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# SFP+ Direct Attach Copper Interoperability Demonstration White Paper

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# Introduction

In October 2009, Ethernet Alliance members AppliedMicro, Amphenol, Broadcom, ClariPhy, Cortina Systems, FCI, Intel, Molex, Panduit, Tyco Electronics, Vitesse and Volex successfully conducted multi-vendor interoperability testing of the Direct Attach Copper “10GSFP+Cu” option of the SFF-8431 specifications. This white paper provides additional detail about the testing setup, procedure and test results.

The participants successfully conducted multi-vendor interoperability testing of SFP+ copper cable assemblies with each host port physical layer (PHY) or network interface card (NIC). Standalone PHYs with high speed electrical interface (SFI) were mated with an SFI channel, per SFF-8431, in order to create SFP+ host ports. Tests were conducted in three phases. The first phase was compliance testing of each PHY or NIC transmitter against the SFI host transmitter specifications at compliance point B, and each cable assembly to the SFP+ cable specifications. The second phase tested compliance of the cable output at compliance point C, for all combinations of host transmitters and cables. The third phase consisted of 10 Gigabit Ethernet full duplex Bit Error Rate (BER) testing where each cable was connected between all combinations of PHYs or NICs. The cables used in the interoperability testing ranged in length from 1 to 8.5 meters. In the third phase BER testing, all combinations successfully met or exceeded the 1E-12 BER requirements of 10 Gigabit Ethernet.

| Physical Layer IC Participants | Direct Attach Cable Suppliers |
|--------------------------------|-------------------------------|
| AppliedMicro                   | Amphenol                      |
| Broadcom                       | FCI                           |
| ClariPhy                       | Molex                         |
| Cortina Systems                | Panduit                       |
| Intel                          | Tyco Electronics              |
| Vitesse                        | Volex                         |

## SFP+ background

The SFP+ interface offers the highest density, lowest cost, and lowest power 10 Gigabit Ethernet solution commercially available today. Further SFP+ enables mass migration of the 1GbE network to 10 GbE by offering a very low cost 10GSFP+Cu (direct attached copper cable assembly) option for short reach interconnects along with multimode and single mode fiber options. The SFP+ interface accepts along with hot-pluggable, small-footprint, optical transceivers, a Direct Attach Cable “10GSFP+Cu”, which replaces two optical modules and a connectorized optical fiber with a twinaxial copper cable assembly. The 10GSFP+Cu option is defined for 10GbE applications over passive copper with a reach of  $\leq 8.5m$ . The 10GSFP+Cu link utilizes a receive equalizer in the host PHY/SerDes in order to compensate

for the Inter Symbol Interference (ISI) introduced by the cable. Electrical and mechanical specifications for SFP+ optical modules, 10GSFP+Cu, and hosts are defined in the SFF-8431 specification developed by the SFF Committee, with broad industry participation. These Direct Attach copper cable assemblies were the focus of the interoperability testing.

## Test Plan

The purpose of the event was to demonstrate the 10GSFP+Cu specification's consistency and host interoperability over various cable lengths, host channels, and PHYs. The test philosophy was to verify host transmitter compliance and cable compliance but assume the host receiver is compliant to 10GSFP+Cu. A host transmitter and cables operating with host receiver with BER <1E-12 is considered compliant and interoperable. The event focused on verification and compliance testing to demonstrate when compliant PHYs, host channels, and cables are combined it will result in interoperable system.

### Questions addressed while developing the test plan

- *What are the component level tests to be performed?*  
To ensure that parameters of the following individual components were within the limits specified by the specifications, it was agreed to test each of them for compliance prior to actual interoperability test.
  - SFI Channel
  - Transmitter Output
  - Direct Attach Cable
  - Host Receiver Input Signal
- *What SFI trace length to use?*  
To enable the interoperability tests to be run in parallel, it was decided to mate each PHY with a specific SFI trace length and measure the PHY transmitter and receiver compliance only for that particular trace length. The trace lengths selected were between 1.6" and 5", covering the range of host board trace lengths in typical SFP+ host designs. This eliminated the need for interoperability tests to be run sequentially, and the need to disconnect and reconnect PHY boards to the SFI trace board.
- *What cable lengths to test?*  
The intention was to test cables at the limits of the specification and also a variety of lengths to ensure that the specification is robust with an objective to catch any potential issues or concerns in the specification. Cables of lengths from 1m to 8.5m were used to cover the range of of cable lengths that may be used in actual field applications.
- *What transmitter, cable and receiver combinations to test?*  
To ensure complete interoperability between compliant components, it was decided that interoperability BER tests would be run for all transmitter, receiver and cable combinations. The only combination that was eliminated was a PHY transmitter interoperating with its own receiver.

### List of Tests Performed

- *Test 0: Calibration and compliance verification of SFI Channel*  
In this step, the S-parameters of each SFI channel on the host test board (1.6" to 5" of FR4-6) was measured and verified for compliance to the SFI channel transfer recommendations specified in section A.2 of the SFF-8431 specification.
- *Test 1: Calibration and compliance verification of host transmitter 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 mated to its transmitter (1.6" to 5" of FR4-6). The NIC card was tested with the nominal trace on the card.
- *Test 2: Direct Attach Cable characterization*  
Cables were tested for compliance to the cable assembly specifications detailed in the SFF-8431 specification.
- *Test 3: Compliance verification of receiver input signal*  
The receiver input signal was measured and verified for compliance to the linear host receiver specifications in Table 15 of SFF-8431. The receiver input signal was measured for all combinations of host transmitters and cables.
- *Test 4: Interoperability between host transmitters, cables and receivers*  
10GbE traffic tests were performed for all transmitter, receiver and cable combinations.

## Test Setup

### Reference boards:



Figure 1: Module Compliance Board (MCB)



Figure 2: Host Compliance Board (HCB)

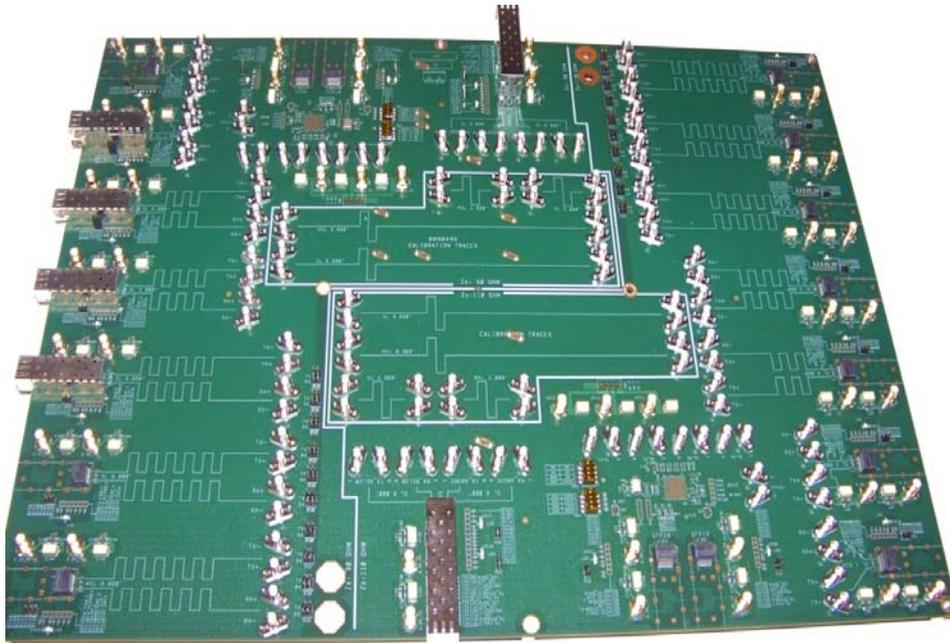


Figure 1: SFI Host Channel

Test equipment:



Figure 2: Agilent 86100C DCA-J



Figure 3: Agilent 8720 Vector Network Analyzer (VNA)



Figure 4: BertScope 12.5G Signal Integrity Analyzer

Test configurations:

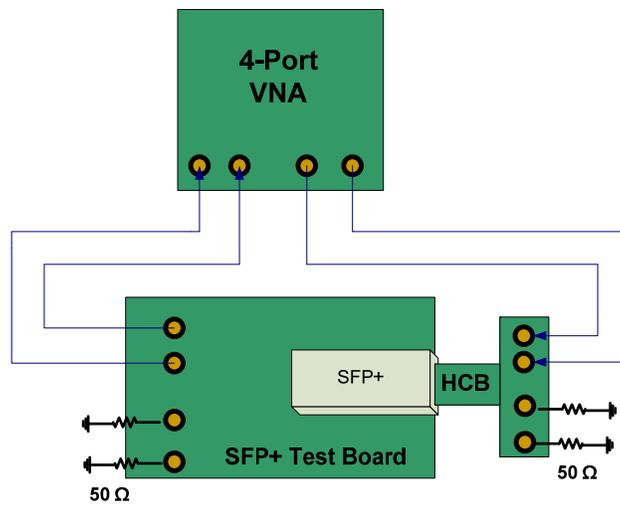


Figure 5: SFI Channel Compliance

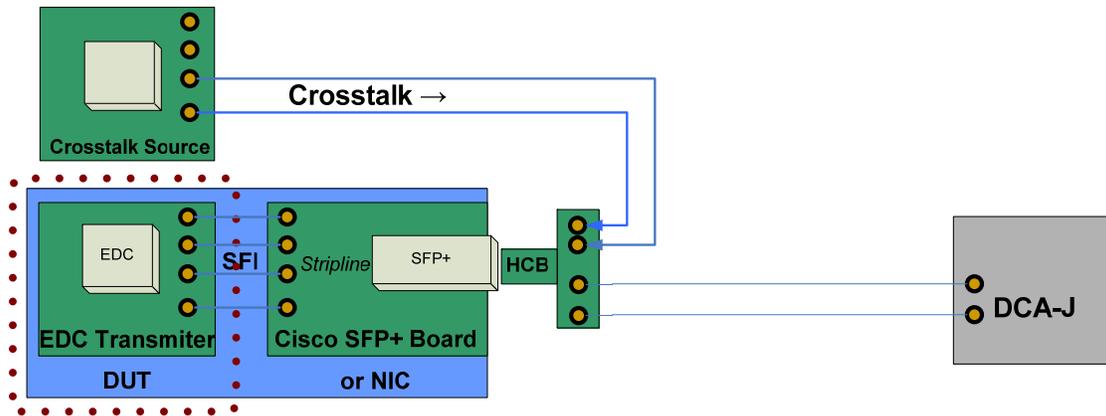


Figure 6: Test 1, Host Transmitter Compliance

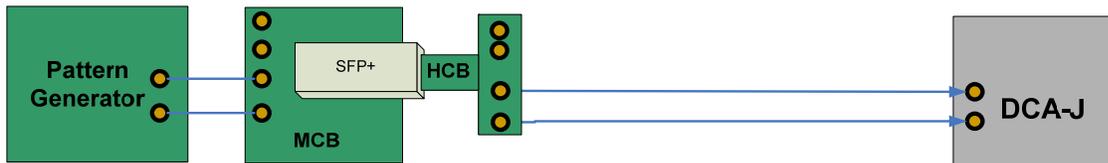


Figure 7: Cross talk source calibration

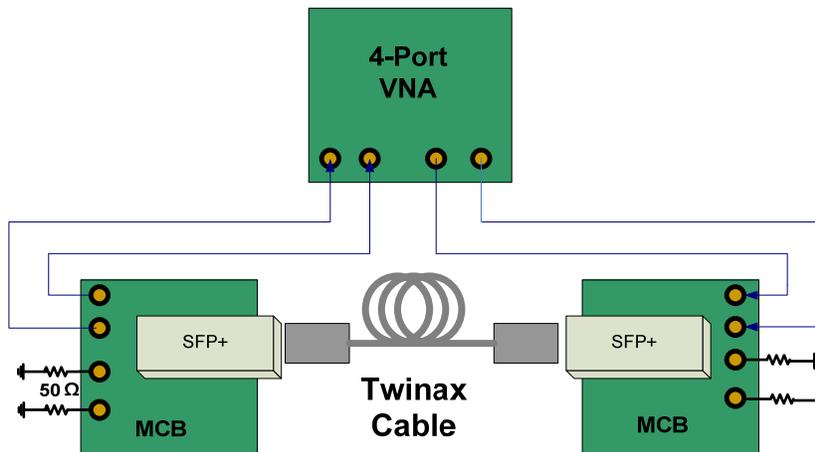


Figure 8: Cable S-parameter measurement

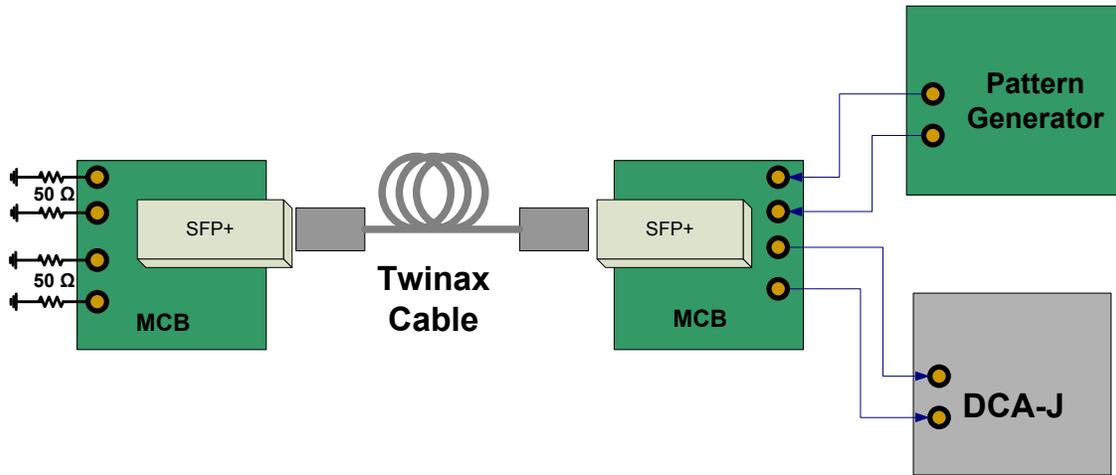


Figure 9: Cable cross talk test set-up as per SFF-8431 E.4.1

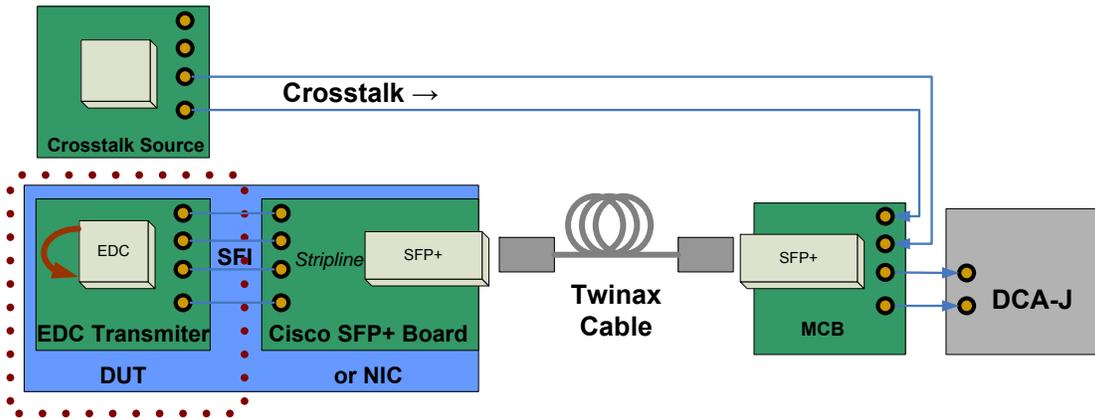


Figure 10: Receive signal characterization

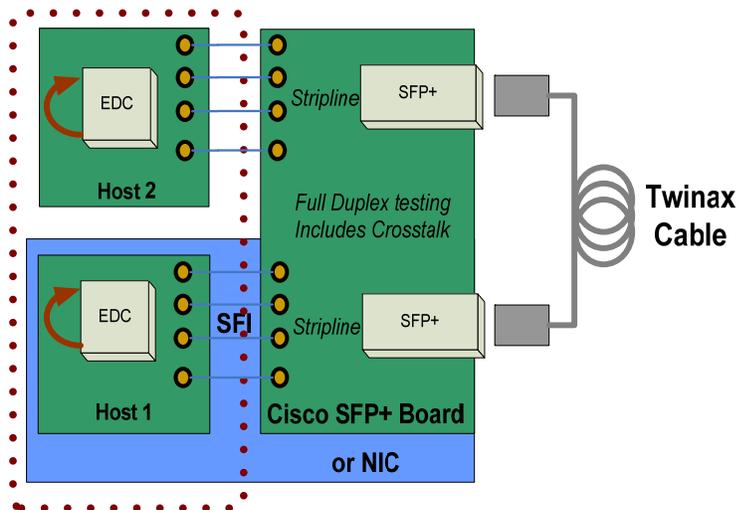


Figure 11: Interoperability test set-up

# Test Results

This section outlines the results from the host transmitter compliance test (Test 1), Direct Attach Cable Compliance test (Test 2), Receiver input signal compliance verification testing (Test 3), and the actual SFP+ interoperability tests (Test 4). The test results are presented anonymously throughout, with the PHY participants randomly labeled A through G and the cable participants randomly labeled 1 through 6.

## Test 0: SFI channel compliance

Test 0 measured the insertion loss for the different SFI traces used for discrete PHYs and verified that these are within the informative limits specified by SFF-8431. Note that the reference insertion loss limits in the SFF-8431 specifications include losses in the device package, which are not captured in these measurements.

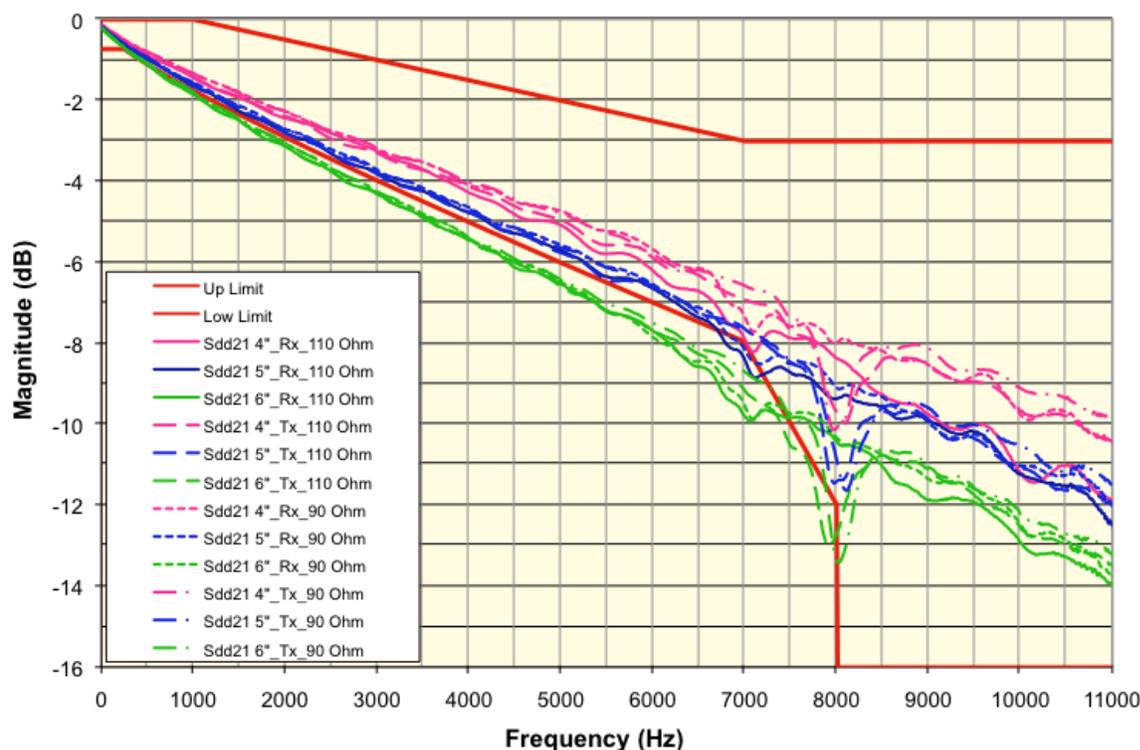


Figure 12: Host Channel Insertion Loss

In addition, 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 FR4-6 channel board. Thus the channel insertion loss as seen by the PHY transmitter and receiver is higher than in the plots below.

## Test 1: Host Transmitter Compliance

Each standalone PHY was mated with one of the Cisco SFP+ test board SFI host channels. As can be seen from Figure 3, the board has two symmetric halves, with SFP+ cages on the edges. The SFP+ channels on the board have one half made with low impedance 90  $\Omega$  traces and the other half are made with high impedance 110  $\Omega$  traces. Each SFP+ channel has compliant SFF-8083 connectors on the

module end and SMA connectors on the other end for mating to the PHYs test boards made from FR4-6 (Isola 370HR). Each PHY was mated to a specific SFP+ channel on Cisco SFP+ board in order to create an SFP+ host. The traces used for this evolution were 5 mils wide stripline. The traces had two via stubs each <15 mils long, one at the SMA launch and the 2<sup>nd</sup> one at the SFF-8083 connector. Figure 14 shows differential insertion loss for the 4”, 5”, and 6” host channel when measured with HCB. With 6” trace clearly exceeding max insertion loss, the following trace lengths and impedance combinations on the board were used for the interoperability tests: 5” and 110 Ω, 5” and 90 Ω, 4” and 110 Ω, 4” and 90 Ω, 1.6” and 90 Ω. An identical channel is encountered by the PHY as transmit and receive traces on this board are symmetric. 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 Cisco test board using high speed coaxial cables.

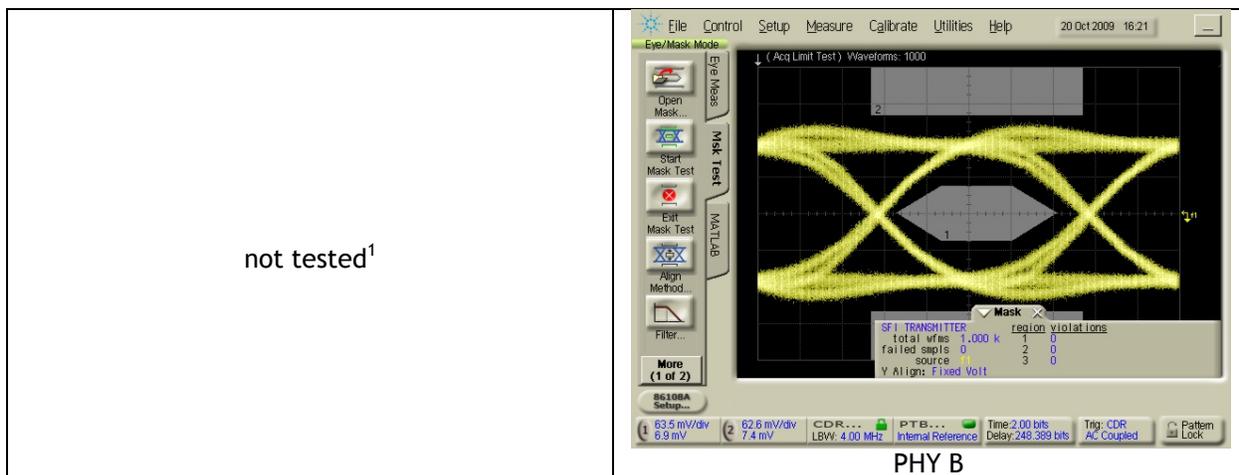
For NIC cards, the SFI trace lengths on transmit and receive paths were limited to the board trace on the NIC card from the PHY device to the SFP+ connector.

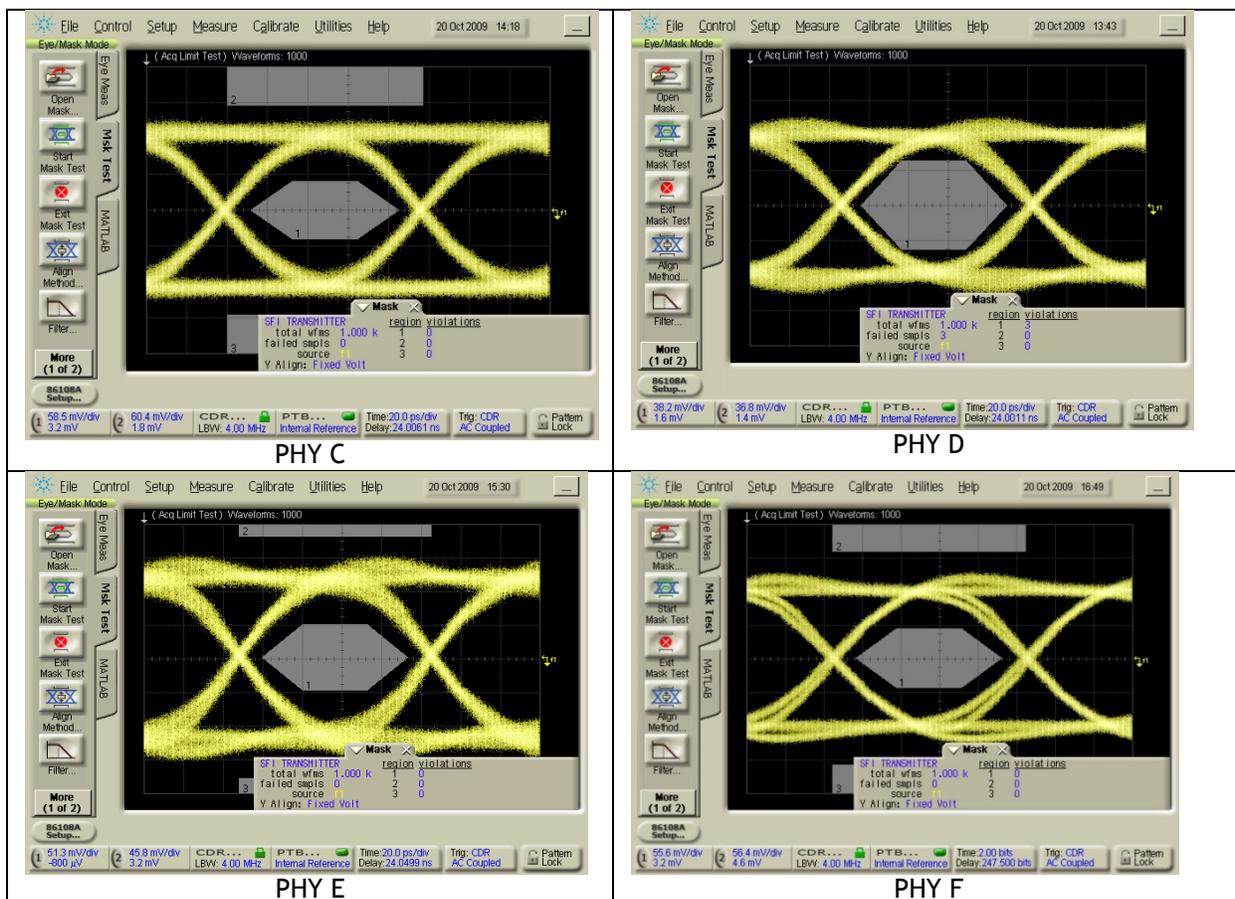
Test 1 measured key transmit eye parameters at the SFP+ connector, in the presence of asynchronous crosstalk, as specified by Tables, 11, 12 and 33 of the SFF-8431 specifications. Crosstalk was calibrated using a mated Host Compliance Board (HCB), Module Compliance Board (MCB) combination. Amplitude and Rise/Fall times were set as specified in Table 12 of SFF-8431. Table below summarizes the PHY transmit output measurement results:

| PHY/NIC Vendor | SFI Trace Length | SFI Trace Impedance | VMA (mV) | TWDP (dB) | DDJ (UI) | DDPWS (UI) |
|----------------|------------------|---------------------|----------|-----------|----------|------------|
| Limit          |                  |                     | 300      | 10.7      | 0.1      | 0.055      |
| A              | N/A              |                     | 513      | 10.56     | .090     | .0028      |
| B              | 5”               | 90 Ω                | 473      | 9.78      | .097     | .051       |
| C              | 4”,              | 110 Ω               | 504      | 10.39     |          | .047       |
| D              | 5”,              | 110 Ω               | 303      | 10.39     | .082     | .049       |
| E              | 1.6”,            | 110 Ω               | 460      | 10.2      | .092     | .047       |
| F              | 4”,              | 90 Ω                | 411      | 9.56      | .093     | .048       |

### Transmit eye mask captures

The transmitter mask measurements were performed as specified Table 12 of the SFF-8431 specifications.





1: Was not tested due to set-up issues

## Test 2: Cable Compliance

Test 2 measured compliance of the SFP+ direct attach cables to key cable parameters specified in Table 37 of the SFF-8431 specification.

### Cable S-parameters

The cable S-parameters for each of the cable vendor were measured and designated by Sxx□m, where □ is the cable vendor designation 1-6 and □ is the cable length followed by m for meter. Cable through response SDDxy are plotted for each of the cables as shown in Figure 13. This was not a required test but shown for information.

Cable differential responses SDDxx are plotted for each of the cables as shown in Figure 14 and every cable passed with margin.

Cable common mode responses SCCxx were plotted for each of the cables as shown in Figure 13 and two of the cables did exceed the common mode mask limit. The MCB SCCxx limit is also shown on Figure 15 where the limit line is dominated by SFF-8083 connector. With the MCB SCCxx limit line < 2 dB from the cable limit line at 3.5 GHz, meeting the cable limit with only 2 dB margin is quite challenging. Since common mode response has no direct impact on link operation and was added because of unquantified EMI concerns, it is recommended that SFF-8431 consider relaxing SCC limit line..



The cable differential responses SCDxx are plotted for each of the cables as shown in Figure 16 and every cable passes with margin.

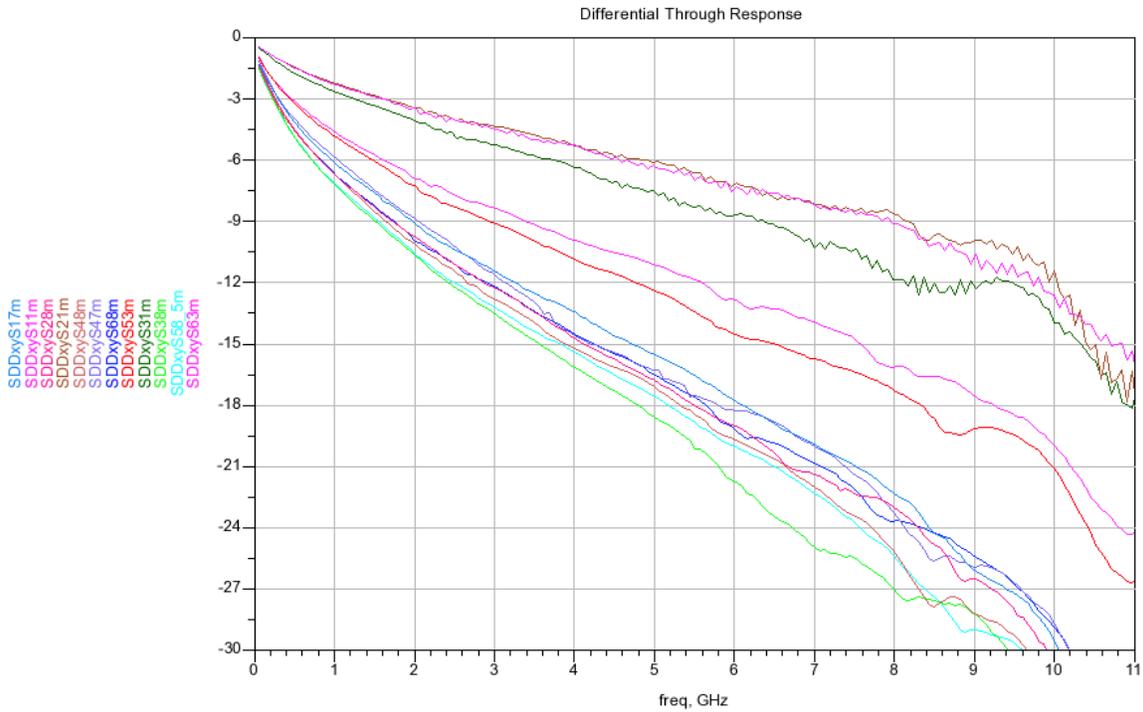


Figure 13: Cable loss (Informative)

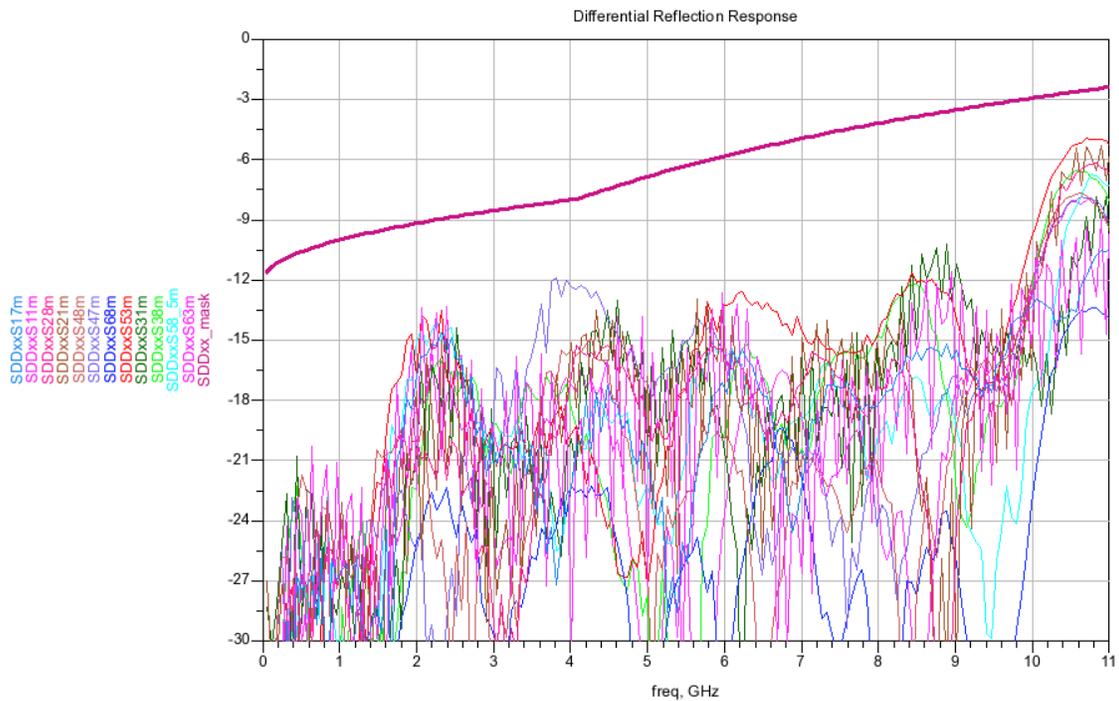


Figure 14: Cable differential response

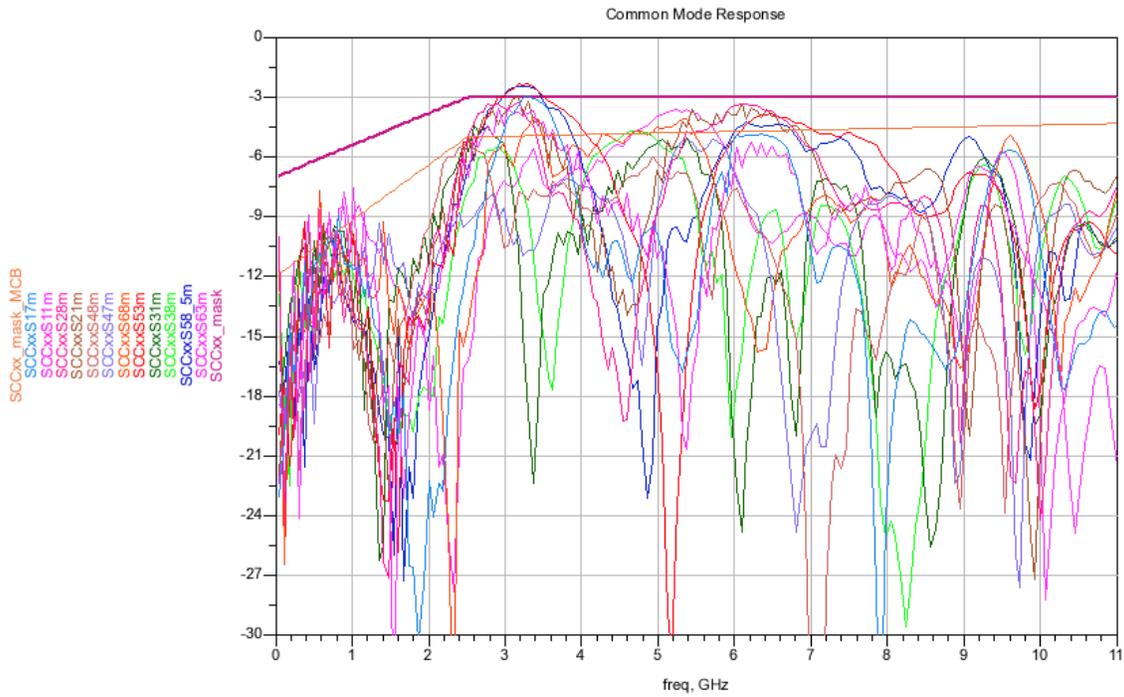


Figure 15: Cable common mode response

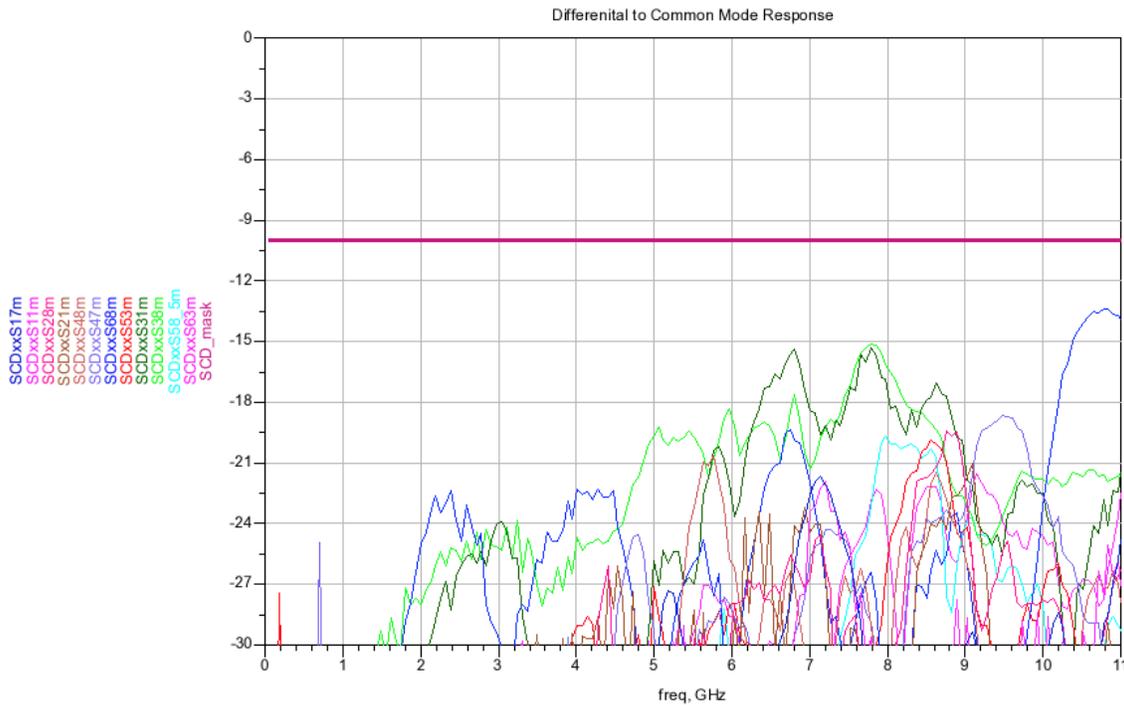


Figure 16: Cable differential to common response



Cable Loss and Crosstalk

VMA loss and dWDP were implicitly calculated from PRBS9 waveform captures of cable input and output signals. The Voltage to Noise Ratio (VCR) was computed from the measured RMS crosstalk noise, and cable VMA loss, as specified in Section E.4.4 of SFF-8431 specifications. The recorded values for cable loss parameters are the average across the parameter values obtained with the different PHY outputs.

| Cable Vendor | Cable Length | VMA Loss (dB) | dWDP (dB) | Crosstalk RMS (mV) | VCR (dB)          |
|--------------|--------------|---------------|-----------|--------------------|-------------------|
| Limit        | Any          | 4.4           | 6.75      | 2.1                | 32.5 <sup>1</sup> |
| 1            | 7m           | 3.97          | 5.37      | 1.01               | 38.43             |
| 2            | 8m           | 4.14          | 5.59      | 1.53               | 34.73             |
| 3            | 8m           | 4.54          | 6.53      | 1.43               | 34.99             |
| 4            | 8m           | 4.30          | 5.80      | 2.27               | 31.17             |
| 5            | 8.5m         | 4.62          | 6.05      | 1.37               | 35.31             |
| 6            | 8m           | 4.17          | 5.73      | 1.98               | 32.45             |
| 1            | 1m           | 1.07          | 1.60      | 0.85               | 42.83             |
| 2            | 5m           | 3.87          | 4.98      | 1.70               | 34.01             |
| 3            | 1m           | 1.36          | 2.00      | 1.25               | 38.52             |
| 4            | 7m           | 3.76          | 5.18      | 1.87               | 33.31             |
| 5            | 3m           | 2.86          | 3.85      | 1.05               | 38.98             |
| 6            | 3m           | 2.77          | 3.46      | 1.69               | 34.90             |

Note 1: The VCR number in Rev 4.1 of SFF-8431 is incorrect. The corrected VCR value for a cable with VMA loss of 4.4 with 2.1mV RMS crosstalk should be 31.78 dB instead of 32.5 dB.

### Test 3: Receiver Input Signal Compliance

Each transmitter was paired with every cable to confirm that the pairing of a compliant transmitter and compliant cable generated a host receiver input signal that is compliant to the WDP and VMA limits specified in Table 15 of SFF-8431. Only the results for the longer cable lengths are reported here. Measurements were performed for all PHY-Cable combinations, and it was verified that the receiver input signals for all combinations were compliant.

| Cable (Vendor, Length)    | PHY | VMA (mV)                | WDP (dB)                |
|---------------------------|-----|-------------------------|-------------------------|
| Vendor: 1<br>Length: 7m   | A   | 320                     | 7.46                    |
|                           | B   | 296                     | 7.29                    |
|                           | C   | 316                     | 7.99                    |
|                           | D   | 200                     | 7.33                    |
|                           | E   | 287                     | 7.21                    |
|                           | F   | 262                     | 6.84                    |
| Vendor: 2<br>Length: 8m   | A   | 312                     | 7.80                    |
|                           | B   | 289                     | 7.38                    |
|                           | C   | 307                     | 8.03                    |
|                           | D   | 191                     | 7.62                    |
|                           | E   | 297                     | 7.46                    |
|                           | F   | 254                     | 7.12                    |
| Vendor: 3<br>Length: 8m   | A   | not tested <sup>1</sup> | not tested <sup>1</sup> |
|                           | B   | not tested <sup>1</sup> | not tested <sup>1</sup> |
|                           | C   | not tested <sup>1</sup> | not tested <sup>1</sup> |
|                           | D   | 182                     | 8.57                    |
|                           | E   | not tested <sup>1</sup> | not tested <sup>1</sup> |
|                           | F   | 240                     | 7.82                    |
| Vendor: 4<br>Length: 8m   | A   | 301                     | 7.73                    |
|                           | B   | 288                     | 7.54                    |
|                           | C   | 307                     | 8.61                    |
|                           | D   | 191                     | 7.75                    |
|                           | E   | 277                     | 7.65                    |
|                           | F   | 254                     | 7.41                    |
| Vendor: 5<br>Length: 8.5m | A   | 297                     | 8.29                    |
|                           | B   | 275                     | 7.79                    |
|                           | C   | 294                     | 8.33                    |
|                           | D   | 183                     | 8.23                    |
|                           | E   | 266                     | 8.08                    |
|                           | F   | 244                     | 7.44                    |
| Vendor: 6<br>Length: 8m   | A   | 314                     | 7.81                    |
|                           | B   | 290                     | 7.73                    |
|                           | C   | 310                     | 8.22                    |
|                           | D   | 191                     | 7.75                    |
|                           | E   | 282                     | 7.56                    |
|                           | F   | 257                     | 7.23                    |

1: Was not tested due to set-up issues

Test 4: Interoperability Testing

To ensure that the interoperability measurements were comprehensive, interoperability of each PHY transmitter was tested against all other PHY receivers, over all the cables in both transmit and receive directions.

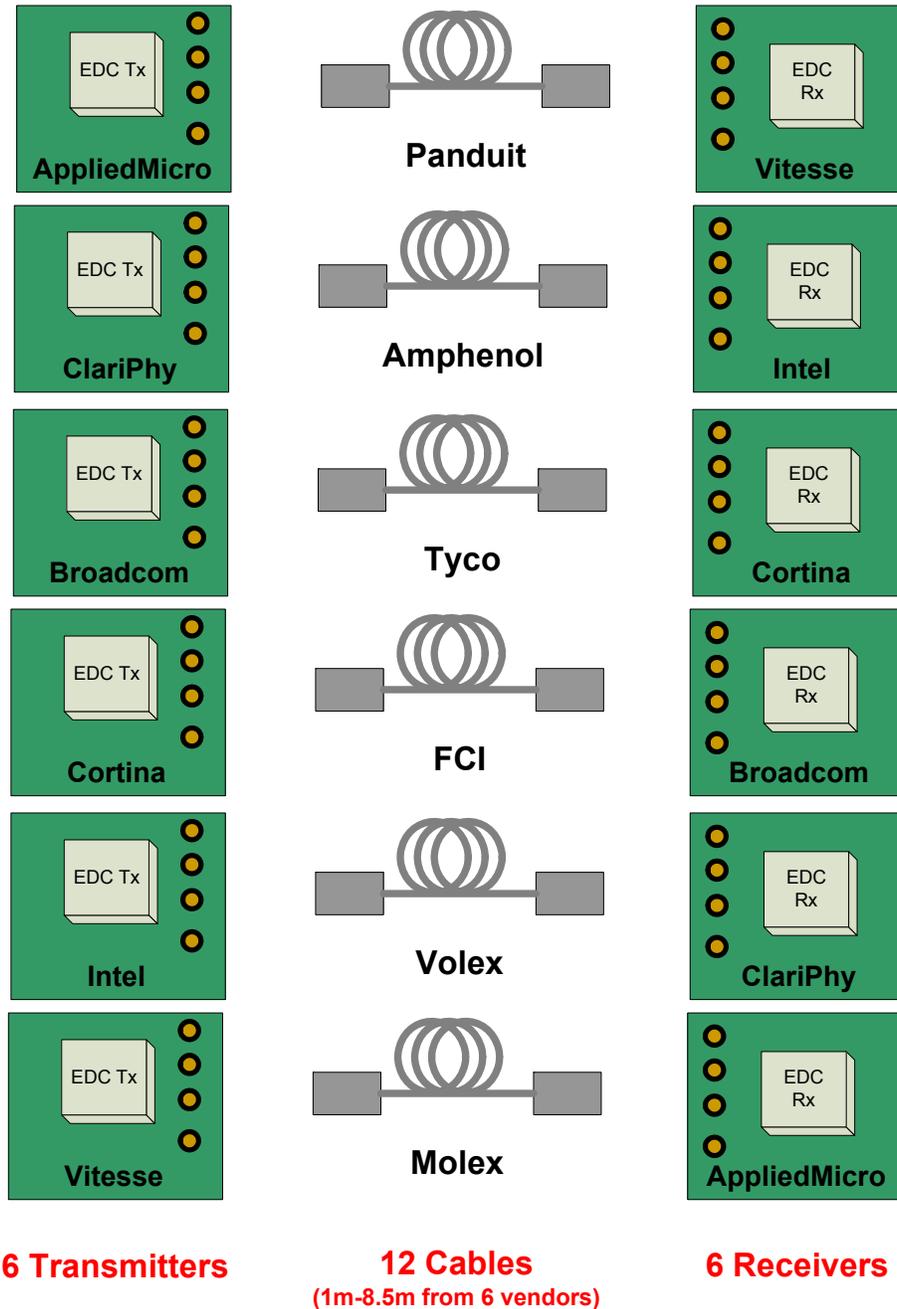


Figure 17: Interoperability test configuration



The overall intent was to show that the SFP+ SFF-8431 specification for copper direct attach cable is robust and interoperable over a range of cables and host ports widely available in the industry. The passing criteria for this test was a BER better than the SFF-8431 requirement of 1E-12.

All PHY transmitter, cable, and PHY receiver combinations were tested. With 6 different PHYs measured in both directions connected over 12 cables from 6 vendors, this amounted to a total of 360 links tested. The measurements were done transmitting 10GbE traffic at 10.3125Gbps, with a 5 minute gating time for each test. All of the combinations tested resulted in a measured BER better than 1e-12, therefore passing the SFF8431 SFP+ specification.

## Summary

The 10GSFP+Cu interoperability demonstration and this white paper are the result of collaboration between a broad set of semiconductor, system, and cable vendors. Full matrix interoperability to the limits of the specification impressively demonstrated that the specification was adequately developed. The favorable results also give IT managers a high degree of confidence that an interoperable and highly-available 10 Gigabit Ethernet network can be achieved when using equipment from multiple vendors with SFP+ host ports and SFP+ cable assemblies that are compliant to SFF-8431.

## About Ethernet Alliance

The Ethernet Alliance was created to promote industry awareness, acceptance and advancement of technology and products based on existing and emerging IEEE 802 Ethernet standards. The organization accelerates industry adoption and removes barriers to market entry by providing a cohesive, market responsive, industry voice on IEEE 802 Ethernet projects. For more information, visit [www.ethernetalliance.org](http://www.ethernetalliance.org). Individuals who would like to receive updates on Ethernet Alliance news, activities and events may sign up for the organization's newsletter by [clicking here](#).

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