission Queue

NVM	R←	2.5	RequesterID	CompleterID	Admin Cmd	OPC	FUSE	CID	NSID	MPTR Hi	MPTR Low	PRP1 Hi	PRP1 Low	PRP2 Hi	PRP2 Low	QSIZE	QID	CQID	QPRIO	PC
150		x4	008:00:0	000:00:0		Create I/O SQ	b00	0x0024	0x00000000	0x00000000	0x00000000	0x00000001	0xEF31A000	0x00000000	0x00000000	1023	3	3	Medium	1

NVM	R←	2.5	RequesterID	Command Completion	SQHD	SQID	CID	P	ST	SC	SCT	M	DNR	Time Delta	Time Stamp
151		x4	008:00:0	0x00000000	0x0025	0x0000	0x0024	1		0x0000	0x00	0	0	26.736 us	0048 [illegible] 517 192 s

Courtesy SanDisk 2012

Physical Region Page pointer

Data Transfer

Command Completion

File Setup Record Generate Report Search View Tools Window Help

NVM	R←	2.5	RequesterID	CompleterID	IO Cmd	OPC	FUSE	CID	NSID	MPTR Hi	MPTR Low	PRP1 Hi	PRP1 Low	PRP2 Hi	PRP2 Low	SLBA	LR	FUA	PRINFO
195		x4	008:00:0	000:00:0		Read	b00	0x0000	0x00000001	0x00000000	0x00000000	0x00000001	0xEED31000	0x00000000	0x00000000	0x00000000:00000000	0	0	0x0

NLB	DSM	Incompressible	SR	AL	AF	EILBRT	ELBAT	ELBATM	Time Delta	Time Stamp
0x0000		0	0	None	None	0x00000000	0x0000	0x0000	163.968 µs	0079 . 553 228 928 s

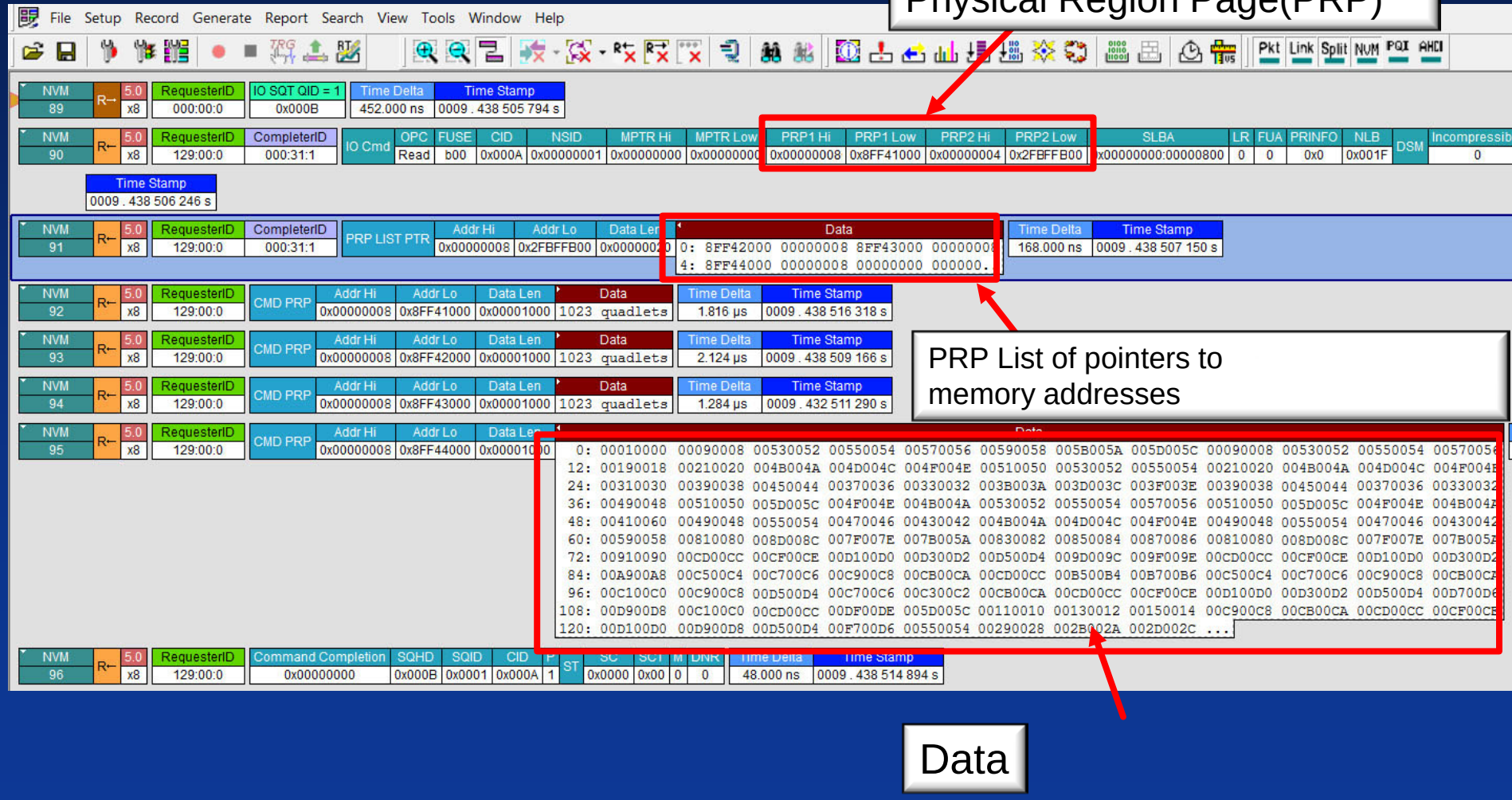
NVM	R←	2.5	RequesterID	CMD PRP	Addr Hi	Addr Lo	Data Len	Data	Time Delta	Time Stamp
196		x4	008:00:0		0x00000001	0xEED31000	0x00000200	127 quadlets	313.872 µs	0079 . 553 392 896 s

NVM	R←	2.5	RequesterID	Command Completion	SQHD	SQID	CID	P	ST	SC	SCT	M	DNR	Time Delta	Time Stamp
197		x4	008:00:0	0x00000000	0x0001	0x0010	0x0000	1		0x0000	0x00	0	0	26.720 µs	0079 . 553 706 768 s

Courtesy SanDisk 2012

Data

Viewing the NVM Express 1.0c NVMe Multiple Pointer Based Transactions



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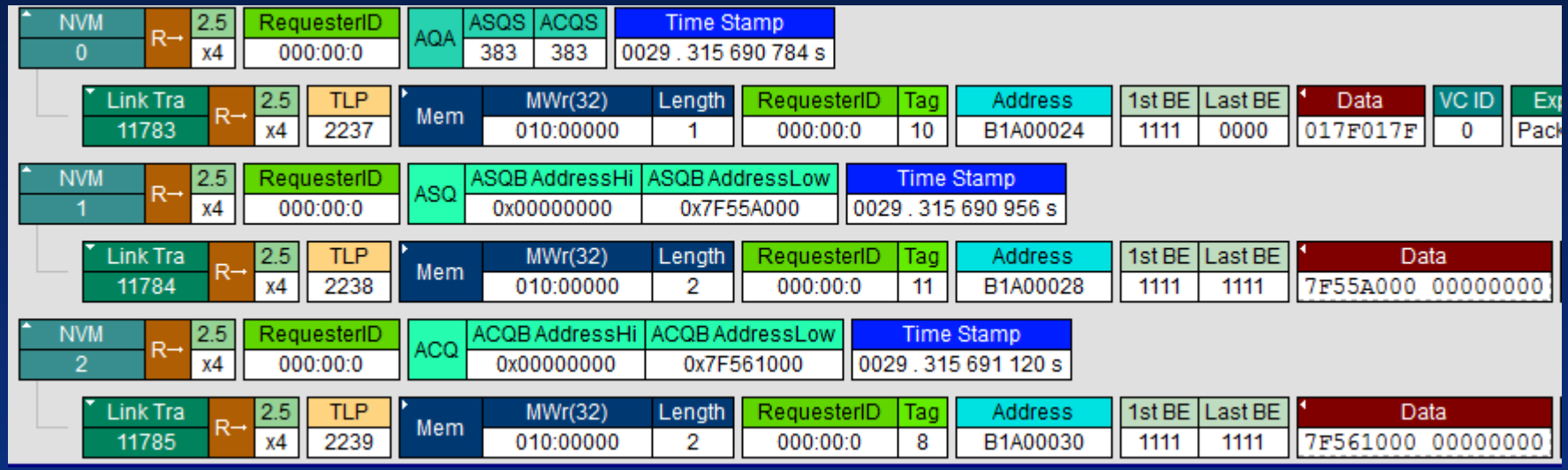
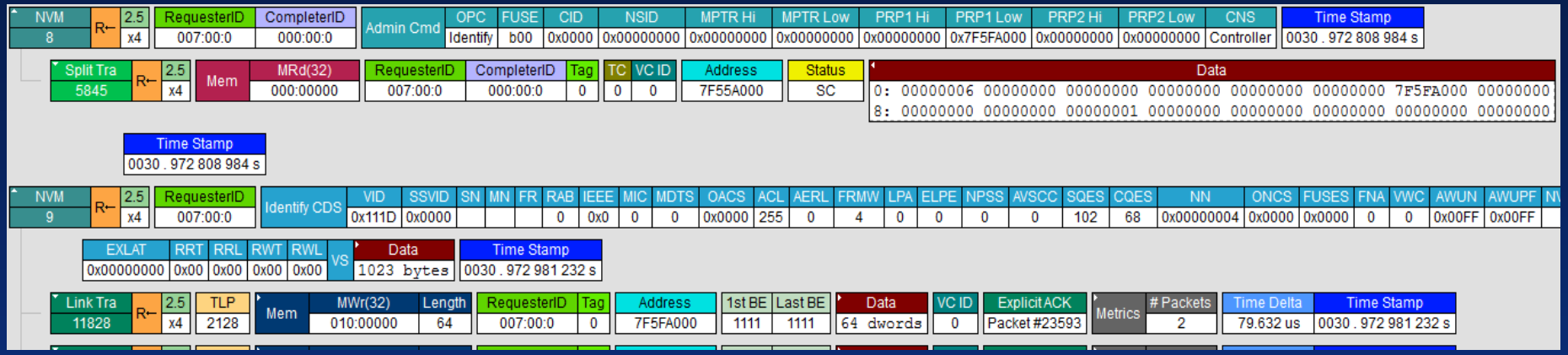
NVMe Device script Submission Queue Setup



| | | |

NVMe Device script Command fetch



- The controller fetches the command(s) in the Submission Queue from host memory
- The Admin submission queue base address register

  0x7F55A000is read from implemented memory resource through field substitution

```
packet = TLP {
    TLPType = MRd64
    Length = 0x10
    RequesterId = (8:0:0)
    Tag = 0x0
    LastDwBe = 0xF
    FirstDwBe = 0xF
    AddressHi = ( FROM_MEM32_A, 0x28 )
                                    # 0x1
    AddressLo = ( FROM_MEM32_A, 0x2C )
                                # 0xEF224000  }
```

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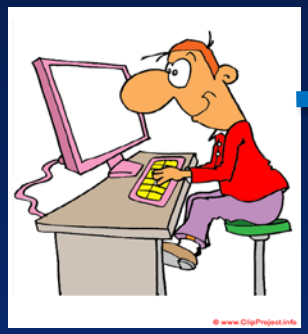
Testing NVM Express

- NVMe Registers emulation
  - Setup Admin Queue
  - Doorbell Registers
- Admin Commands
  - Delete I/O Submission Queue
  - Create I/O Submission Queue
  - Delete I/O Completion Queue
  - Create I/O Completion Queue
  - Get Log Page
  - Identify
  - Abort
  - Set Features
  - Get Features
  - Format NVM
  - Extensible for Vendor Specific Commands

Summit Z3-16 Protocol Exerciser

Pre-Silicon Device emulation



RTL Design

RTL Test Vectors

SimPass

CATC Trace

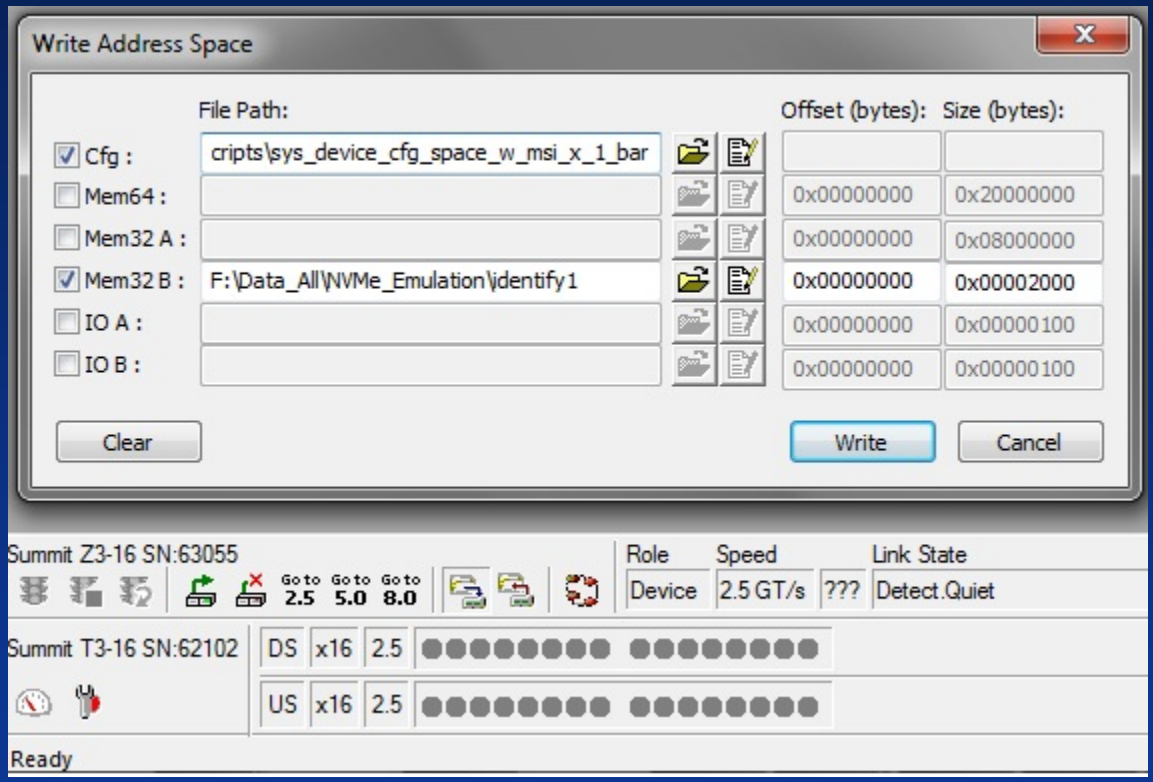
PE Tracer Export to Generation script

Z3 Exerciser Generation Script

Summit Z3

Summit T3

Loading Config Space and Implementing Memory Space



SSD Drive Emulation

NVM		2.5	RequesterID	ASQS	ACQS	Time Delta	Time Stamp
4	R→	x4	000:00:0	127	127	1.464 µs	0199 . 362 722 052 s

NVM		2.5	RequesterID	ASQB AddressHi	ASQB AddressLow	Time Delta	Time Stamp
5	R→	x4	000:00:0	0x00000002	0x3D61B000	2.872 µs	0199 . 362 723 516 s

NVM		2.5	RequesterID	ACQB AddressHi	ACQB AddressLow	Time Delta	Time Stamp
6	R→	x4	000:00:0	0x00000002	0x3D61D000	2.904 µs	0199 . 362 726 388 s

NVM		2.5	RequesterID	EN	CSS	MPS	AMS	SHN	IOSQES	IOCQES	Time Delta	Time Stamp
7	R→	x4	000:00:0	1	NVM command set	0	b00	b00	0	0	34.200 µs	0199 . 362 729 292 s

NVM		2.5	RequesterID	CompleterID	RDY	CFS	SHST	Time Delta	Time Stamp
8	R→	x4	000:00:0	008:00:0	1	0	b00	14.988 ms	0199 . 362 763 492 s

NVM		2.5	RequesterID	Admin SQT QID = 0	Time Delta	Time Stamp
9	R→	x4	000:00:0	0x0001	192.276 µs	0199 . 377 751 104 s

NVM		2.5	RequesterID	CompleterID	Admin Cmd	OPC	FUSE	CID	NSID	MPTR Hi	MPTR Low	PRP1 Hi	PRP1 Low	PRP2 Hi	PRP2 Low	CNS
10	R←	x4	008:00:0	000:00:0		Identify	b00	0x0000	0x00000000	0x00000000	0x00000000	0x00000002	0x3D2DA160	0x00000002	0x3D2DB000	Controller

Time Delta	Time Stamp
1.179 ms	0199 . 377 943 380 s

NVM		2.5	RequesterID	Identify CDS	VID	SSVID	SN	MN	FR	RAB	IEEE	MIC	MDTS	OACS	ACL	AERL	FRMW	LPA	ELPE	NPSS	AVSCC	SQES
11	R←	x4	008:00:0		0x1570	0x1570		NVMeLeCroy000000	0x00000000AD55A46B	0	0x0	0	0	0x0303	0	6	0	63	0	4	0	0

CQES	NN	ONCS	FUSES	FNA	VWC	AWUN	AWUPF	NVSCC	PSD0	MP	ENLAT	EXLAT	RRT	RRL	RWT	RWL	PSD1	MP	ENLAT	EXLAT	RRT	RRL
0	0x44660000	0x1	0x0	0	2	0x0	0x0	0		0x0000	0x00000000	0x00000000	0x00	0x00	0x00	0x00		0x0000	0x00000000	0x00000000	0x00	0x00

RWT	RWL	PSD2	MP	ENLAT	EXLAT	RRT	RRL	RWT	RWL	PSD3	MP	ENLAT	EXLAT	RRT	RRL	RWT	RWL	PSD4	MP	ENLAT	EXLAT	RRT	RRL
0x00	0x00		0x0000	0x00000000	0x00000000	0x00	0x00	0x00	0x00		0x0000	0x00000000	0x00000000	0x00	0x00	0x00	0x00		0x0000	0x00000000	0x00000000	0x00	0x00

RWT	RWL	VS	Data	Time Delta	Time Stamp
0x00	0x00		1023 bytes	663.720 µs	0199 . 379 122 220 s

NVM		2.5	RequesterID	Command Completion	SQHD	SQID	CID	P	ST	SC	SCT	M	DNR	Time Delta	Time Stamp
12	R←	x4	008:00:0	0x00000000	0x0001	0x0000	0x0000	1		0x0000	0x00	0	0	18.232 µs	0199 . 379 785 940 s

Link Tra		2.5	TLP	Mem	MWr(32)	Length	RequesterID	Tag	Address	1st BE	Last BE	Data	VC ID	Explicit ACK	Metrics	# Packets	Time Delta
1965	R←	x4	995		010:00000	1	008:00:0	0	FEE3F00C	1111	0000	1 dword	0	Packet #7599		2	10.420 µs

Time Stamp
0199 . 379 804 172 s

NVM		2.5	RequesterID	Admin CQH QID = 0	Time Delta	Time Stamp
13	R→	x4	000:00:0	0x0001	13.547 ms	0199 . 379 814 592 s

Setting up Controller Registers

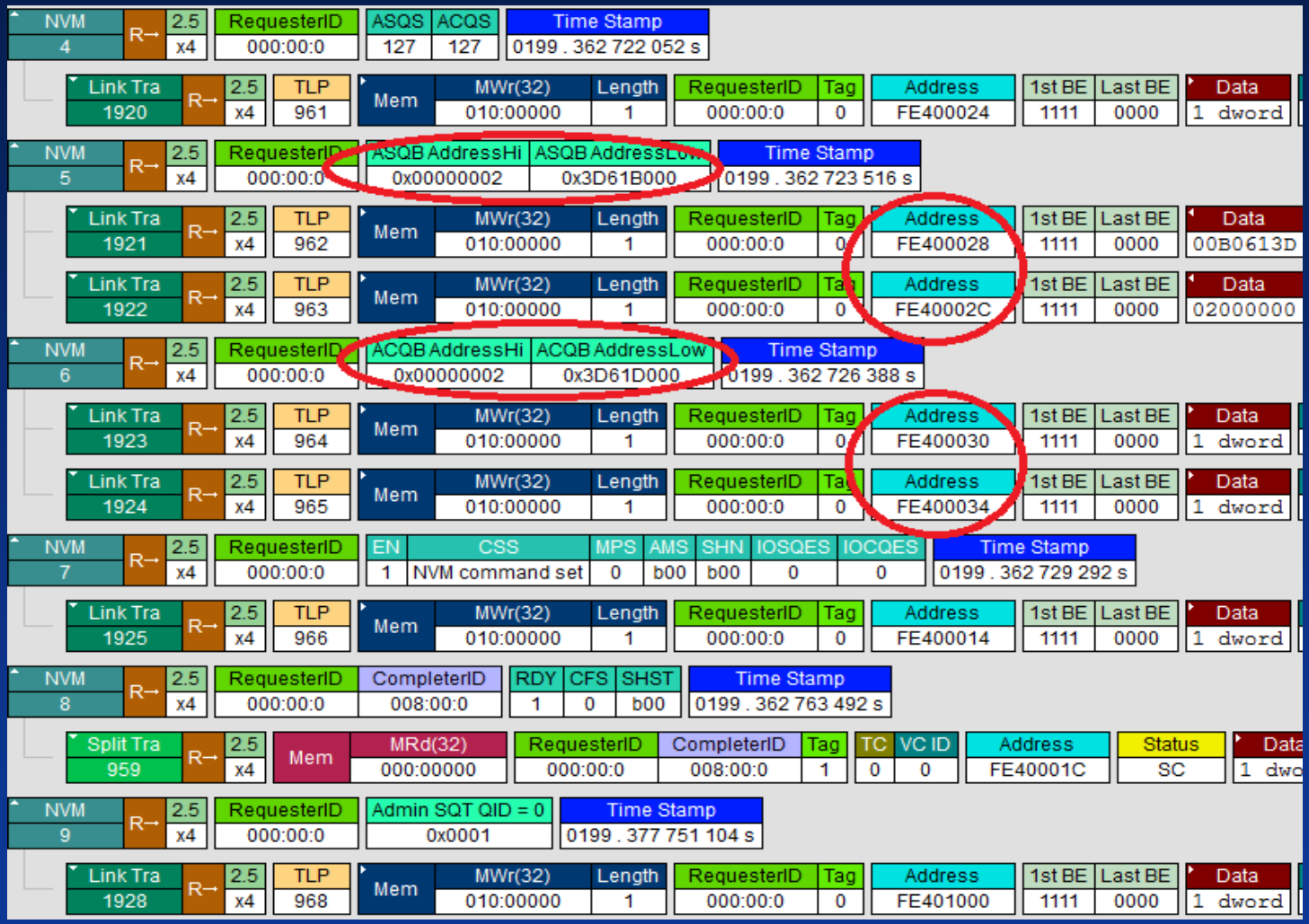
Submission queue size

Submission queue BAR

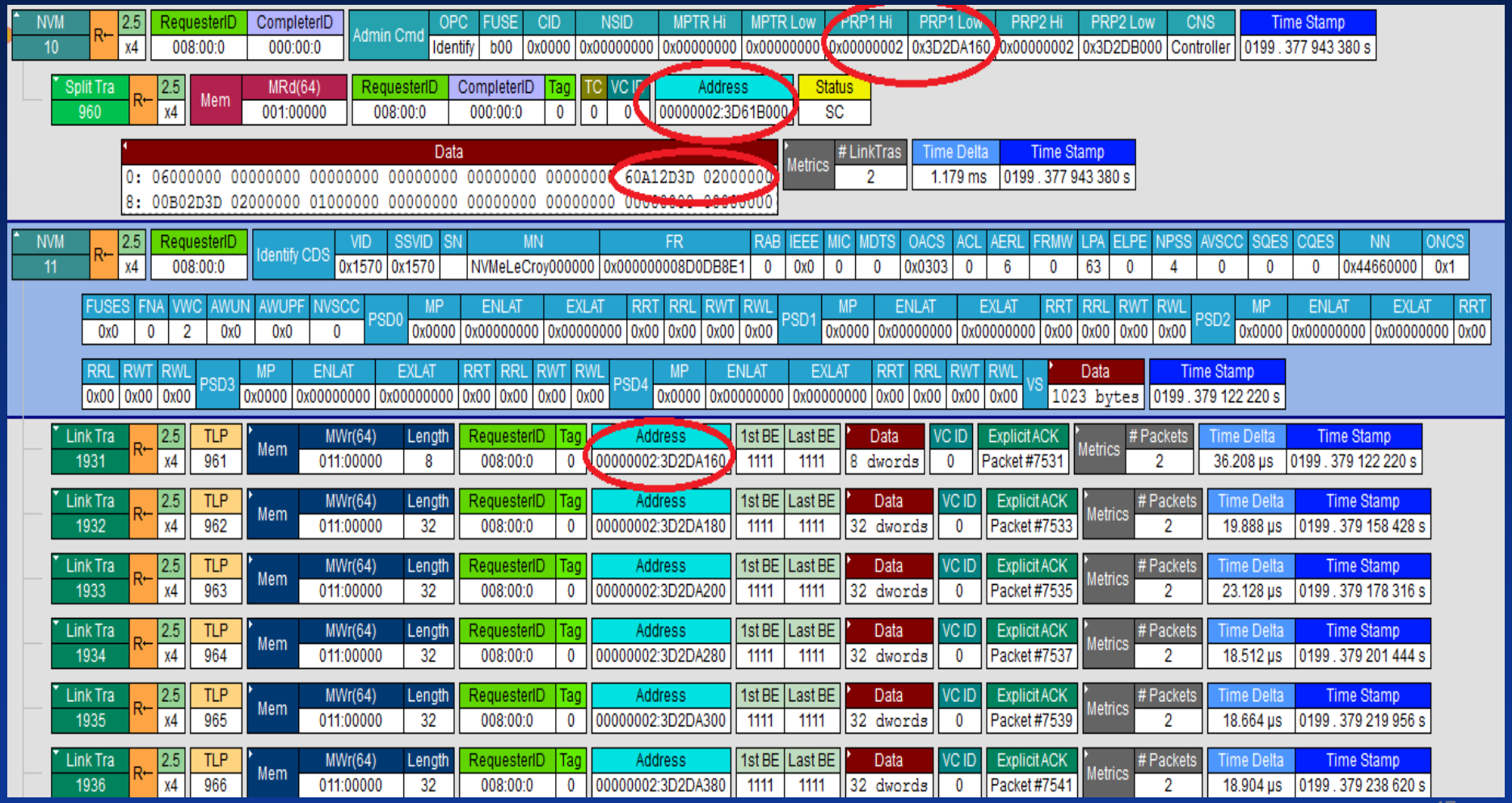
Completion queue BAR

Enable doorbell execution

Submission queue tail doorbell



Identify Command Execution



Identify Command Execution

System Memory command

Address	Data
0x3D61B000	0x3D2DA160

NVMe Controller registers

Register	Address	Data
ASQB	0x28	3D61B000

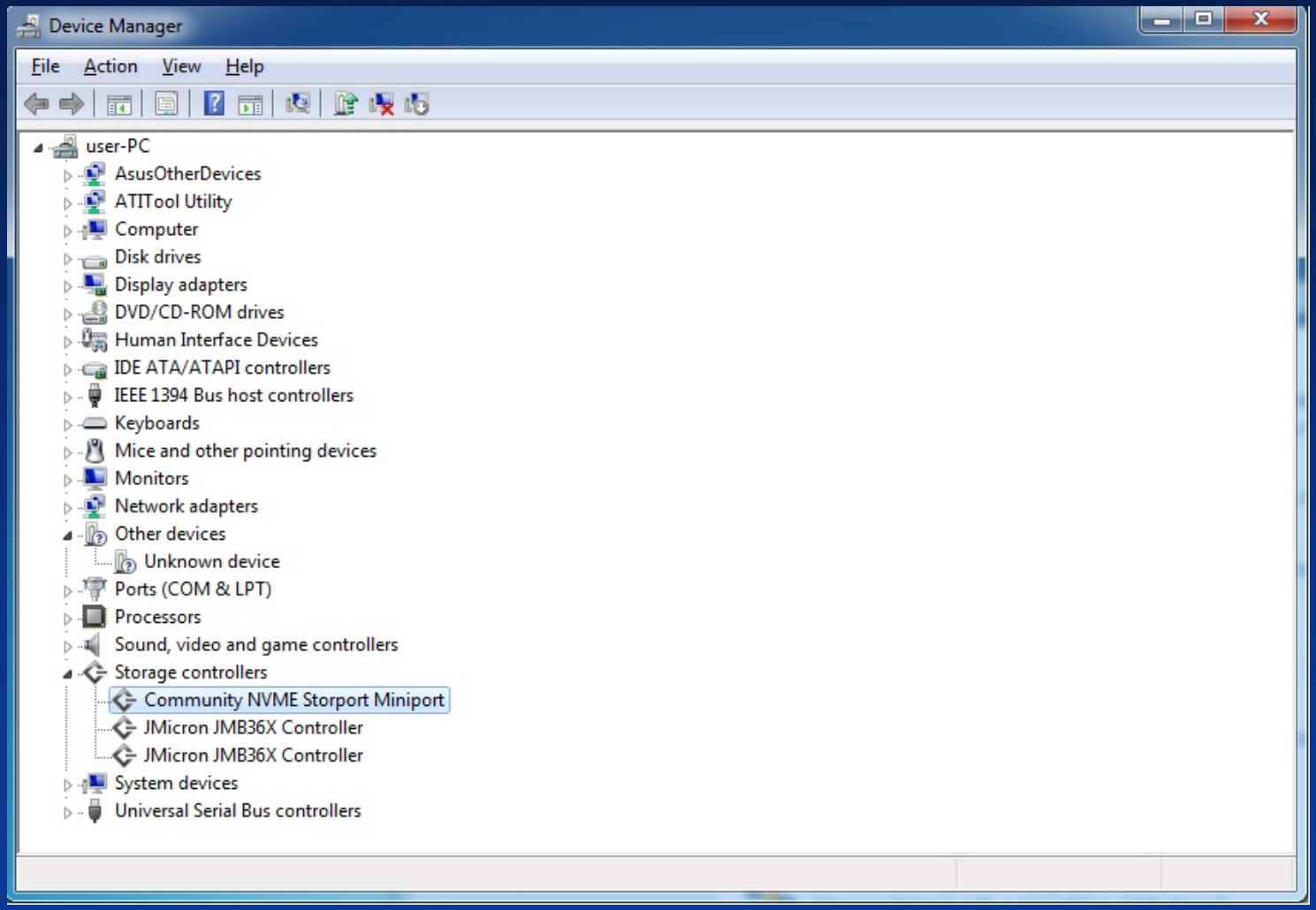
System Memory Data

Address	Data
0x3D2DA160	0x70157015

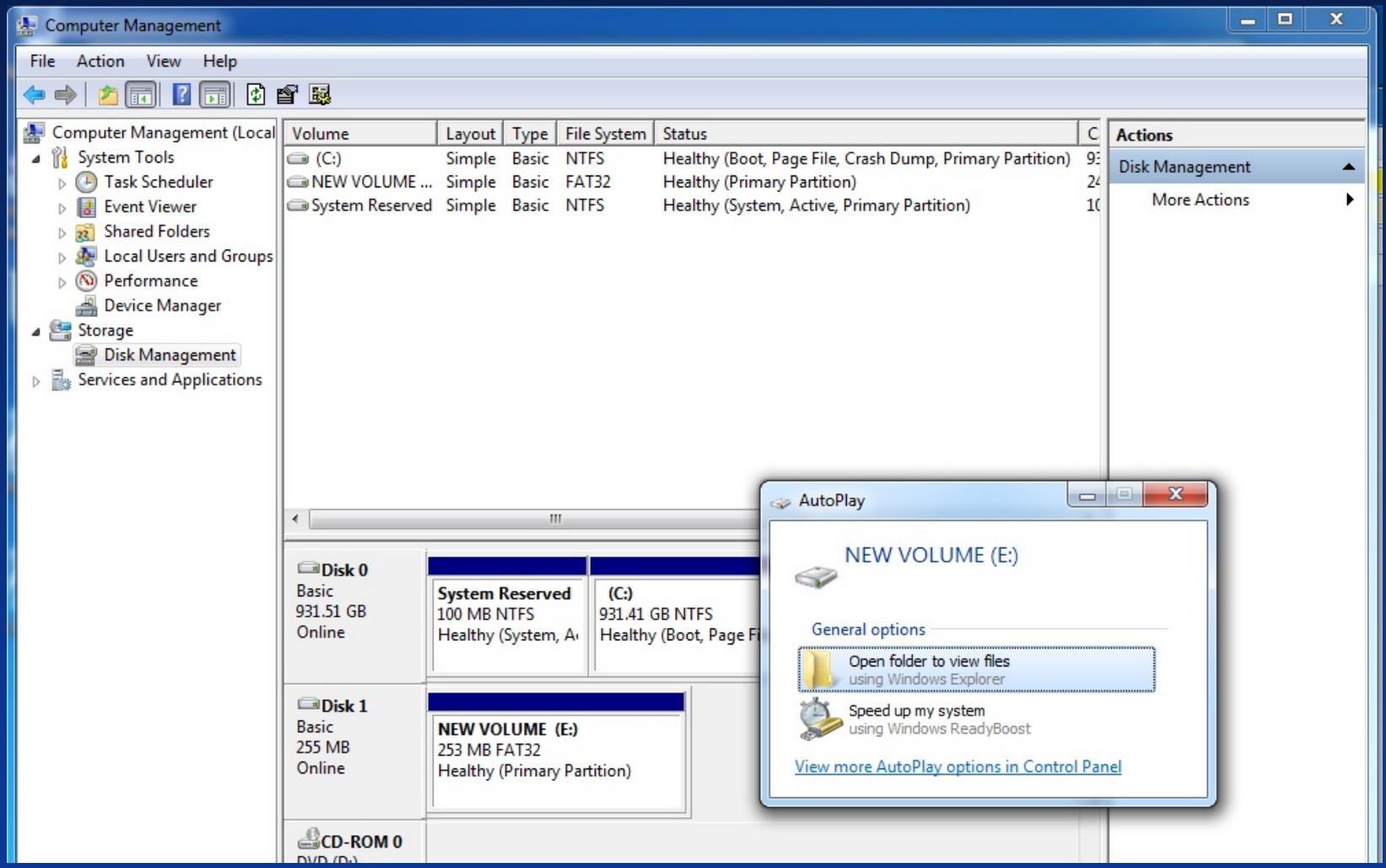
NVMe Device memory space

Address	Data
0x3D61B000	3D2DA160

Emulated NVMe Device Shown in Device Manager



Emulated Drive Shown in Disk Management



Agenda

- Storage over PCI Express® architecture
  - SATA Express / AHCI
  - SCSI Express / SOP – PQI
  - NVM Express
- Command queue generation example
- Emulating an SSD controller
- Emulating an SSD host
- Command Validation

Testing NVM Express

- 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)

Initialization example

; **This script performs basic initialization of an NVMe device**

; Set up BARs;

; Enable bus master, memory space,

set interrupt disable;

; Set Max payload and read request in Device Control;

; Write MSI-X table and enable MSI-X.

```
include="nvme_definitions.peg“
packet="Temp_ConfigWrite0"
{
    Register = 0x10
    Payload = ( BAR0_ADDRESS_FLIPPED )
}
wait=TLP { TLPType = Cpl }
packet="Temp_ConfigWrite0"
{
    Register = 0x14
    Payload = ( 0 )
}
wait=TLP {    TLPType = Cpl }
```

; This script performs NVM specific initialization by writing Controller registers on the device

```
include="nvme_definitions.peg“
; Set ACQS and ASQS in AQA – Admin Queue Attributes register
packet="Temp_OneDwordWrite"
{
Address = ( CONTROLLER_REGISTERS_BASE + 0x24 )
    Payload = ( 7F007F00 )
}
; Set Admin submission Queue address base ASQB high and low . This address corresponds to the base address set for Mem_64 Host region in the generation options file "host_go.gen"

; ASQ – Admin Submission Queue Base Address low
packet="Temp_OneDwordWrite"
{
Address =
( CONTROLLER_REGISTERS_BASE + 0x28 )
 Payload = ( 0080AA2F )  }
```

Exerciser Features for Storage over PCIe validation

- Read completion payload storage for later processing to implement command queuing
- Branch upon write payload and procedure activation to implement doorbell registers
- DMA descriptor implementation and the use of descriptor data through field substitution
- Creation of data structures in emulator memory
- Trace export to generation file with different timing options
- Extraction of configuration file from trace and import to device emulator

Agenda

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Command Validation- NVMe - Generation script

```
include="nvme_start.peg"
; Pre-program command in the Host Memory Region. This is the Mem_64 Host region
; defined in the generation options file "nvme_host_gen_options.gen"
; Command data is copied from the trace taken a the last call
AddressSpace=Write
{
    Location=Mem64
    Offset = 0
    Size = 128
    LoadFrom =
    (0x06 0x00 0x00 0x00  0x00 0x00 0x00 0x00  0x00 0x00 0x00 0x00  0x00 0x00 0x00 0x00
     0x00 0x00 0x00 0x00  0x00 0x00 0x00 0x00  0x90 0xB1 0x25 0x3F  0x08 0x00 0x00 0x00
     0x00 0xC0 0x25 0x3F  0x08 0x00 0x00 0x00  0x01 0x00 0x00 0x00  0x00 0x00 0x00 0x00
     0x00 0x00 0x00 0x00  0x00 0x00 0x00 0x00  0x00 0x00 0x00 0x00  0x00 0x00 0x00 0x00

     0x06 0x00 0x01 0x00  0x01 0x00 0x00 0x00  0x00 0x00 0x00 0x00  0x00 0x00 0x00 0x00
     0x00 0x00 0x00 0x00  0x00 0x00 0x00 0x00  0x00 0xE0 0x47 0x3E  0x02 0x00 0x00 0x00
     0x00 0x00 0x00 0x00  0x00 0x00 0x00 0x00  0x00 0x00 0x00 0x00  0x00 0x00 0x00 0x00
     0x00 0x00 0x00 0x00  0x00 0x00 0x00 0x00  0x00 0x00 0x00 0x00  0x00 0x00 0x00 0x00 )
}               # Identify Controller and Identify Namespace
```

Command Validation- NVMe - Generation script

```
; Write Admin Submission queueTail Doorbell Register
packet="Temp_OneDwordWrite"
{
    Address = ( CONTROLLER_REGISTERS_BASE + 0x1000 )
    Payload = ( 01000000 )
}
; Wait for the Controller to process the command. This will include writing the Identify data,
; writing the Admin completion Queue, and sending the MSI-X interrupt at vector
wait=TLP
{
    TLPType = MWr32
    Address = ADMIN_INT_VECTOR_ADDRESS
}
; Write Admin Completion Queue Head Doorbell Register
packet="Temp_OneDwordWrite"
{
    Address = ( CONTROLLER_REGISTERS_BASE + 0x1004 )
    Payload = ( 01000000 )
}
```

Command Validation- NVMe - Verification script

```
#   Constant definitions

# Test stage definitions, should be sequential
const STAGE_NVME_CONFIG       = 0;
const STAGE_ADMIN_DORBELL_1   = 1;
const STAGE_READ_CMD_1        = 2;
const STAGE_TRANSFER_DATA_1   = 3;
const STAGE_WRITE_CPL_1       = 4;
const STAGE_SEND_INTERRUPT_1  = 5;
const STAGE_ADMIN_DORBELL_2   = 6;
const STAGE_READ_CMD_2        = 7;
const STAGE_TRANSFER_DATA_2   = 8;
const STAGE_WRITE_CPL_2       = 9;
const STAGE_SEND_INTERRUPT_2  = 10;
```

```
#      Variable declarations

set Admin_SQB_Low  = 0;
set Admin_SQB_High = 0;
set Admin_CQB_Low  = 0;
set Admin_CQB_High = 0;
set PRP1_High = 0;
set PRP1_Low  = 0;
set PRP2_High = 0;
set PRP2_Low  = 0;
set Cmd_Dw10  = 0;
set CurrentIdentifyXferredLength = 0;
set TestStage  = 0;
set CurrentChannel = 0;
```

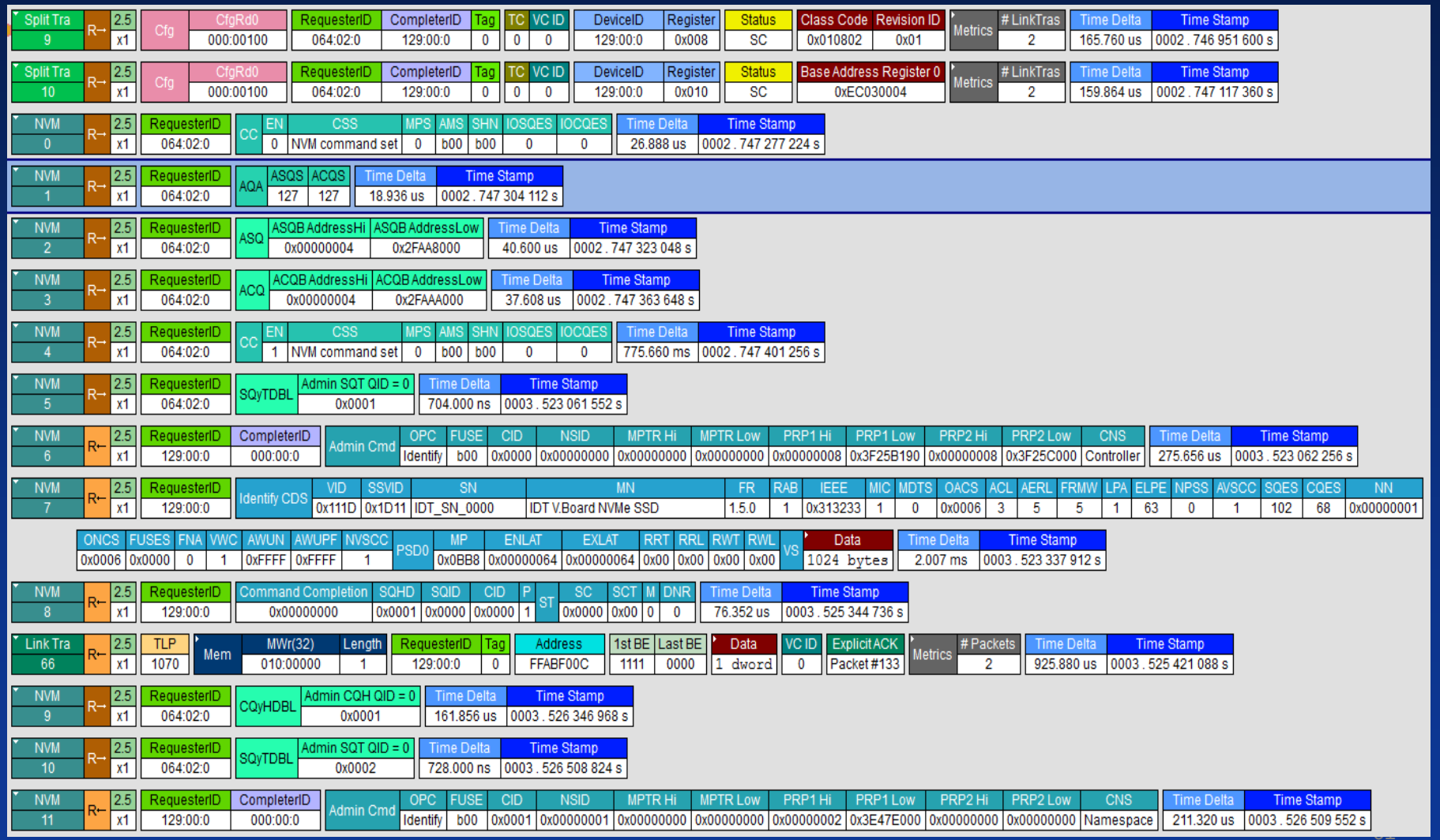
Command Validation- NVMe - Verification script

```
# Function:    OnStartScript()
# Description: The application calls this function at the beginning of the script execution.
OnStartScript()
{    ReportText( "Verifying Identify Command..." );
    SendAllChannels();
    SendLevelOnly( _LINK );
    SendTraceEvent( _LINK_CONFIG );
    SendTraceEvent( _LINK_COMPLETION );
    SendTraceEvent( _LINK_MEMORY );
    Admin_SQB_Low  = 0; # initialize variables
    Admin_SQB_High = 0;
    Admin_CQB_Low  = 0;
    Admin_CQB_High = 0;
    PRP1_High = 0;
    PRP1_Low  = 0;
    PRP2_High = 0;
    PRP2_Low  = 0;
    Cmd_Dw10  = 0;
    CurrentIdentifyXferredLength = 0;
    TestStage  = STAGE_NVME_CONFIG;}
```

Command Validation- NVMe- Verification script

```
# Function:    ProcessEvent()
# Description: Entry point of the script.
#              The application calls this function every time it finds the relevant trace event.
ProcessEvent()
{
    CurrentChannel = in.Channel;
    event_type = in.TraceEvent;
    # transaction status checking
    if( in.TransactionStatus == LINK_TRA_STATUS_INCOMPLETE )
    {
        FailTest( "Transaction wasn't complete at the Link Layer" );
        return null;
    }
    select
    {
        event_type == _LINK_CONFIG      : ProcessCfgRequest();
        event_type == _LINK_COMPLETION  : ProcessCompletion();
        event_type == _LINK_MEMORY      : ProcessMemReadOrWrite();
    };
    return Complete();
}
```

NVMe Command Validation Resulting Trace



Split Tra	R↔	2.5	Cfg	CfgRd0	RequesterID	CompleterID	Tag	TC	VC ID	DeviceID	Register	Status	Class Code	Revision ID	Metrics	# LinkTras	Time Delta	Time Stamp
9		x1		000:00100	064:02:0	129:00:0	0	0	0	129:00:0	0x008	SC	0x010802	0x01		2	165.760 us	0002 . 746 951 600 s
Split Tra	R↔	2.5	Cfg	CfgRd0	RequesterID	CompleterID	Tag	TC	VC ID	DeviceID	Register	Status	Base Address Register 0		Metrics	# LinkTras	Time Delta	Time Stamp
10		x1		000:00100	064:02:0	129:00:0	0	0	0	129:00:0	0x010	SC	0xEC030004			2	159.864 us	0002 . 747 117 360 s

NVM	R↔	2.5	RequesterID	CC	EN	CSS	MPS	AMS	SHN	IOSQES	IOCQES	Time Delta	Time Stamp
0		x1	064:02:0		0	NVM command set	0	b00	b00	0	0	26.888 us	0002 . 747 277 224 s

NVM	R↔	2.5	RequesterID	AQA	ASQS	ACQS	Time Delta	Time Stamp
1		x1	064:02:0		127	127	18.936 us	0002 . 747 304 112 s

NVM	R↔	2.5	RequesterID	ASQ	ASQB AddressHi	ASQB AddressLow	Time Delta	Time Stamp
2		x1	064:02:0		0x00000004	0x2FAA8000	40.600 us	0002 . 747 323 048 s

NVM	R↔	2.5	RequesterID	ACQ	ACQB AddressHi	ACQB AddressLow	Time Delta	Time Stamp
3		x1	064:02:0		0x00000004	0x2FAAA000	37.608 us	0002 . 747 363 648 s

NVM	R↔	2.5	RequesterID	CC	EN	CSS	MPS	AMS	SHN	IOSQES	IOCQES	Time Delta	Time Stamp
4		x1	064:02:0		1	NVM command set	0	b00	b00	0	0	775.660 ms	0002 . 747 401 256 s

NVM	R↔	2.5	RequesterID	SQyTDBL	Admin SQT QID = 0	Time Delta	Time Stamp
5		x1	064:02:0		0x0001	704.000 ns	0003 . 523 061 552 s

NVM	R↔	2.5	RequesterID	CompleterID	Admin Cmd	OPC	FUSE	CID	NSID	MPTR Hi	MPTR Low	PRP1 Hi	PRP1 Low	PRP2 Hi	PRP2 Low	CNS	Time Delta	Time Stamp
6		x1	129:00:0	000:00:0		Identify	b00	0x0000	0x00000000	0x00000000	0x00000000	0x00000008	0x3F25B190	0x00000008	0x3F25C000	Controller	275.656 us	0003 . 523 062 256 s

NVM	R↔	2.5	RequesterID	Identify CDS	VID	SSVID	SN	MN	FR	RAB	IEEE	MIC	MDTS	OACS	ACL	AERL	FRMW	LPA	ELPE	NPSS	AVSCC	SQES	CQES	NN
7		x1	129:00:0		0x111D	0x1D11	IDT_SN_0000	IDT V.Board NVMe SSD	1.5.0	1	0x313233	1	0	0x0006	3	5	5	1	63	0	1	102	68	0x00000001

ONCS	FUSES	FNA	VWC	AWUN	AWUPF	NVSCC	PSD0	MP	ENLAT	EXLAT	RRT	RRL	RWT	RWL	VS	Data	Time Delta	Time Stamp
0x0006	0x0000	0	1	0xFFFF	0xFFFF	1		0x0BB8	0x00000064	0x00000064	0x00	0x00	0x00	0x00		1024 bytes	2.007 ms	0003 . 523 337 912 s

NVM	R↔	2.5	RequesterID	Command Completion	SQHD	SQID	CID	P	ST	SC	SCT	M	DNR	Time Delta	Time Stamp
8		x1	129:00:0	0x00000000	0x0001	0x0000	0x0000	1		0x0000	0x00	0	0	76.352 us	0003 . 525 344 736 s

Link Tra	R↔	2.5	TLP	Mem	MWr(32)	Length	RequesterID	Tag	Address	1st BE	Last BE	Data	VC ID	Explicit ACK	Metrics	# Packets	Time Delta	Time Stamp
66		x1	1070		010:00000	1	129:00:0	0	FFABF00C	1111	0000	1 dword	0	Packet #133		2	925.880 us	0003 . 525 421 088 s

NVM	R↔	2.5	RequesterID	CQyHDBL	Admin CQH QID = 0	Time Delta	Time Stamp
9		x1	064:02:0		0x0001	161.856 us	0003 . 526 346 968 s

NVM	R↔	2.5	RequesterID	SQyTDBL	Admin SQT QID = 0	Time Delta	Time Stamp
10		x1	064:02:0		0x0002	728.000 ns	0003 . 526 508 824 s

NVM	R↔	2.5	RequesterID	CompleterID	Admin Cmd	OPC	FUSE	CID	NSID	MPTR Hi	MPTR Low	PRP1 Hi	PRP1 Low	PRP2 Hi	PRP2 Low	CNS	Time Delta	Time Stamp
11		x1	129:00:0	000:00:0		Identify	b00	0x0001	0x00000001	0x00000000	0x00000000	0x00000002	0x3E47E000	0x00000000	0x00000000	Namespace	211.320 us	0003 . 526 509 552 s

Summary

- Full SCSI and ATA command level storage over PCIe decodes essential to SSDs traffic analysis
- Hierarchical expandable display
- NVM Express, SCSI Express, and SATA Host and Device emulation are now implemented using traditional PCIe exercisers
- Official UNH IOL and NVMe consortium conformance test setup
- Support for SFF8639 and M.2 form factors through dedicated interposers