Higher Speed Ethernet Plugfest

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Introduction & Background

The IEEE Std 802.3ba™-2010 40 Gb/s and 100 Gb/s Ethernet amendment of the IEEE Std 802.3™-2008 Ethernet standard was approved on June 17, 2010 by the IEEE Standards Association Standards Board. The development of the standard started in 2006 with the IEEE 802.3 Higher Speed Study Group (HSSG). While the standard matured, vendors developed prototype and production components for the Higher Speed Ethernet (HSE) ecosystem.

The state of HSE components was relatively advanced at the time of the ratification, with experimental and deployed 40 Gb/s and 100 Gb/s devices and networks. In order to determine the extent of the ecosystem and basic interoperability, a plugfest event was held from September 14-16, 2010 in Santa Clara, CA. The event was hosted by Ixia at its iSimCity facility.

The intent of the plugfest was to determine basic interoperability and not to measure standards conformance. In addition to achieving "link up" for all connections, sufficient layer 1 or layer 2 traffic was sent to ensure conformance to error rates.

The following types of components were used in the plugfest:

1. Transceivers – forming physical layer connections to cables.
    a. CFP MSA – used for both 40 Gb/s and 100 Gb/s.
    b. QSFP+ - used for 40 Gb/s.
2. Optical cables – connecting transceivers.
3. Copper cable assemblies – QSFP+ Direct Attach Copper (DAC) cable assemblies.
4. Systems – including test systems, switches/routers and computers with HSE NICs.
5. Development boards – used to develop and test transceiver/cable combinations.
6. Active copper and optical cable assemblies – copper and optical cable assemblies with attached active transceivers. These assemblies are not part of the IEEE 802.3ba™-2010 standard. Results from these tests are included in Appendix B.

The list of components, organized by vendor, is included in Appendix A. One cable from one vendor was found to be incorrectly assembled and was eliminated from the results.

HSE Plugfest Objectives

Two series of tests were executed:

1. Cables and transceivers – the Ixia test system was used to test combinations of transceivers and cables, as well as cable assemblies.
2. System – combinations of systems were interconnected.

Cable and Transceiver Test Results

All cable and transceiver tests were performed by connecting either QSFP+ Direct Attach Copper (DAC) cables or transceiver / cable connections. For each test, the Ixia test port was used to transmit and verify 12 x 10^{12} bits of PRBS-31 patterns to verify a bit error rate of 10^{-12}. Two issues were encountered during the tests:

- Some of the QSFP+ Direct Attach Copper (DAC) cables had difficulty establishing a good connection to the Ixia ports. This was solved by fully inserting the cable and then slightly pulling it back out.
- Very high BERs or no link were observed when testing with most passive cables longer than 1m. It was determined that the issue was caused by the default amplitude and pre-emphasis settings used on the Ixia ports. The settings were changed and then passing results were observed over all passive and active cables using the new settings.

40 Gb/s QSFP+ DAC Tests

The passive QSFP+ Direct Attach Copper (DAC) cables that were tested can be found in Table 1. All cables tested were observed to successfully pass the BER test with zero errors. Results with active copper and optical cables can be found in Appendix B.

Table 1: QSFP+ DAC Test Results

Vendor	Length	Result
A	3m	Pass
	5m	Pass
B	1m	Pass
	3m	Pass
	7m	Pass
C	1m	Pass
	5m	Pass
	6m	Pass
D	1m	Pass
	3m	Pass
	5m	Pass
	7m	Pass
E	1m	Pass
	3m	Pass
	5m	Pass
	6m	Pass
	7m	Pass

Transceiver/Cable Combination Tests

The testing of transceivers and fiber optic cables consisted of plugging two QSFP or CFP transceivers into the Ixia test ports, connecting them with the fiber optic cable under test, and then transmitting PRBS-31 to verify the BER.

This was completed using all possible combinations of transceivers and fiber optic cables. The transceiver types tested were:

- 40GBASE-LR4
- 40GBASE-SR4
- 100GBASE-LR4
- 100GBASE-SR10

The fiber optic cable types were SMF with SC connectors, 1x12 MMF with MTP/MPO connectors, and 2x12 MMF with MTP/MPO connectors.

One problem was encountered during this series of tests. The SR4 transceivers were unable to establish link over one particular 1x12 MMF and the SR10 transceivers were unable to establish link over one 2x12 MMF. It was determined that the problem was lane mapping. A new cable was selected with the proper mapping, which successfully passed the BER tests.

$12x10^{12}$ bits were transmitted to verify BER with 40GBASE-LR4, 40GBASE-SR4, and 100GBASE-LR4 transceivers. $30x10^{12}$ bits were transmitted to verify BER with 100GBASE-SR10 transceivers. The combinations of transceivers and fiber optic cables tested with Ixia can be found in Tables 2-5. All combinations tested were observed to successfully pass the BER test with zero errors.

Table 2: 40GBASE-LR4 Results

Cable Supplier	SMF Cable Reach	Transceiver 1	Transceiver 2	Pass/Fail
A	25m	40GBASE-LR4 CFP #2	40GBASE-LR4 CFP #2	Pass
	25m	40GBASE-LR4 CFP #1	40GBASE-LR4 CFP #1	Pass
	25m	40GBASE-LR4 CFP #1	40GBASE-LR4 CFP #2	Pass
B	5m	40GBASE-LR4 CFP #1	40GBASE-LR4 CFP #1	Pass
	5m	40GBASE-LR4 CFP #1	40GBASE-LR4 CFP #2	Pass
	5m	40GBASE-LR4 CFP #2	40GBASE-LR4 CFP #2	Pass
	10km	40GBASE-LR4 CFP #1	40GBASE-LR4 CFP #1	Pass
	10km	40GBASE-LR4 CFP #1	40GBASE-LR4 CFP #2	Pass
	10km	40GBASE-LR4 CFP #2	40GBASE-LR4 CFP #2	Pass
C	5m	40GBASE-LR4 CFP #1	40GBASE-LR4 CFP #1	Pass
	5m	40GBASE-LR4 CFP #1	40GBASE-LR4 CFP #2	Pass
	5m	40GBASE-LR4 CFP #2	40GBASE-LR4 CFP #2	Pass
	1km	40GBASE-LR4 CFP #1	40GBASE-LR4 CFP #1	Pass
	1km	40GBASE-LR4 CFP #1	40GBASE-LR4 CFP #2	Pass
	1km	40GBASE-LR4 CFP #2	40GBASE-LR4 CFP #2	Pass

Table 3: 100GBASE-LR4 Results

Cable Supplier	SMF Cable Reach	Transceiver 1	Transceiver 2	Pass/Fail
A	1m	100GBASE-LR4 CFP #3	100GBASE-LR4 CFP #1	Pass
	25m	100GBASE-LR4 CFP #1	100GBASE-LR4 CFP #1	Pass
	25m	100GBASE-LR4 CFP #2	100GBASE-LR4 CFP #2	Pass
	25m	100GBASE-LR4 CFP #2	100GBASE-LR4 CFP #1	Pass
	25m	100GBASE-LR4 CFP #3	100GBASE-LR4 CFP #1	Pass

	25m	100GBASE-LR4 CFP #3	100GBASE-LR4 CFP #2	Pass
B	5m	100GBASE-LR4 CFP #1	100GBASE-LR4 CFP #1	Pass
	5m	100GBASE-LR4 CFP #2	100GBASE-LR4 CFP #1	Pass
	5m	100GBASE-LR4 CFP #2	100GBASE-LR4 CFP #2	Pass
	5m	100GBASE-LR4 CFP #3	100GBASE-LR4 CFP #1	Pass
	5m	100GBASE-LR4 CFP #3	100GBASE-LR4 CFP #2	Pass
	10km	100GBASE-LR4 CFP #1	100GBASE-LR4 CFP #1	Pass
	10km	100GBASE-LR4 CFP #2	100GBASE-LR4 CFP #1	Pass
	10km	100GBASE-LR4 CFP #2	100GBASE-LR4 CFP #2	Pass
	10km	100GBASE-LR4 CFP #3	100GBASE-LR4 CFP #1	Pass
	10km	100GBASE-LR4 CFP #3	100GBASE-LR4 CFP #2	Pass
C	5m	100GBASE-LR4 CFP #1	100GBASE-LR4 CFP #1	Pass
	5m	100GBASE-LR4 CFP #2	100GBASE-LR4 CFP #1	Pass
	5m	100GBASE-LR4 CFP #2	100GBASE-LR4 CFP #2	Pass
	5m	100GBASE-LR4 CFP #3	100GBASE-LR4 CFP #1	Pass
	5m	100GBASE-LR4 CFP #3	100GBASE-LR4 CFP #2	Pass
	1km	100GBASE-LR4 CFP #1	100GBASE-LR4 CFP #1	Pass
	1km	100GBASE-LR4 CFP #2	100GBASE-LR4 CFP #1	Pass
	1km	100GBASE-LR4 CFP #2	100GBASE-LR4 CFP #2	Pass
	1km	100GBASE-LR4 CFP #3	100GBASE-LR4 CFP #1	Pass
	1km	100GBASE-LR4 CFP #3	100GBASE-LR4 CFP #2	Pass

Table 4: 40GBASE-SR4 Results

Cable Supplier	Type/Cable Reach	Transceiver 1	Transceiver 2	Pass/Fail
A	OM3 / 100m	40GBASE-SR4 CFP	40GBASE-SR4 CFP	Pass
B	OM3 / 5m	40GBASE-SR4 CFP	40GBASE-SR4 CFP	Pass
	OM3 / 5m	40GBASE-SR4 CFP	40GBASE-SR4 QSFP	Pass
	OM3 / 100m	40GBASE-SR4 CFP	40GBASE-SR4 CFP	Pass
	OM3 / 100m	40GBASE-SR4 CFP	40GBASE-SR4 QSFP	Pass
	OM3 / 100m	40GBASE-SR4 QSFP	40GBASE-SR4 QSFP	Pass
	OM4 / 150m	40GBASE-SR4 CFP	40GBASE-SR4 CFP	Pass
	OM4 / 150m	40GBASE-SR4 CFP	40GBASE-SR4 QSFP	Pass
	OM4 / 150m	40GBASE-SR4 QSFP	40GBASE-SR4 QSFP	Pass
C	OM3 / 100m	40GBASE-SR4 CFP	40GBASE-SR4 CFP	Pass
	OM3 / 100m	40GBASE-SR4 CFP	40GBASE-SR4 QSFP	Pass
	OM3 / 100m	40GBASE-SR4 QSFP	40GBASE-SR4 QSFP	Pass
	OM4 / 150m	40GBASE-SR4 CFP	40GBASE-SR4 CFP	Pass
	OM4 / 150m	40GBASE-SR4 CFP	40GBASE-SR4 QSFP	Pass
	OM4 / 150m	40GBASE-SR4 QSFP	40GBASE-SR4 QSFP	Pass

Table 5: 100GBASE-SR10 Results

Cable Supplier	Type/Cable Reach	Transceiver 1	Transceiver 2	Pass/Fail
A	OM3 / 5m	100GBASE-SR10 CFP	100GBASE-SR10 CFP	Pass
B	OM3 / 5m	100GBASE-SR10 CFP	100GBASE-SR10 CFP	Pass
	OM3 / 100m	100GBASE-SR10 CFP	100GBASE-SR10 CFP	Pass
	OM4 / 150m	100GBASE-SR10 CFP	100GBASE-SR10 CFP	Pass

System Test Results

The system Interoperability and BER tests were performed by transmitting 1518-byte PING packets over several combinations of transceivers and fiber optic cables. 948 million packets were transmitted for 40GBASE-LR4, 40GBASE-SR4, and 100GBASE-LR4. 2.37 billion packets were transmitted for 100GBASE-SR10. The test results are summarized in Tables 6 and 7. All combinations tested were observed to successfully pass the BER test with zero errors.

Table 6: System Tests for 40 Gigabit Ethernet

	40G System #2 / 40GBASE-SR4 CFP	40G System #2 / 40GBASE-SR4 QSFP	40G System #2 / QSFP Cable	40G System #3 / 40GBASE-SR4 QSFP
40G System #1 / 40GBASE-SR4 CFP	100m 1x12 OM3 #1 PASS	150m 1x12 OM4 #1 PASS		100m 1x12 OM3 #1 PASS
	100m 1x12 OM3 #3 PASS	150m 1x12 OM4 #2 PASS		150m 1x12 OM4 #1 PASS
				100m 1x12 OM3 #4 PASS
40G System #3 / 40GBASE-SR4 QSFP		150m 1x12 OM4 #2 PASS		
40G System #4 / 40GBASE-SR4 QSFP	150m 1x12 OM4 #1 PASS			
40G System #4 / QSFP Cable			3m QSFP passive copper cable #1 PASS	
			3m QSFP passive copper cable #4 PASS	
			5m QSFP passive copper cable #4 PASS	

Table 7: System Tests for 100 Gigabit Ethernet

	100G System #3 / 100GBASE-LR4 CFP #1	100G System #1 / 100GBASE-LR4 CFP #2	100G System #1 / 100GBASE-LR4 CFP #3	100G System #3 / 100GBASE-SR10 CFP	100G System #1 / 100GBASE-LR4 CFP #1	100G System #1 / 100GBASE-LR4 CFP #2	100G System #1 / 100GBASE-SR10 CFP
100G System #1 / 100GBASE-LR4 CFP #1		*1km SMF* *PASS*			*25m SMF* *PASS*		
100G System #1 / 100GBASE-LR4 CFP #2			*25m SMF* *PASS*			*25m SMF* *PASS*	
100G System #1 / 100GBASE-LR4 CFP #3	*10km SMF* *PASS*					*25m SMF* *PASS*	
100G System #1 / 100GBASE-SR10 CFP				*150m 1x24 OM4* *PASS*			*100m 1x24 OM3* *PASS* *150m 1x24 OM4* *PASS*
100G System #2 / 100GBASE-LR4 CFP #1	*5m SMF* *PASS*						
100G System #2 / 100GBASE-LR4 CFP #2	*5m SMF* *PASS*						
100G System #2 / 100GBASE-LR4 CFP #3	*5m SMF* *PASS*						

Additional BER Tests

Some additional BER testing was performed using cable lengths that exceeded the IEEE Std 802.3ba required maximum lengths to indicate the viability of the HSE ecosystem. All combinations tested were observed to successfully pass the BER test with zero errors. The results are summarized in Table 8.

Table 8: BER Test Results with Additional Cables

Cable Provider	Type / Cable Reach	System / Transceiver 1	System / Transceiver 2	Pass/Fail
A	QSFP+ / 8m Passive Copper Cable	40G System #2	40G System #2	Pass
B	OM3 / 120m 1x12	40G System #2 / 40GBASE-SR4 CFP	40G System #2 / 40GBASE-SR4 CFP	Pass
		40G System #2 / 40GBASE-SR4 CFP	40G System #2 / 40GBASE-SR4 QSFP	Pass
		40G System #2 / 40GBASE-SR4 QSFP	40G System #2 / 40GBASE-SR4 QSFP	Pass
		40G System #3 / 40GBASE-SR4 QSFP	40G System #2 / 40GBASE-SR4 CFP	Pass
		40G System #4 / 40GBASE-SR4 QSFP	40G System #2 / 40GBASE-SR4 QSFP	Pass
B	OM4 / 170m 1x12	40G System #2 / 40GBASE-SR4 CFP	40G System #2 / 40GBASE-SR4 CFP	Pass
		40G System #2 / 40GBASE-SR4 QSFP	40G System #2 / 40GBASE-SR4 QSFP	Pass
B	OM3-OM4 / 500m 1x12 (4 concatenated cables)	40G System #2 / 40GBASE-SR4 CFP	40G System #2 / 40GBASE-SR4 CFP	Pass
B	OM3 / 120m 1x24	100G System #3 / 100GBASE-SR10 CFP	100G System #3 / 100GBASE-SR10 CFP	Pass
B	OM4 / 170m 1x24	100G System #3 / 100GBASE-SR10 CFP	100G System #3 / 100GBASE-SR10 CFP	Pass
		100G System #3 / 100GBASE-SR10 CFP	100G System #1 / 100GBASE-SR10 CFP	Pass
A	OM3-OM4 / 250m 1x24 (4 concatenated cables)	100G System #3 / 100GBASE-SR10 CFP	100G System #3 / 100GBASE-SR10 CFP	Pass
B	OM3-OM4 / 270m 1x24 (4 concatenated cables)	100G System #3 / 100GBASE-SR10 CFP	100G System #3 / 100GBASE-SR10 CFP	Pass

A	**OM3-OM4 / 275m 1x24 (7 concatenated cables)**	100G System #3 / 100GBASE-SR10 CFP	100G System #3 / 100GBASE-SR10 CFP	Pass

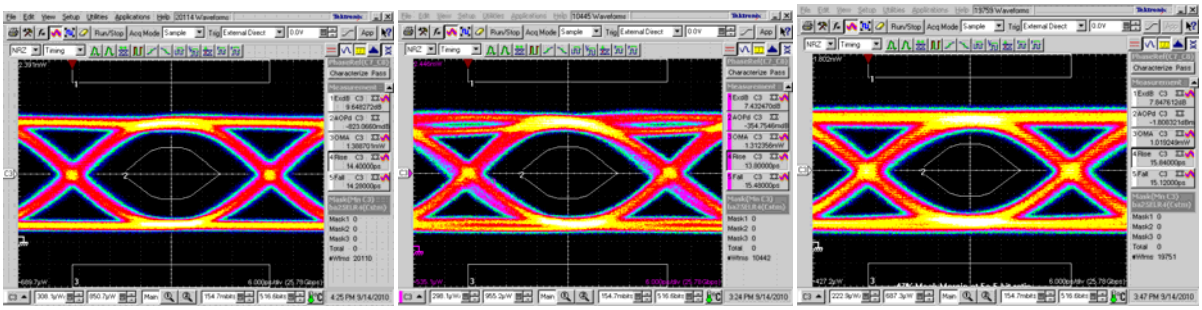
100GBASE-LR4 Transmit Eye Mask Compliance

While formal standard conformance testing was not an objective of this interoperability event, it is of interest to highlight the physical layer performance of 100GBASE-LR4 CFP transceiver modules, since this is the IEEE Std 802.3ba physical variant which required development of fundamentally higher-speed technology. In particular, optical transmitter eye mask testing was performed to determine module vendors' readiness of meeting IEEE Std 802.3ba.

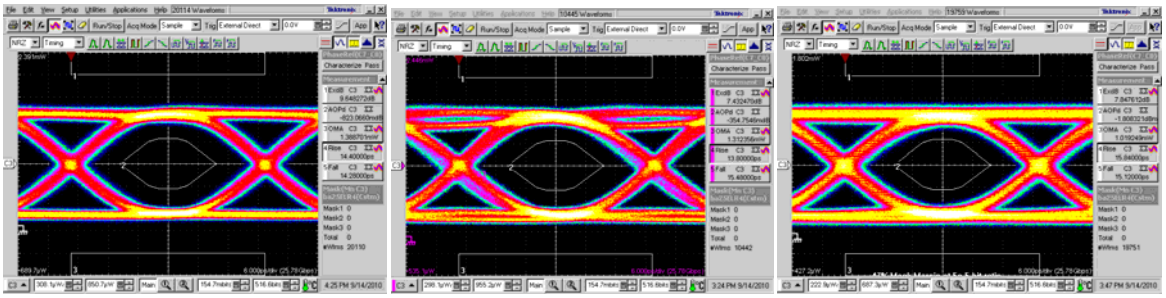
All three participating 100GBASE-LR4 CFP modules were tested successfully (Finisar, Opnext, Sumitomo). The transmitter mask measurements were conducted under the following conditions: Each CFP module was plugged into the Altera 100G Development Kit, Stratix IV GT Edition and set to transmit a PRBS-31 pattern with all four optical lanes operating. The compliance test setup consisted of the following:

- Optical lane L_0 centered at 1295.56nm was arbitrarily chosen for the mask test and dropped from the CFP output port with a LAN-WDM optical demux at 0.8dB insertion loss.
- This single-lane 25.78125 Gb/s signal was inserted into a sampling oscilloscope equipped with a 65GHz optical plug-in module set to its selectable IEEE Std 802.3ba compliant reference receiver filter with corner frequency of 19.34 GHz.
- The electrical Data output of the reference receiver module was used to drive the 28.6GHz clock recovery module set to a corner bandwidth of 10 MHz. The recovered clock served as trigger signal for the oscilloscope.
- A total of up to 20,000 filtered waveforms were acquired to generate each transmitter eye diagram. Extinction ratio, optical power, optical modulation amplitude and rise/fall times were measured. Mask margins were determined at the allowed 5×10^{-5} mask hit ratio level.

The acquired eye diagrams overlaid with the specified eye mask are shown below for all three devices (in random order). Each transceiver easily passes the standard mask and not a single mask hit was encountered. The measured mask margins are 52%, 47% and 32% (left to right). Extinction ratios are in the 7.4dB to 9.6dB range easily surpassing the required 4dB minimum. Launch powers and optical modulation amplitudes are well within the IEEE Std 802.3ba specified range.



In conclusion, all three tested 100GBASE-LR4 transceivers exceed the IEEE Std 802.3ba transmitter mask test specifications by wide margins and meet all other measured signal parameter requirements. This is clear evidence of the industry's remarkable development progress towards 100G Ethernet deployment.



In conclusion, all three tested 100GBASE-LR4 transceivers exceed the IEEE Std 802.3ba transmitter mask test specifications by wide margins and meet all other measured signal parameter requirements. This is clear evidence of the industry's remarkable development progress towards 100G Ethernet deployment.

Conclusion

Aside from minor, to be expected setup issues, all tested components interoperated. The interoperability results were impressive considering that this was the first time so many vendors had participated in such an event. The test results will give service providers an increased level of comfort knowing that there will be a wide availability of HSE products and a greater breadth of vendor choice.

This interoperability event demonstrates that the 40 and 100 Gbps Ethernet ecosystem is real and ready for deployment. The fact that widespread interoperability was so quickly achieved is testament to the strong engineering teams of the member-participants and to the standard itself.

About Ethernet Alliance

The Ethernet Alliance is a global community of Ethernet end users, system and component vendors, industry experts and university and government professionals who are committed to the continued success and expansion of Ethernet. The Ethernet Alliance brings Ethernet standards to life by supporting activities that span from incubation of new Ethernet technologies to interoperability demonstrations, certification and education.

Appendix A – Vendor Equipment

Altera
- 100G Development Kit, Stratix IV GT Edition
- Amphenol
- 40GBASE-CR4, QSFP passive copper cables
- 40GBASE-CR4, QSFP active copper cables
- 40GBASE-SR4, QSFP active optical cables

CommScope
- 40GBASE-SR4, 1 x 12 MPO, MMF, OM3
- 40GBASE-SR4, 1 x 12 MPO, MMF, OM4
- 100GBASE-SR10, 2 x 12 MPO trucks with 1x24 MPO at transceiver interfaces, MMF, OM3
- 100GBASE-SR10, 2 x 12 MPO trucks with 1x24 MPO at transceiver interfaces, MMF, OM4

Cisco
- Catalyst 6500
- CRS-3

Finisar
- 40GBASE-LR4 CFP

FCI
- 40GBASE-CR4, QSFP+ passive copper cables

Finisar
- 40GBASE-SR4, QSFP+ active optical cable
- 40GBASE-SR4 QSFP
- 100GBASE-LR4 CFP

Ixia
- Ixia XM12 chassis supporting multiple load modules
- Ixia “K2” CFP 40/100 GE load modules, software switchable interface
- Ixia “K2” QSFP 40 GE load module

Leviton

- 40/100GBASE-LR4, SC, SMF
- 40GBASE-SR4, 1 x 12 MTP, MMF, OM3
- 100GBASE-SR10, 1x24 MTP, MMF, OM3

Mellanox
- 40 Gigabit QSFP Network Adapter

Opnext
- 40GBASE-LR4 CFP
- 100GBASE-LR4 CFP

Panduit
- 40GBASE-CR4, QSFP passive copper cables
- 40GBASE-SR4, 1 x 12 MPO, MMF, OM3
- 40GBASE-SR4, 1 x 12 MPO, MMF, OM4
- 40/100GBASE-LR4, SC, SMF
- 100GBASE-SR10, 1 x 24 MPO, MMF, OM3
- 100GBASE-SR10, 1 x 24 MPO, MMF, OM4

Siemon
- 40GBASE-CR4, QSFP passive copper cables
- 40GBASE-CR4, QSFP active optical cables
- 40GBASE-SR4, 1 x 12 MPO, MMF, OM3
- 40GBASE-SR4, 1 x 12 MPO, MMF, OM4
- 40/100GBASE-LR4, SC, SMF

Sumitomo
- 40GBASE-LR4 CFP
- 100GBASE-LR4 CFP

Vitesse
- 40Gb/s Development Board with QSFP connector

Volex
- 40GBASE-CR4, QSFP passive copper cables

Appendix B – 40 Gb/s Active QSFP+ DAC Tests

The Active QSFP+ Direct Attach cables that were tested can be found in Table 8. An issue was encountered during the tests. Some of the cables had difficulty establishing a good connection to the Ixia ports. This was solved by fully inserting the cable and then slightly pulling it back out. Following that all cables tested were observed to successfully pass the BER test with zero errors.

Copper / Optical	Reach	System	System	Pass/Fail
Copper	10m	40G System #2	40G System #2	Pass

Copper	12m	40G System #2	40G System #2	Pass
Copper	15m	40G System #2	40G System #2	Pass
Optical	10m	40G System #2	40G System #2	Pass
		40G System #2	40G System #3	Pass
		40G System #2	40G System #4	Pass
Optical	10m	40G System #2	40G System #2	Pass
		40G System #2	40G System #3	Pass
		40G System #2	40G System #4	Pass
Optical	15m	40G System #2	40G System #2	Pass
		40G System #2	40G System #3	Pass
		40G System #2	40G System #4	Pass
Optical	100m	40G System #2	40G System #2	Pass