



Negative Testing

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Topics

- PCI Express[®] Error Capabilities
- Positive Testing
- Negative Testing
- Approaches to Testing
- RAS Capabilities
- Recommendations

PCI Express Error Capabilities

- Error Signaling Messages
 - ✓ Correctable Error (ERR_COR)
 - ✓ **Uncorrectable Fatal (ERR_FATAL)**
 - ✓ Uncorrectable Non-Fatal (ERR_NONFATAL)

- Role-Based Error Reporting
 - ✓ Device Capabilities register

- Advanced Error Reporting (AER) Capability (**optional**)
 - ✓ Mask Registers
 - ✓ Status Registers
 - ✓ Severity Registers
 - ✓ Advanced Error Capabilities and Control Register
 - ✓ Header Log Register
 - ✓ Root Error Command / Status
 - ✓ Identification Register

Positive Error Types

- System Recovers

- Examples
 - ✓ Correctable Error (ERR_COR)
 - Handled by hardware
 - ✓ Uncorrectable Non-Fatal (ERR_NONFATAL)
 - A transaction is considered unreliable but the Link fine
 - Software required

- Side Effects of these types of errors
 - ✓ Performance and latency Issues possible

Negative Error Types

- System is normally brought down

- Examples
 - ✓ Uncorrectable Fatal (ERR_FATAL)
 - Link and related hardware considered unreliable
 - Reset may or may not fix....
 - ✓ Uncorrectable Non-Fatal (ERR_NONFATAL)
 - AER settings?
 - A transaction is considered unreliable but the Link fine
 - Software required

- Side Effects of these types of errors
 - ✓ System Reset

Tools For Error Generation

Common Tools for Error Injection

- Protocol Test Card (PTC)
 - ✓ Used for PCI-SIG Integrator's List
- Exerciser Cards
 - ✓ Many Vendors
- Known “Bad” Card
 - ✓ Cards that are have known errors



Tools For Error Generation

Protocol Test Card for 2.0 (PTC) – 2 different vendors

- Used for PCI-SIG compliance testing
- GUI Interface
- No device driver needed
- Specified in the Link layer Test spec
 - ✓ Bad CRC injection
 - ✓ Replay timer
 - ✓ Replay order
 - ✓ AER capabilities by checking the responses to a config request to an invalid function
- Can be testing in a system or a backplane

Tools For Error Generation

Protocol Test Card for 2.0 (PTC) – cont.

System or a backplane?

- System

- ✓ Advantages

- Can install device driver
- Can use external application through the OS

- ✓ Disadvantages

- If you're in bring-up, OS may not be able to support device
- Bulky (requires a full system (Case, monitor, keyboard...) + Notebook to control PTC)

- Backplane

- ✓ Advantage

- OS is removed can control exact transactions to device
- Very portable (single back plane, only need notebook)
- Resets very quick (no OS and other hardware)

- ✓ Disadvantages

- Can't use any external application
- Can't use your device driver

Tools For Error Generation

- Exerciser Cards
 - ✓ Many Vendors
 - ✓ Allows error injections and Detects Protocol Violations
 - physical, data link and transactional
 - NAK (can be injected as positive testing)
 - incorrect LCRC
 - disparity errors
 - poisoned TLP
 - incorrect LCRC
 - incorrect disparity
 - nullified TLP
 - wrong payload size
 - wrong TLP Digest
 - incorrect ECRC
 - wrong payload size
 - returns abort status
 - sends fatal error message
 - Requester sends nonfatal error message
 - ignores flow control
 -
 - ✓ GUI Interface

Tools For Error Generation

- Known Bad Card
 - ✓ Normally has 1 fixed type of error
 - ✓ Error can change over time
 - Device starts having other issues over time
 - ✓ Not very deterministic
 - Device may get disabled from system
 - Is it a positive test or negative
 - ✓ Is a good real world example

Approaches to Testing

Equipment List

- Hardware (one or more)
 - ✓ Protocol Test Card (PTC)
 - ✓ Exerciser Cards
 - ✓ Known “Bad” Card
 - ✓ Built in
 - Logic that creates the error

- Analyzer
 - ✓ Verify the error is generated
 - ✓ Verify response
 - Did the error get generated correctly
 - System may hang or reboot

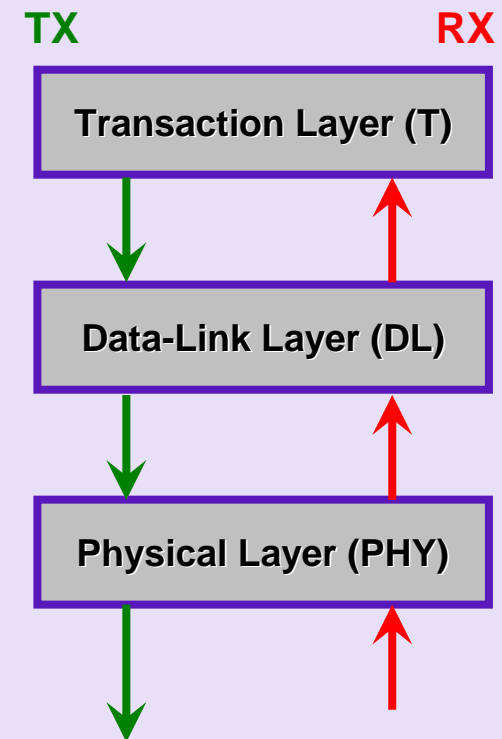


Examples of Error cases

- Correctable
 - ✓ Receiver Error (PHY)
 - ✓ Data Link Errors (*Depends on AER... Error Severity Register and Mask*)
 - Bad TLP (DL)
 - Bad DLLP (DL)
 - Replay Timeout (DL)
 - REPLAY (DL)
 - NUM Rollover (DL)

- Uncorrectable Non-Fatal
 - ✓ Unexpected Completion
 - ✓ Unsupported Request (T)
 - ✓ Completion Abort (T)
 - ✓ Completion Time-out (T)
 - ✓ Poisoned TLP Received (T)
 - ✓ ECRC Failed (T)
 - ✓ Unexpected Completion (T)
 - ✓ ACS Violation (T)

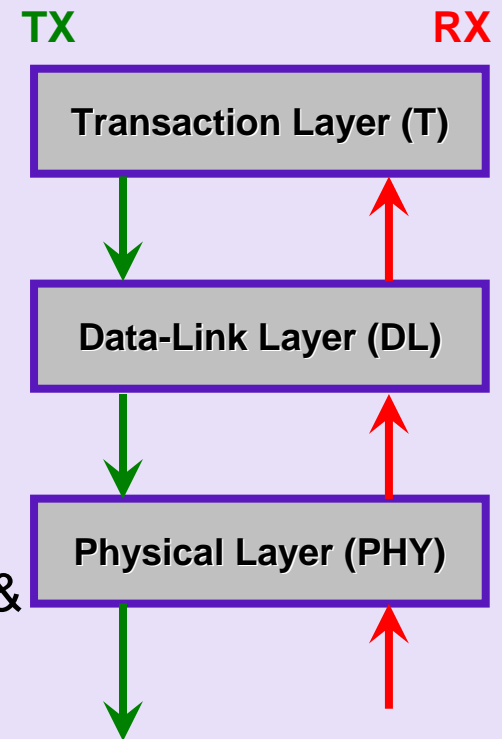
- Uncorrectable **Fatal**
 - ✓ Flow Control Protocol Error (T)
 - ✓ Malformed TLP (T)
 - ✓ Training Error - Undefined (PHY)
 - ✓ DLL Protocol Error (DL)
 - ✓ Receiver Overflow (T)
 - ✓ Surprise Down (DL)



System Error Injection

■ Using Exerciser Cards

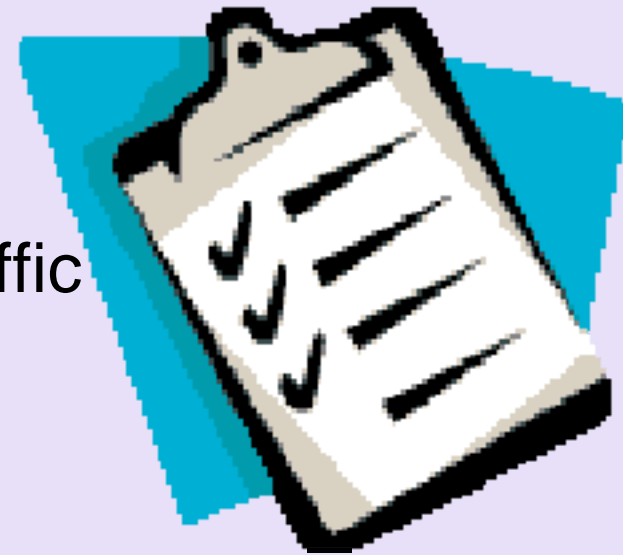
- ✓ What is your System Recovery Plan?
 - Predictive Failures
 - Disable Device
 - Bring System Down
 - Availability, Recovery, Performance Mix
- ✓ What is your reporting / logging plan?
 - Log all errors or just after a threshold
 - When to notify user?
- ✓ Action on errors plan – RAS (Reliability, Availability & Serviceability)?
 - Disable device?
 - Retrain?
 - Ignore?
 - Bring system down?



RAS – Positive Testing

Positive Testing

- System / Device see errors that are correctable
 - ✓ Receiver Error (PHY)
 - ✓ Data Link Errors (**Depends on AER...** *Error Severity Register and Mask*)
 - Bad TLP (DL)
 - Bad DLLP (DL)
 - Replay Timeout (DL)
 - REPLAY (DL)
 - NUM Rollover (DL)
- Injected while doing normal traffic
- Insure that the error...
 - 1. Was injected
 - 2. Is detected
 - 3. Cleared



RAS – Positive Testing

- What to do about consistent errors?
 - ✓ 1. Nothing
 - ✓ 2. Set thresholds
 - ✓ 3. Take device offline

- Correctable errors should be observed over time
 - ✓ When error is seen clear register

- Take Action
 - ✓ Logging
 - After a threshold
 - Identify potential issues

 - ✓ Physical action
 - Reset Link
 - Fail over
 - Change lane width
 - Change lane speed



LCRC Error

+	2054	27.49505731...	688 ns	Completion		F 95	04								FF 8F 07 04
+	2055	27.49505740...	92 ns		Ack	F 95									
+	2056	27.49505769...	292 ns	Memory Write		F 96	00	0 80	Address=00 19 F0 00						A9 AB 7E 93
		StartTag STP (FB)	Sequence Number F 96	Fmt 3DW header, with data (10)	Type Memory Write (00)	Traffic Class 000	TLP Digest Absent (0)	TLP poisoned false (0)	Attr 00	Length 0 80	Requester ID 06 00	Tag 00	Last DW BE 1111	First DW B 1111	
+	2057	27.49505796...	272 ns	Memory Write		F 97	00	0 80	Address=00 19 F2 00						FE 5C 8B B1
+	2058	27.49505804...	76 ns		Nak	F 95									
M2	+	2059	27.49505824...	196 ns	Memory Write		F 98	00	0 80	Address=00 19 F4 00					45 DC 50 80

Record Decode

FB 0F 96 40	Errors = Incorrect LCRC: A9AB7E93, expected 5654816C
00 00 80 06	StartTag = FB
00 00 FF 00	Reserved = 0000
19 F0 00 00	Sequence Number = F 96
00 00 00 00	Reserved = 0
00 00 00 FF	Fmt = 10
FF FF FF FF	Type = 00
FF FF FF 00	Reserved = 0
00 00 00 00	
00 00 00 FF	

Disparity Error

+	2003	87.64006614...	104 ns		Ack	8 BD								
▶	-	2004	87.64006655...	404 ns	2		8 BE	00					Reques	
		StartTag	Sequence Number	Fmt	Type	Routing Mechanism	Traffic Class	TLP Digest	TLP poisoned	Attr	Requester ID	Tag	Message Code	LCF
		STP (FB)	8 BE	3DW/ header, no data (00)	2	Broadcast from Root Complex (011)	000	Absent (0)	false (0)	00	06 00	00	FF	00
T	+	2005	87.64006682...	268 ns	Memory Write		8 BF	00	0 80		Address=00 19 F2 00			Reques
	+	2006	87.64006709...	272 ns	Memory Write		8 C0	00	0 80		Address=00 19 F4 00			Reques
M2	+	2007	87.64006736...	272 ns	Memory Write		8 C1	00	0 80		Address=00 19 F6 00			Reques

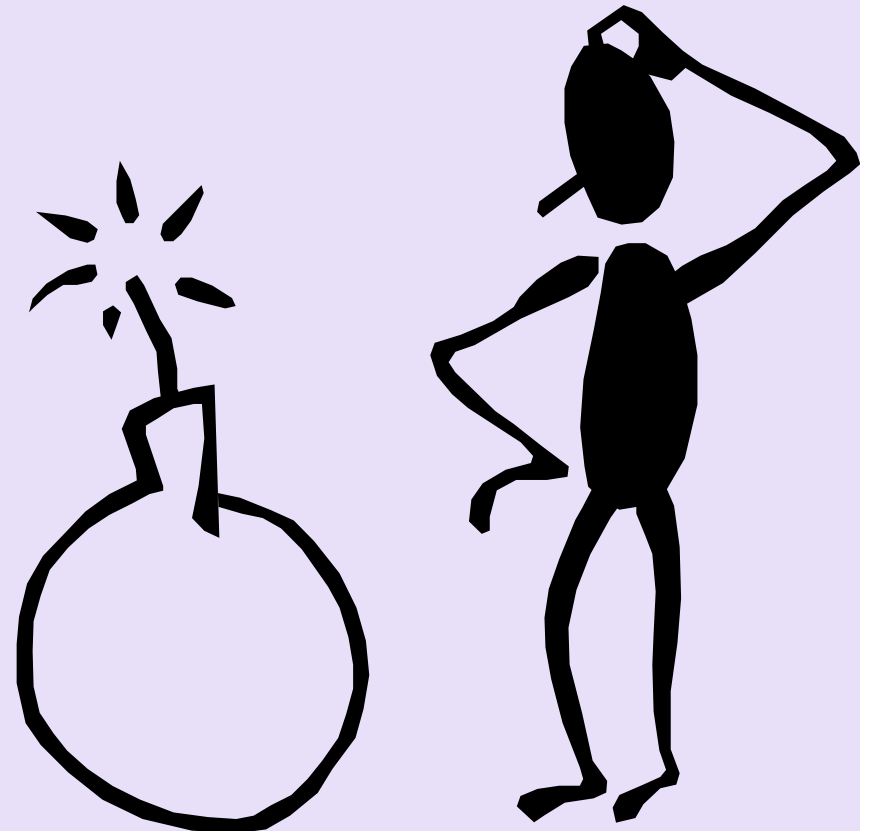
Record Decode

FB 08 BE 13	Errors = Unexpected end of packet, Disparity Error, Undefined TLP Type Error, Undefined TLP Type Error, Length field must be 0 for TLPs without data, Incorrect LCRC: 00
00 00 80 06	StartTag = FB
00 00 FF 00	Reserved = 0000
19 F0 00 00	Sequence Number = 8 BE
00 00 00 00	Reserved = 0
00 00 00 FF	Fmt = 00
FF FF FF FF	Type = 2
FF FF FF 00	Routing Mechanism = 011
00 00 00 00	
00 00 00 FF	

RAS – Negative Testing

Negative Testing – Non-Fatal

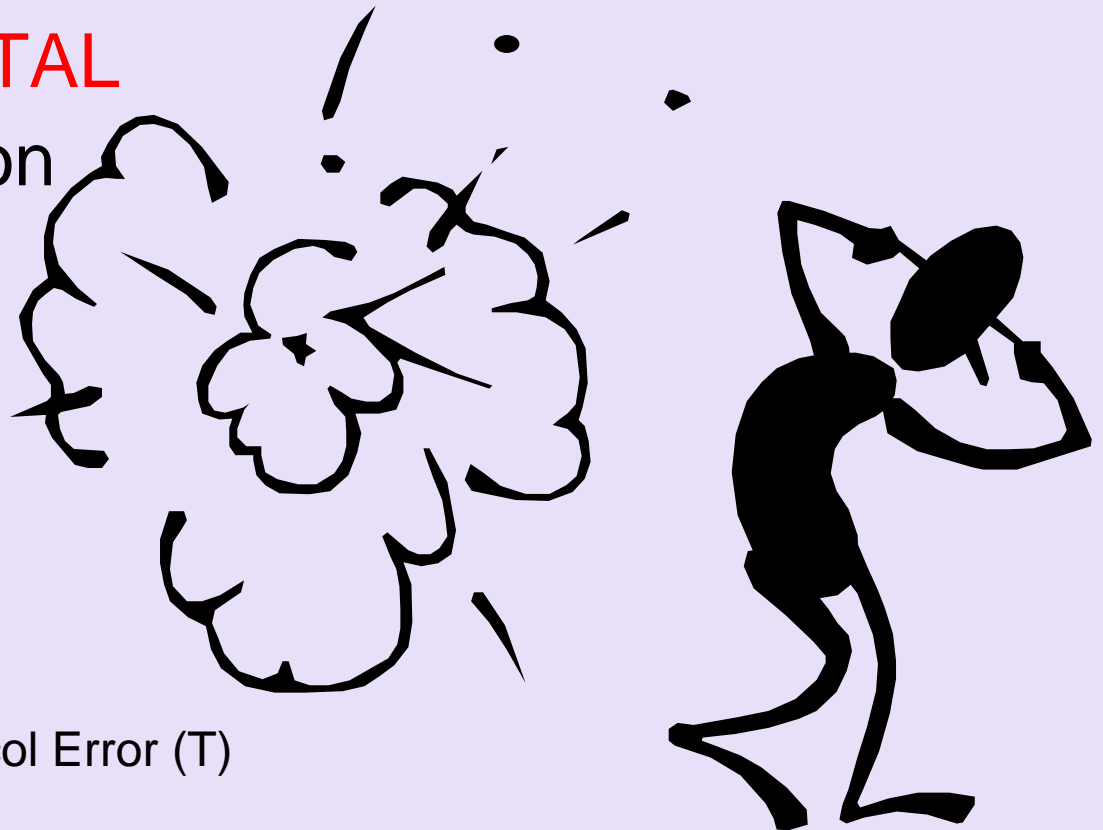
- Expect some action taken
 - ✓ OS hangs
 - ✓ System hangs
 - ✓ Log / LED lights up
- Examples
 - Unexpected Completion
 - Unsupported Request
 - Completion Abort
 - Completion Time-out
 - Poisoned TLP Received
 - ECRC Failed



RAS – Negative Testing

Negative Testing – **FATAL**

- Expect extreme action
 - ✓ Failover
 - ✓ System Reboot
 - ✓ System hang
- Examples
 - ✓ Negative Testing
 - Examples
 - Flow Control Protocol Error (T)
 - Malformed TLP (T)
 - Training Error (P)
 - DLL Protocol Error (DL)
 - Receiver Overflow (T)



Poison TLP

Record No	Timestamp	Rel. Time...	103/1:Down...	103/1:Upstream: ...	Sequenc...	Tag	Length	Address,RegisterNu...	Completion Status	Requester ID,Com...																												
2024	9.583770316 s	104 ns		Ack	F 26																																	
2025	9.583774916 s	4.600 us		Config Write Type 0	2 01	04	0 01	Register Number=38		Requester ID=05 00 Completer ID=06 00																												
2026	9.583776260 s	1.344 us		Ack	2 01																																	
2027	9.583776956 s	696 ns		Completion	F 27	04			SC (Successful ...	Requester ID=05 00 Completer ID=06 00																												
2028	9.583777060 s	104 ns		Ack	F 27																																	
Tr 2029	9.583777292 s	232 ns		Memory Write	F 28	00	0 80	Address=05 C0 60 00		Requester ID=06 00																												
<table border="1"> <thead> <tr> <th>StartTag</th> <th>Sequence Number</th> <th>Fmt</th> <th>Type</th> <th>Traffic Class</th> <th>TLP Digest</th> <th>TLP poisoned</th> <th>Attr</th> <th>Length</th> <th>Requester ID</th> <th>Tag</th> <th>Last DW BE</th> <th>First DW BE</th> <th>Add</th> </tr> </thead> <tbody> <tr> <td>STP (FB)</td> <td>F 28</td> <td></td> <td>3DW header, with data (10) Memory Write (00)</td> <td>000</td> <td>Absent (0)</td> <td>true (1)</td> <td>00</td> <td>0 80</td> <td>06 00</td> <td>00</td> <td>1111</td> <td>1111</td> <td>05 C</td> </tr> </tbody> </table>											StartTag	Sequence Number	Fmt	Type	Traffic Class	TLP Digest	TLP poisoned	Attr	Length	Requester ID	Tag	Last DW BE	First DW BE	Add	STP (FB)	F 28		3DW header, with data (10) Memory Write (00)	000	Absent (0)	true (1)	00	0 80	06 00	00	1111	1111	05 C
StartTag	Sequence Number	Fmt	Type	Traffic Class	TLP Digest	TLP poisoned	Attr	Length	Requester ID	Tag	Last DW BE	First DW BE	Add																									
STP (FB)	F 28		3DW header, with data (10) Memory Write (00)	000	Absent (0)	true (1)	00	0 80	06 00	00	1111	1111	05 C																									
2030	9.583777564 s	272 ns		Memory Write	F 29	00	0 80	Address=05 C0 62 00		Requester ID=06 00																												
2031	9.583777652 s	88 ns		Ack	F 28																																	
2032	9.583777836 s	184 ns		Memory Write	F 2A	00	0 80	Address=05 C0 64 00		Requester ID=06 00																												
2033	9.583777924 s	88 ns		Ack	F 29																																	
2034	9.583778108 s	184 ns		Memory Write	F 2B	00	0 80	Address=05 C0 66 00		Requester ID=06 00																												

RAS – Negative Testing

- Negative Testing can't be combined with other testing
- Must insure that error reporting and logging is correct
 - ✓ Is device reporting correct error?
 - ✓ Is the system identifying the correct error?
 - ✓ Correct Device?
 - ✓ Action taken correct?
 - Insure no data issues
- Take Action
 - ✓ Logging
 - Identify exact issue
 - Identify exact device
 - ✓ Physical action
 - OS hang (kernel panic, blue Screen, etc...)
 - System Hang
 - LED lights up



RAS Take Action / Recovery...

- Change Link Speed and Width?
 - ✓ Dynamic **link speed management** allows developers to control the speed at which the link is operating
 - Requires both system and device to insure capabilities and reporting
 - ✓ Link bandwidth **notification alerts** platform software (operating system, device drivers, etc) of changes in link speed and width
 - Gives you verification points and enhanced RAS

- Is this required?



RAS Take Action / Recovery...

- New card and system Interoperability REQUIREMENT
 - ✓ Allowed → now required
- All PCI Express add-in cards **must be able to negotiate and operate in all smaller Link widths** from the full Link width down to x1. The x2 and x12 Link widths are optional.
- The upstream PCI Express components **on a system board must be able to negotiate and operate in all smaller Link widths** from the full Link width down to x1. The x2 and x12 Link widths are optional.

CEM Spec 2.0

Table 6-2: Card Interoperability

Connector Card	x1	X4	X8	x16
x1	Required	Required	Required	Required
x4	No	Required	Required	Required
x8	No	No	Required	Required
x16	No	No	No	Required

RAS Take Action / Recovery...

Where do you check or handle for speed?

- Link Capabilities Register
 - ✓ Supported Link Speeds
 - ✓ Maximum Link Width

- Link Status Register
 - ✓ Current Link Speed
 - ✓ Negotiated Link Width
 - ✓ Link Bandwidth Management Status
 - ✓ Link Autonomous Bandwidth Status

- Link Control Register
 - ✓ Retrain Link bit
 - ✓ Link Disable

- Link Control 2 Register
 - ✓ Target Link Speed



RAS Take Action / Recovery...



Slot Width

- Link Capabilities Register
 - ✓ Maximum Link Width

- Link Status Register
 - ✓ Negotiated Link Width
 - ✓ Link Bandwidth Management Status
 - ✓ Link Autonomous Bandwidth Status (covers width too)

- Link Control Register
 - ✓ Retrain Link bit
 - ✓ Link Disable

- **Set Link Width???**

RAS - Recommendations

- Build in error injection in your product, if you can
- Make sure you use an analyzer
 - ✓ For Error generation
 - ✓ For Responses
- Make sure you can handle errors
 - ✓ Threshold
 - ✓ Logging
 - ✓ Reporting
- Try to correct the problem if possible
 - ✓ Change the speed
 - ✓ Change the width

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