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SFP+ Interoperability Demonstration White Paper

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Introduction and Background

In April 2008, Ethernet Alliance members AMCC, Avago Technologies, Broadcom, ClariPhy, Cortina Systems, ExceLight Communications, Finisar, Gennum, Inphi, Intel, JDSU, MergeOptics, NetLogic Microsystems, Opnext and Vitesse successfully conducted multi-vendor interoperability testing of SFP+ 10GBASE-SR and 10GBASE-LR optical interfaces. This white paper provides additional detail about the testing setup, procedure and test results.

Testing was held at the UNH-IOL by the Ethernet Alliance SFP+/EDC subcommittee. The testing demonstrated multiple SFP+ SR and LR optical transceivers and PHY ICs interoperating over 270 meters of OM3 multimode fiber and 10 km of single-mode fiber. In addition, the group examined multiple SFP+ SR and LR optical transceivers and PHY ICs interoperating with XENPAK, X2, and XFP over the same distances. These tests were successful and demonstrated that SFP+ optical interfaces are robust and ready for market.

Physical-layer IC participants	Optical module participants
AMCC	Avago Technologies
Broadcom	ExceLight/Sumitomo
ClariPhy	Finisar
Cortina Systems	Intel
Gennum	JDSU
Inphi	MergeOptics
NetLogic Microsystems	Opnext
Vitesse	

Table 1—Testing Applicants of Participants

SFP+ Background

SFP+ modules are hot-pluggable, small-footprint optical transceivers. SFP+ interfaces offer the smallest, lowest-power solution for 10 Gigabit Ethernet, enabling increased density in enterprise and data center applications. SFP+ modules and PHY ICs are being developed for SR, LR, LRM and ER optical reaches per IEEE Std.

802.3ae™-2002 and IEEE Std. 802.3aq™-2006. Electrical and mechanical specifications for SFP+ modules, direct attach cables, and hosts are under definition by the SFF Committee, a multi-source agreement group with broad industry participation.

Test Plan

The purpose of the event was to demonstrate interoperability, as opposed to compliance –the test plan reflects this guiding philosophy. The event focused on transmission testing to demonstrate interoperability between available components over representative optical and electrical channels. In keeping with the intent of the demonstration, the reference electrical and optical channels and the overall environment were chosen to reflect a realistic case that might be encountered in field installations, as opposed to a best or worst case . Limited testing was done to measure parametric performance relative to the SFP+ specifications or IEEE standards; participants were expected to complete testing on their own prior to the event. The combination of worst case PHY and reference-board channels may have resulted in some cases exceeding the SFP+ specifications. Instead, several questions were addressed when developing the test plan.

Which reaches/PMDs to test?

Due to time constraints and the relative maturity of the solutions, the group chose to limit the testing to IEEE SR and LR. Testing of LRM and copper direct attach solutions are planned for a subsequent SFP+ interoperability demonstration.

Which host PHY configuration to test?

Most SFP+ host designs are implemented using a PHY IC as a front end device located after the SFP+ electrical host connector. We tested this configuration using an EDC function linear interfaces but is also beneficial for limiting interfaces as well.

Which test cases to test?

Considering the large number of potential transmit and receive PHY-optics combinations[1], some amount of simplification was done to the test matrix to ensure a practical set of tests. The overall test matrix was split into two separate sub-matrices: first, a worst-case transmitter component combination was selected for both SR and LR, then worst-case combinations were used as reference transmitters for the subsequent interoperability testing, in conjunction with a full matrix of receive component combinations. The worst-case SR and LR transmitter sub-matrices may have violated SFP+ and IEEE802.3ae specifications, but in the spirit of plug fest, the worst case transmitter combination was selected as the source.

The test plan is outlined below; details are given in the following section.

- *Test 0: Calibration of PHY electrical output*
  In this step, each PHY participant had the opportunity to adjust the PHY transmit pre-emphasis settings to optimize the electrical transmit output at the end of the reference electrical channel (1.6" of FR4).

- *Test 1: Optical transmitter characterization and selection*
  Using the pre-emphasis settings from Test 0, various combinations of PHYs and optics were characterized for their optical output waveform (eye mask) in order to select worst-case transmitter combinations for use in Test 2.

- *Test 2: Interoperability between SFP+ PHYs and optics*
  Using the worst-case transmitter combinations from Test 1 as reference transmitters, transmission testing was conducted to demonstrate interoperability over a reference optical and electrical channel with a comprehensive combination matrix of PHYs and optics on the receive side.

- *Test 3: Interoperability with other module form factors*
  In many cases, SFP+ optical interfaces are expected to interoperate with other types of optical interfaces in the field, particularly in the early years of SFP+ deployment. With this in mind, Test 3 demonstrated interoperability between SFP+ and other XENPAK, X2, and XFP.

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[1]Considering **m** possible PHY participants and **n** optical module participants, the number of transmitter tests grows according to the formula **m*n**. For full interoperability with all possible combinations on both transmitter and receiver side, the number of tests grows as **((m-1)*n)*(m*(n-1))**. This quickly adds up to an impractical number of test cases; for instance, in the actual case of 8 PHY participants and 7 optical module participants, the number of test cases, considering only one electrical reference channel and one optical reference channel for each of the two standards tested, the total number of test cases would be 4704. At approximately fifteen minutes per test including setup time, this is clearly not practical.

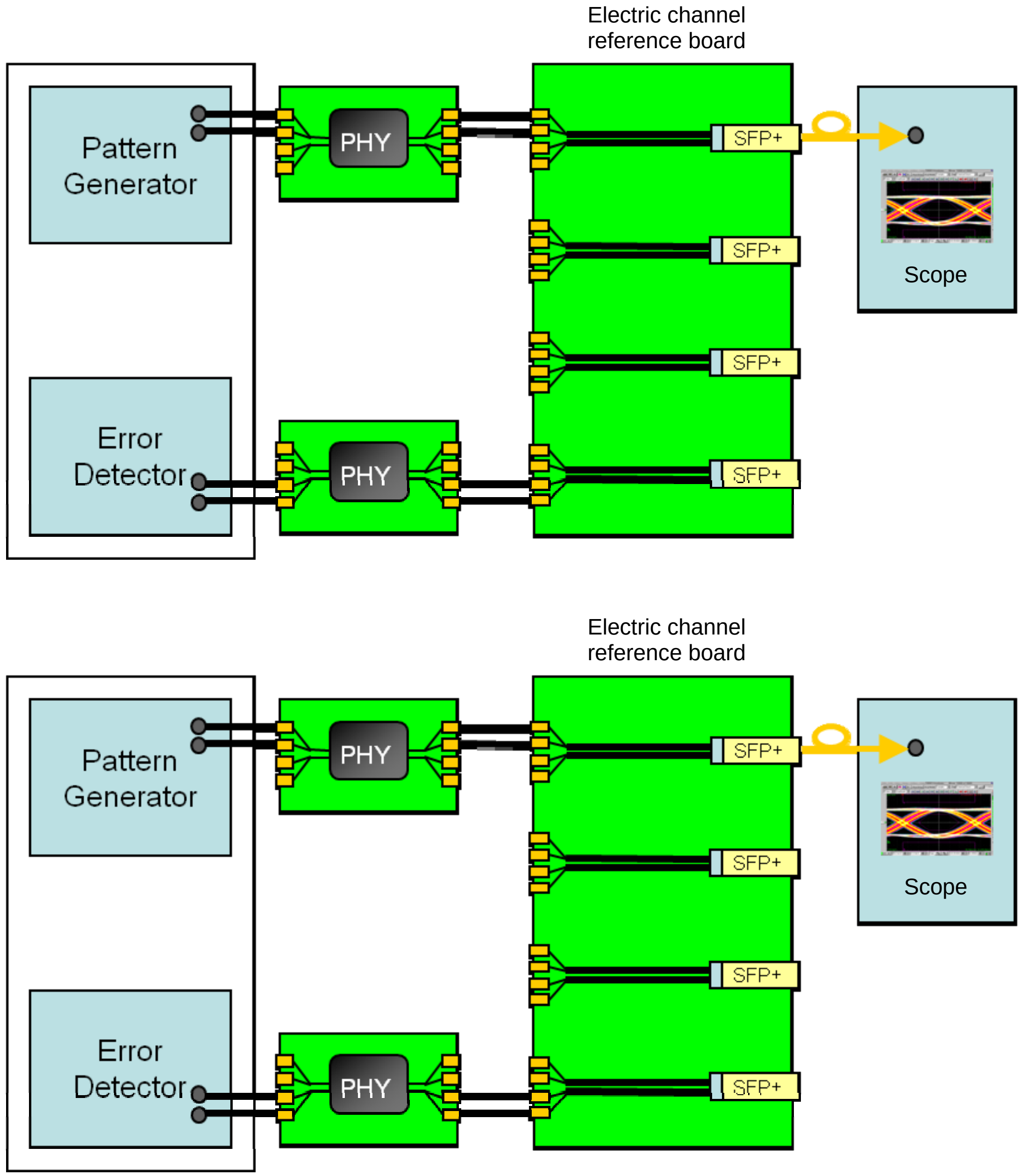


Figure 1—Test 1 Setup

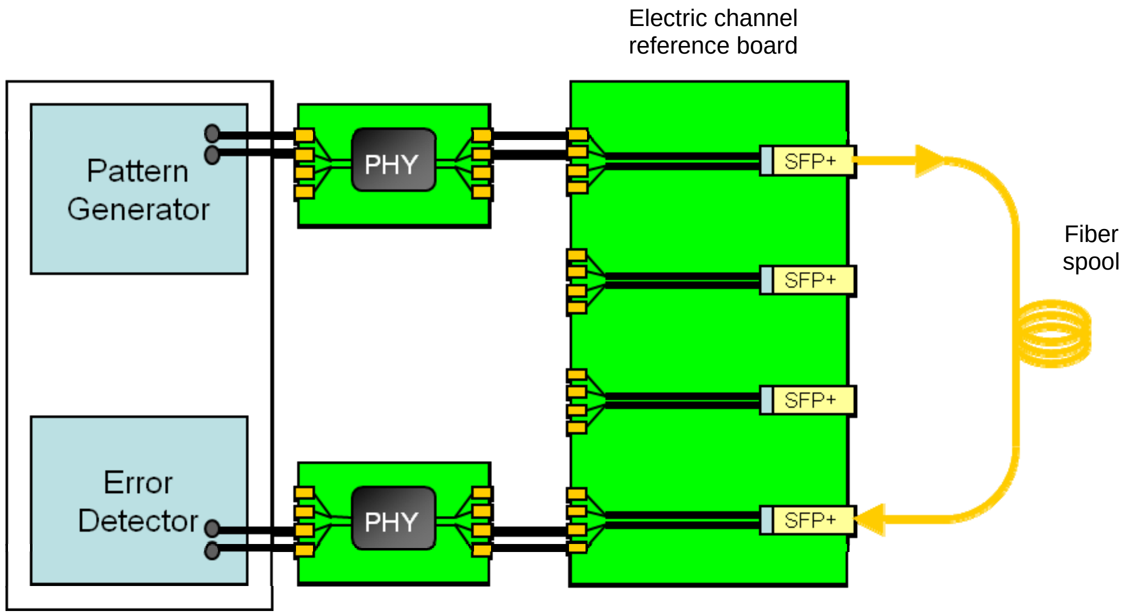


Figure 2—Test 2 Setup

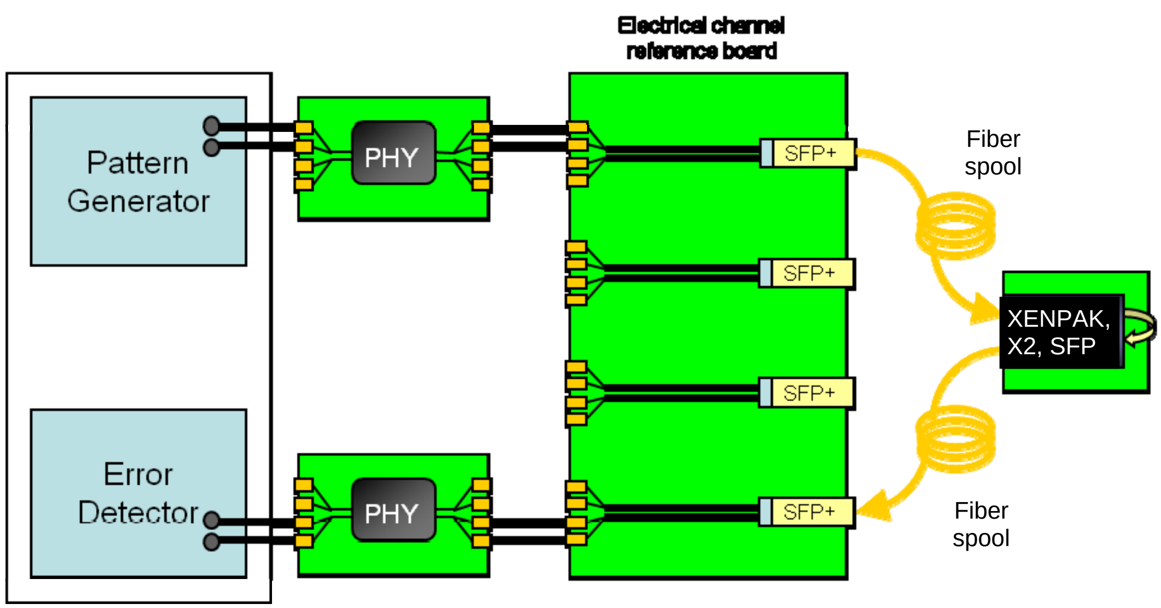
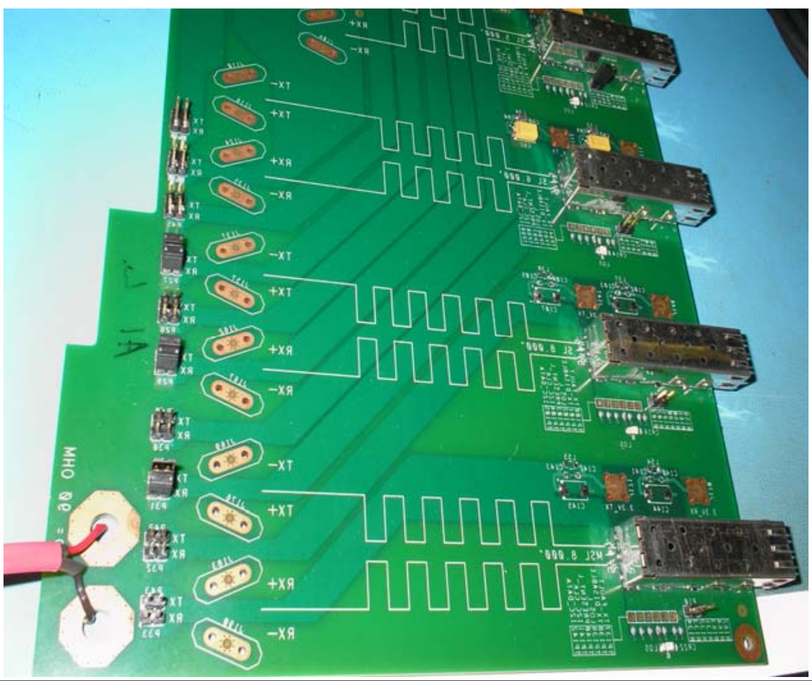


Figure 3—Test 3 Setup

Test Boards and Test Equipment Characterics

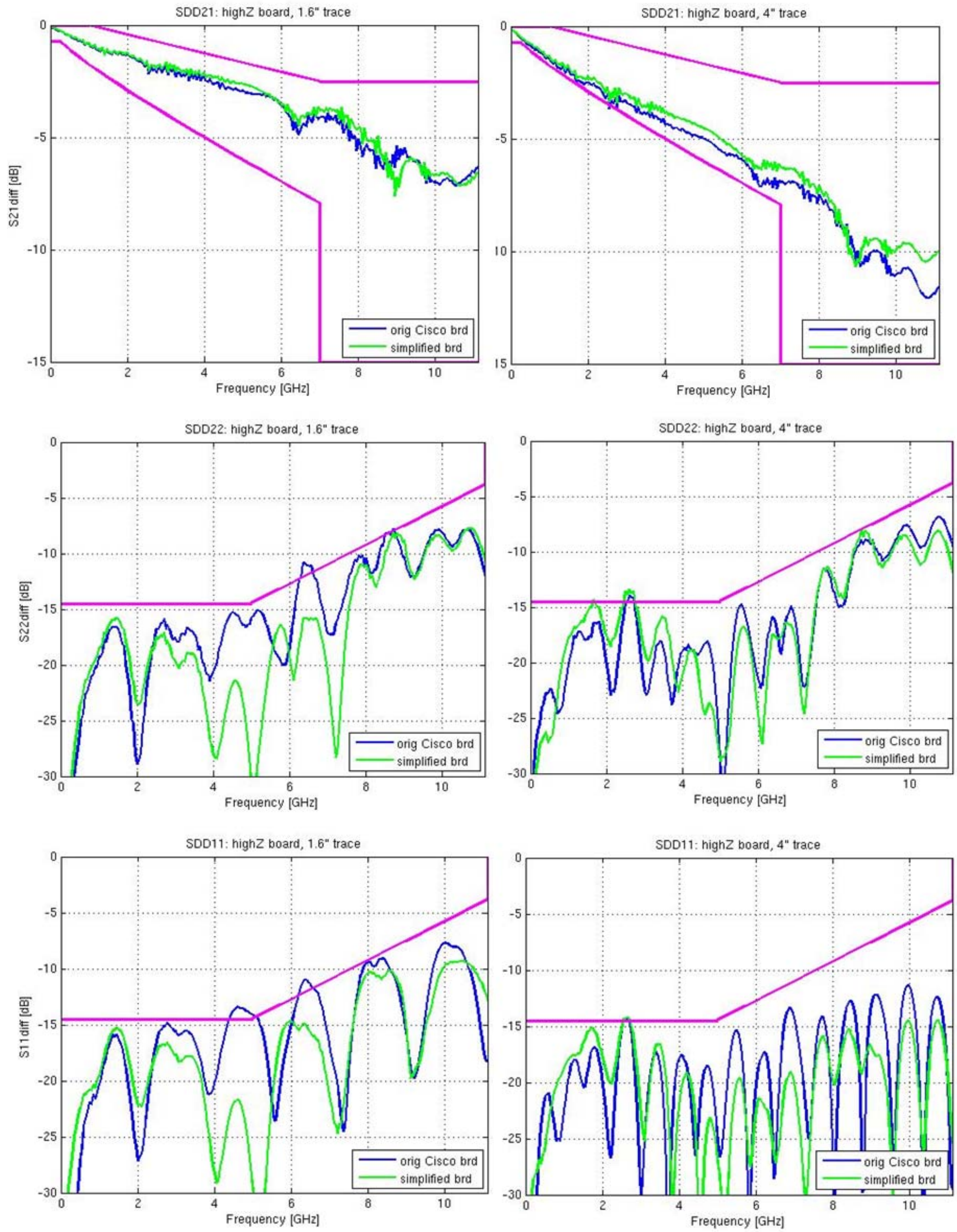
Host test boards

Each participating PHY vendor supplied its own evaluation board for use in the testing. The PHY evaluation board under test conditions was connected to the test board shown below. This provided several different trace lengths on FR4 for use as an electrical host reference channel. In the picture below pads for the SMA connectors (populated on the board used) are shown on the left edge of the board, and SFP+ module cages for each trace are shown on the right edge of the board. As noted above, the transmitter tests were performed with 1.6” of FR4 trace and the receiver tests were performed with 4” of FR4 trace. Note that the effective trace length in each case is somewhat longer due to the trace length on the PHY evaluation board and the SMA cables between the PHY evaluation board and the FR4 channel board.



Photograph 1— Test Board

The S-parameters of this test board were measured (see plots in Graph 1) and the results compared to both the SFP+ specification (pink line in the plots below) and to a Cisco-provided test board already available to most participants.



Graph 1—S-parameters of test board for various trace lengths (highZ impedance is between 100 and 110ohms)

Test equipment

Model and revision numbers for the equipment and reference fibers used are shown below.

Equipment		
Agilent Infinium DCA-J	12.5 GHz	Software Rev: P.08.00
Plug-in modules	83496A Clock Recovery	
	86105C Optical Receiver	
	54754A Differential TDR	
Agilent J-BERT N4903A	12.5GHz	Software Build: 18104
		Firmware: EVO 08/07
Reference optical channels		
Multi Mode Fiber Spool	Siemon Company	Model: 9F5LB2-24B
	OM3, 270 Meters	3 Couplers + 30% drop in CDR module
Single Mode Fiber Spool	Corning	
	10 Kilometers	

Table 2—Test Equipment

Test Results

This section outlines the results from the transmitter selection process (Test 1), the SFP+ interoperability testing (Test 2), and SFP+ interoperability testing with other optical interface types (Test 3). The test results are presented anonymously throughout, with the PHY participants labeled I through VIII and the optical module participants labeled 1 through 7. The interoperability testing was quite successful, with over 98% of the combinations interoperating error-free.

<u>Test 1: Transmitter characterization and selection</u>

Test 1 measured the transmit optical eye mask of various combinations of PHY ICs and SR and LR optical modules, in order to select worst-case transmitter combi-

nations for use in the transmission measurements of Test 2. As explained previously, worst-case transmitters were selected from the results of this step in order to make the number of test combinations for the subsequent interoperability tests manageable.
The worst case transmitter PHY IC was not fully verified to the SFP+ specifications due to time limitation and may not have been compliant.

In this testing step a reference electrical channel of 1.6” was used. (Channel characteristics are given above in the Test Setup section and the optical modules were plugged into the test board in the appropriate slot).

The optical waveform was measured at the optical transmitter output for each PHY-optics combination, and the eye mask margin relative to the relevant IEEE802.3ae standard eye mask was calculated. Test results are shown below. To read the table, find a particular PHY participant (marked with Roman numerals letters on the left side of the table) and then move over to a particular optics vendor (marked with numbers on the top side of the table) to find the mask margin measured for that combination of components.

Eye mask margin, %		SFP+ Tx optics						
		1	**2**	**3**	**4**	**5**	**6**	**7**
SFP+ Tx PHY	**I**	27	33	31	37	37	36	29
	II	15	27	32	34	44	18	32
	III	23	29	35	38	43	26	28
	IV	16	29	23	31	33	27	28
	V	18	26	30	11	22	29	25
	VI	16	23	34	27	38	15	23
	VII	14	25	26	35	45	27	30
	VIII	21	23	30	37	39	27	29

Table 3 —SR Interfaces

Eye mask margin, %		SFP+ Tx optics						
		1	2	3	4	5	6	7
SFP+ Tx PHY	I	41	51	49	41	40	34	44
	II	36	51	40	42	42	36	44
	III	40	51	45	35	44	27	40
	IV	37	49	34	36	37	34	45
	V	33	28	22	24	27	29	35
	VI	33	30	45	32	34	19	33
	VII	38	53	36	41	43	30	44
	VIII	36	52	45	33	45	30	36

Table 4 —LR Interfaces

Based on the mask margin results shown here, PHY-optics combination 4-V was chosen as the worst-case transmitter combination for further SR testing, and combination 6-VI was chosen as the worst-case transmitter combination for further LR testing.

Not fully verifying or enforcing SFP+ compliance to meet DDJ and DDPWS at the host output (point B) may have penalized transmitters resulting in lower eye mask margin and possible failing tTDP. The lesson learned is that SFP+ compliance is crucial .

Test 2: Error-free transmission test

This test demonstrated interoperability of SFP+ SR and LR optical interfaces over a reference optical and electrical channel.

The criterion for successful interoperability was set as operation with a bit error rate of better than $1x10^{-12}$ over the test time interval. Testing was run for 485 seconds (8 minutes 5 seconds, or $5x10^{12}$ bits) to provide a confidence level of 99% for a bit error rate $1x10^{-12}$.

SR and LR tests were run using the worst-case PHY-optics transmitter pairs as determined in the Test 1 characterization. The reference receiver electrical channel was chosen to be four inches of FR4 (for measured characteristics of the test board used, see the Test Setup section above).

SR testing was run through a 270m multi mode (OM3) fiber spool, while LR testing was run through a 10 km single mode fiber spool; fiber spool details are given above in the Test Setup section.

For SR testing, the optical power level at the receiver input was adjusted to -7.4 dBm, close to the minimum stressed receiver sensitivity level (-7.5 dBm) specified in IEEE802.3ae. For SR, this optical power level was achieved by inserting three optical splitters in the optical path in combination with the loss of the fiber spool itself.

For LR testing, the optical power level at the receiver input was adjusted to -10.2 dBm, the minimum stressed receiver sensitivity level specified in IEEE802.3ae. For LR, this optical power level was achieved by the use of an optical attenuator at the output of the transmitter in combination with the loss of the fiber spool itself.

For reference, the optical waveforms at the receiver optical input were captured and are shown below.

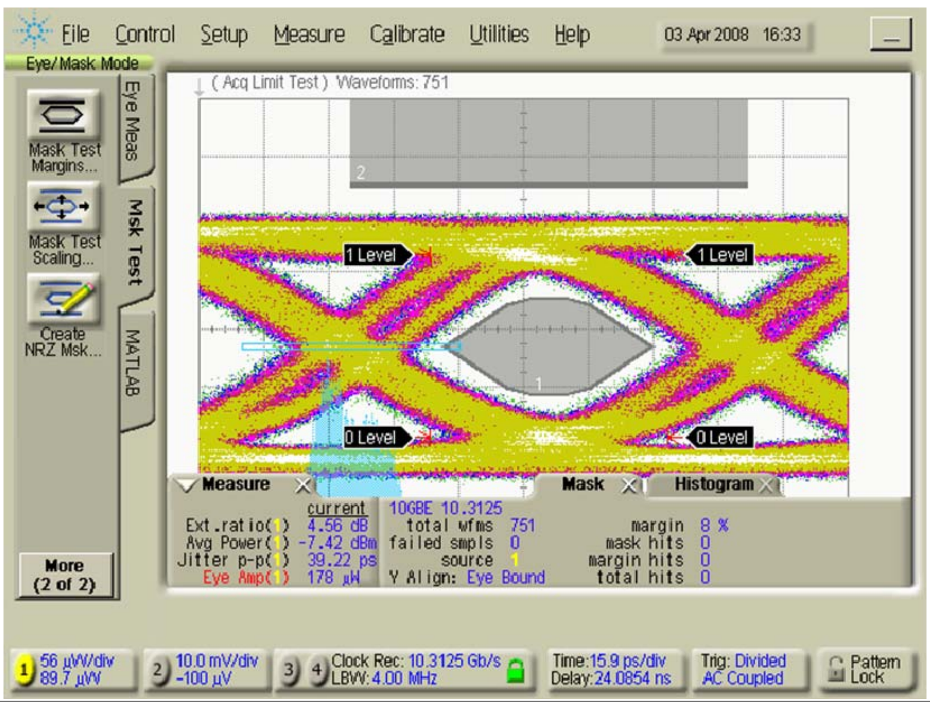


Figure 4 — Received SR optical eye after 270m of fiber has peak to peak

Note: Jitter histogram of of 0.411 UI with estimated 99% jitter histogram of 0.36 UI exceeding IEEE802.3ae limit of 0.3 UI

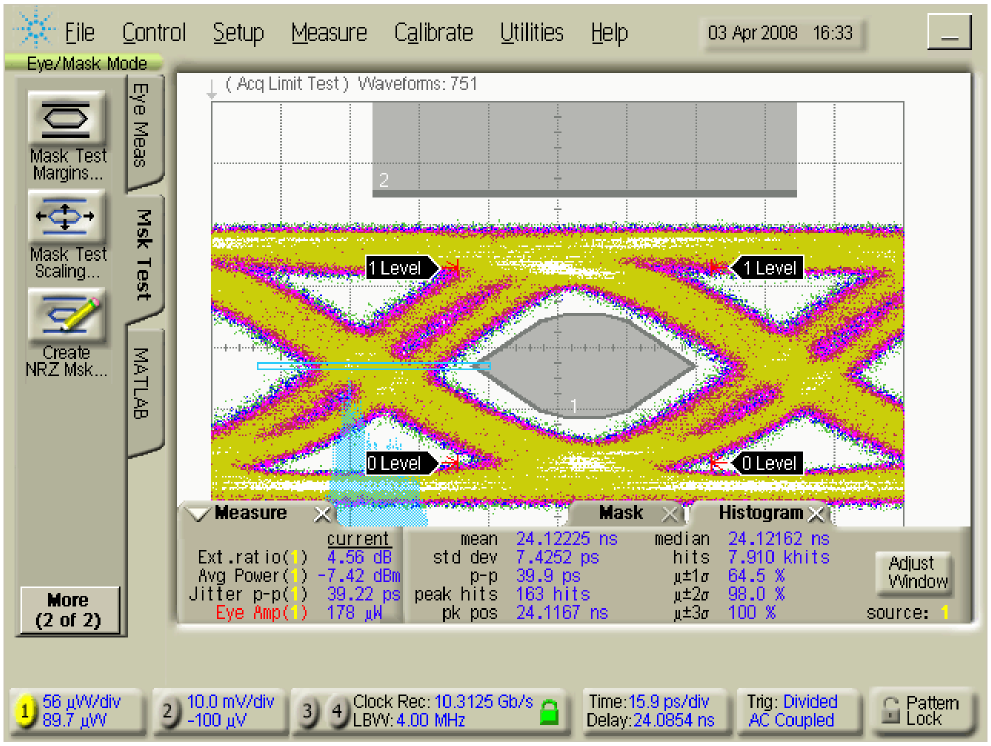


Figure 5 — Received SR optical eye after 270m of fiber; shows jitter measurements

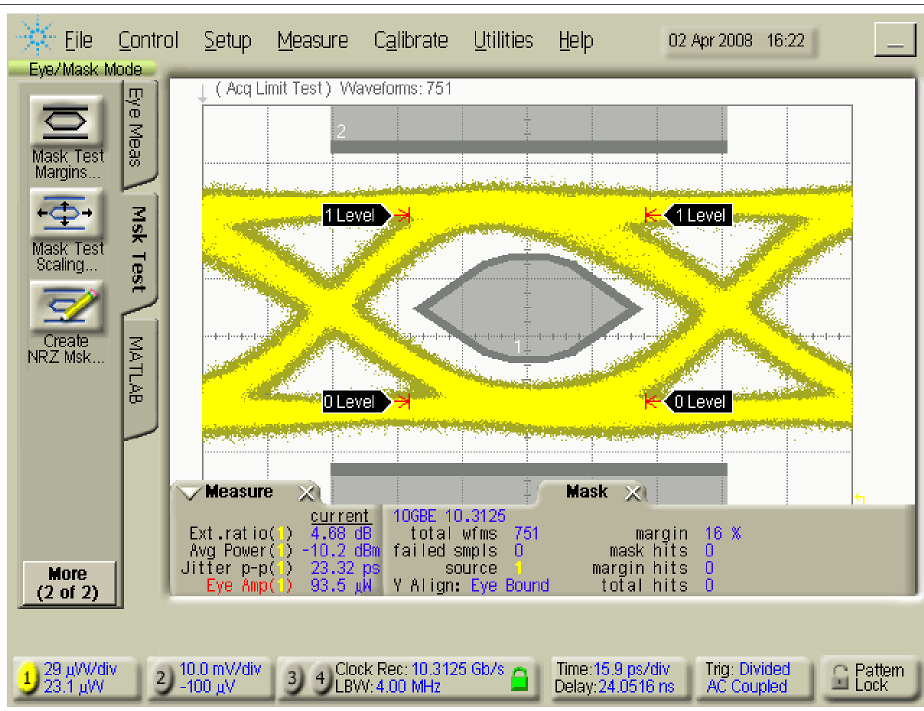


Figure 6 — Received LR optical eye after 10km of fiber

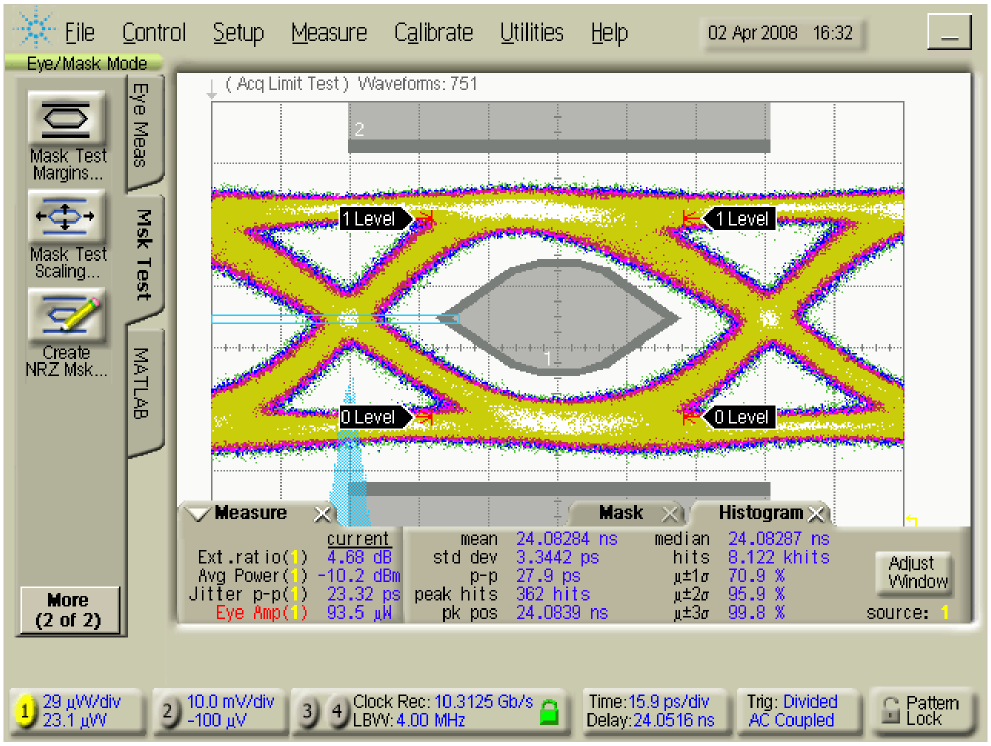


Figure 7 — Received LR optical eye after 10km of fiber; shows jitter measurements

Results from the testing are shown below. A check mark denotes the combination of SFP+ interface components represented by that box (again, PHY participants shown on the left side of the table with letters and optical module participants shown on the top side of the table with numbers) interoperated successfully over the reference electrical and optical channels with the worst-case SFP+ transmitter component combination. A number in the box represents the error rate over the testing time interval for that receiver component combination interoperating. The worst-case SFP+ transmitter component combination at the SR TP3 output eye diagram exceeds IEEE802.3ae limit. This is likely due to non-compliance at the SFP+ electrical transmitter.

SFP+ Tx PHY \ SFP+ Rx optics	1	2	3	4	5	6	7
I	✓	✓	✓	✓	✓	✓	✓
II	✓	✓	✓	✓	8.6e-11	✓	✓
III	✓	✓	✓	✓	2.4e-12	✓	✓
IV	✓	✓	✓	✓	✓	✓	✓
V	✓	✓	✓	✓	✓	✓	✓
VI	✓	✓	✓	✓	✓	✓	✓
VII	✓	✓	✓	✓	✓	✓	✓
VIII	✓	✓	✓	✓	✓	✓	✓

Table 5 —SR Interfaces

SFP+ Tx PHY \ SFP+ Rx optics	1	2	3	4	5	6	7
I	✓	✓	✓	✓	✓	✓	✓
II	✓	✓	✓	✓	✓	✓	✓
III	✓	✓	✓	✓	✓	✓	✓
IV	✓	✓	✓	✓	✓	✓	✓
V	✓	✓	✓	✓	✓	✓	✓
VI	✓	✓	✓	✓	✓	✓	✓
VII	✓	✓	✓	✓	✓	✓	✓
VIII	✓	✓	✓	✓	✓	✓	✓

Table 6 - LR Interfaces

Over 98% of the 112 combinations tested interoperated error-free. After slight adjustment of the transmit PHY pre-emphasis settings which may not have been complaint to SFP+ specifications, all combinations were error-free. The lesson learned is that compliance to SFP+ specification is imperative for reliable link operation. The shorter test timeframe and short-cuts made on the first day, however, limited the scope of this interoperability test.

Test 3: testing interoperability with other module form factors

In many cases, SFP+ optical interfaces are expected to interoperate with other types of optical interfaces in the field, particularly in the early years of SFP+ deployment. With this in mind, Test 3 demonstrated interoperability between SFP+ and other optical module form factors.

Again the transmitters used in each case were the worst-case transmitters identified in the Test 1 characterization step, and the optical eye diagrams at the receiver input of the alternate optical interfaces are the same as those shown above in Test 2. The SFP+ receiver reference electrical channel was again 4 inches of FR4 as in Test 2. See the Test Setup section above for the setup block diagram.

Test results are shown below for various combinations of optical module form factors and SFP+ receivers. All combinations ran error-free.

Other module type	SFP+ Rx optics	SFP+ Rx PHY	Result
XENPAK	2	VII	✓
X2	6	VII	✓
XFP	7	VII	✓

Table 7 —SR Interfaces

Other module type	SFP+ Rx optics	SFP+ Rx PHY	Result
XENPAK	4	I	✓
X2	5	I	✓
XFP	7	I	✓

Table 8—LR Interfaces

Summary

The SFP+ interoperability demonstration and SFP+ White paper is the outcome of collaboration between a broad set of optical component companies. The testing achieved excellent overall results despite the short coming of not enforcing or fully verifying SFP+ compliance. The testing held at the University of New Hampshire Interoperability Lab by the Ethernet Alliance SFP+/EDC subcommittee still achieved its goal to demonstrate robust interoperability of SFP+ SR and LR optical interfaces and components.

Glossary

10GBASE-LR: 10 Gigabit Ethernet short-reach

10GBASE-SR: 10 Gigabit Ethernet short-reach

DDP: data dependent jitter

DDPWS: data dependent pulse width shrinkage

EDC: electronic dispersion compensation

ER: extra-long-wavelength

FR4: Flame Retardant 4

IC: integrated circuit

Linear Interface: straight line input path on the host board

Limiting Interface: input path is divided on the host board

LR: long-reach

LRM: long-wavelength multimode

PHY: physical layer

PMD: performance motion device

S-parameters: scattering parameters

SFP+: Small Form Factor Pluggable

SMA: SubMiniature version A

SR: short-reach

TDP: thermal design power

UNH-IOL: University of New Hampshire Interoperability Lab

X2: a 56 kbit/s modem protocol

XENPAK: standard that defines a type of fiber-optic or copper transceiver module which is compatible with the 10 Gigabit Ethernet (10GE) standard.

XFP: 10 Gigabit Small Form Factor Pluggable