Testing and Interoperability of 10GBASE-LRM Optical Interfaces

Introduction

This article will discuss some of the issues in testing 10GBASE-LRM optical interfaces over multimode fiber, and will outline a methodology for doing so. The article will also describe test results from a recent multi-vendor interoperability test demonstrating the feasibility and robustness of the LRM interface.

Background

Multimode fiber comprises the majority of the installed base of fiber plant for data communications. Older multimode fibers installed in the early 1990s exhibit large amounts of modal dispersion, making for a challenging transmission channel, particularly at 10 Gb/s data rates, and limiting the transmission distance significantly. For instance, 10 Gigabit Ethernet 850 nm devices for multimode fiber (10GBASE-SR) are guaranteed to operate up to only 26 m on worst-case 62.5-µm multimode fiber. 10GBASE-LRM is a new cost-effective and small form factor compatible optical link solution for extended reach on multimode fiber. LRM has been specifically designed for vertical riser applications in building backbones, which require longer transmission distances and where new fiber pulls are cumbersome and costly, to enable the upgrade to 10 Gigabit Ethernet of existing optical links between datacenter switches and workgroup switches. LRM is standardized in the IEEE Std. 802.3aq™-2006 serial optical interface standard, published in November 2006. LRM is a 10G serial interface that uses long wavelength (1310 nm) optics and a receiver with an adaptive electronic equalizer IC in the receive chain in order to transmit up to 220 meters on legacy multimode fiber. The adaptive equalization, known as EDC, is used to compensate for the differential modal dispersion (DMD) present in legacy fiber channels.

Issues with LRM testing over multimode fiber and main parameters definitions

The most direct way to validate LRM optical interfaces is simply to test over actual multimode fiber, as this is most representative of the actual application and is the only way to demonstrate interoperability between two optical transceivers. However, there are two significant difficulties in repeatably and reliably testing transmission over multimode fiber.

First, multimode fibers vary widely in bandwidth and differential mode delay (DMD) profiles, so that signal quality and transmission results will also vary widely from one fiber to another (see Figure 1, below). In the process of producing the LRM standard, the IEEE LRM Task Force took a statistical approach, modelling and testing a number of fibers to define transmit and receiver parameters that would result in error free transmission over 99% of 220m long fibers in the field (the majority of deployed fibers are considerably shorter than this).

Two test parameters in particular relate to the modelled fiber transmission channel and are below defined.

- Transmitter Waveform Dispersion Penalty (TWDP). This penalty is defined as the difference (in dB) between a reference signal to noise ratio (SNR) and the equivalent SNR at the slicer input of a reference equalizer receiver for the measured waveform after propagation through a simulated channel.
  Measuring TWDP involves capturing a transmitter waveform and processing it using code to calculate the penalty of that waveform on a reference equalizer (detailed reference about definitions and processing).

– Comprehensive stressed receiver sensitivity (CSRS). CSRS measurements involve generating a set of stressed optical signals defined by the LRM standard and inputting them to the receiver to verify error-free performance (for details refer to IEEE Std. 802.3aq^{TM}-2006 , paragraph 68.6.9).

These two parameters among others defined by the IEEE are designed to guarantee interoperability and link performance for LRM, and are static and repeatable. However, if one would like to test to the limits of the LRM specification using actual fiber, the significant differences from one fiber to another remain an issue.

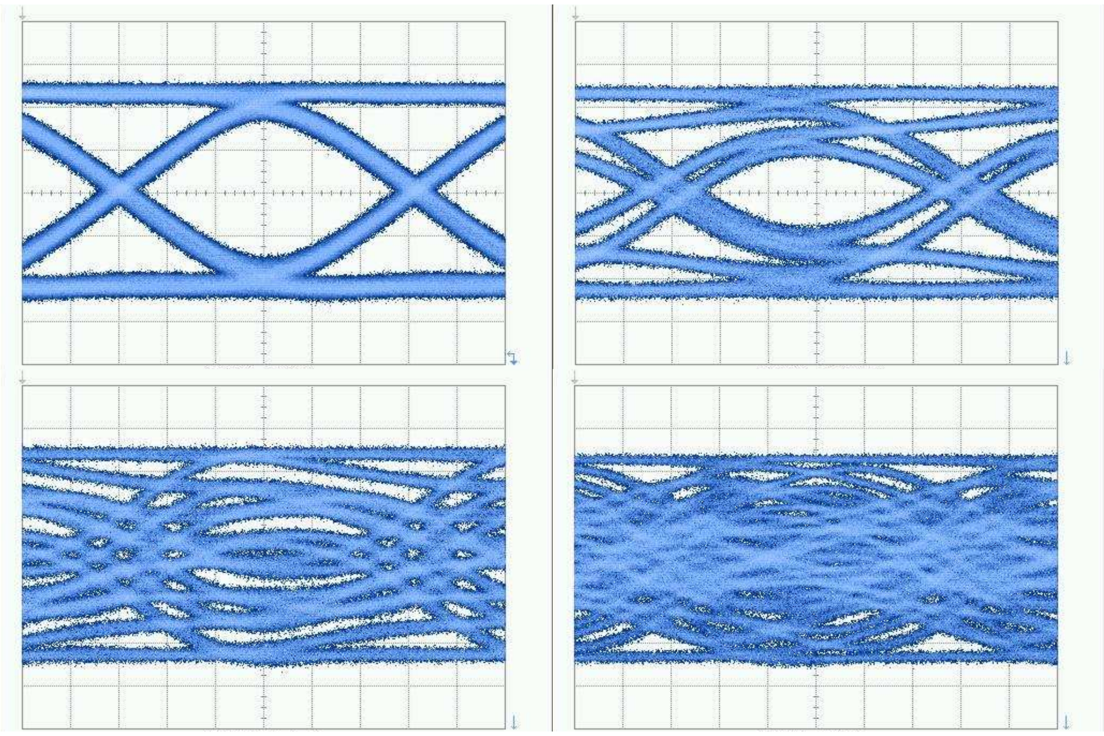

Figure 1. Eye diagrams through 300m multimode fibers of varying bandwidths and DMD profiles

Second, transmission performance over one individual multimode fiber can vary significantly depending on the dynamic state of the fiber (position, bending, polarization, etc.), such that when the fiber is moved, the mode profile of the fiber will change. This can cause test results to vary widely over time and from one measurement or measurement run to the next (the LRM standard defines a rate of dynamic changes of the channel of up to 10 Hz). To address this variability, there are a number of approaches that can be used. A fiber shaker is the most direct approach to perturb the fiber and change the modal response in a semi-deterministic way; however, the equipment is bulky and custom and not in typical use in most optics labs. An alternative to using a fiber shaker is to use a polarization controller, which scrambles the modal delays experienced by the optical signal within the fiber as well, resulting in much the same effect. A polarization controller has the added advantage of being able to change states at a higher speed than a fiber shaker.

In either case, whether using a fiber shaker or polarization controller, the basic LRM fiber testing methodology laid out here is the same:

1. To define a "valid" link by measuring two fiber characteristics. The first one is the TWDP (already defined in this document), while the second is the effective modal bandwidth, EMBW.

   EMBW is the measure of the fiber bandwidth when a particular transceiver and launch condition is considered.

These two measurements repeated over all states of the fiber (polarization states or positions of the fiber shaker) and ensuring that the maximum TWDP is within the LRM receiver spec and that the EMBW meets the minimum specified fiber bandwidth in the LRM standard will give characterization of the link.

2. To continuously sweep through the fiber states while testing transmission to average over all fiber states.

This method ensures that “realistic links” are defined (meaning a fiber that is within 99% of the installed FDDI-grade, OM1, OM2 and OM3 fibers at 220 meters) and by averaging over multiple fiber states, greatly increases the repeatability of over-fiber testing for multimode fibers.

The over-fiber TWDP is then calculated using the Matlab algorithm defined in paragraph 68.6.6.2 of the IEEE LRM standard and setting fiber stressors to 0,1,0,0. If this penalty exceeds that given in the standard (for this experiment we used 4.2 dB, which is the maximum penalty given for the post-cursor stressor), then the fiber is not representative of a “real” fiber one might reasonably expect to find in the field. The effective modal bandwidth (EMBW) is then also calculated from the same waveform, de-convolving the bandwidth of the transmitter and receiver used for the measurement. The IEEE Std. 802.3aq™-2006 LRM standard specifies in table 68-2 a minimum modal bandwidth of 500 MHz*km for FDDI-grade, OM1, OM2, and OM3 fibers; this corresponds to a minimum EMBW of 2.3 GHz over 220m.

Then the polarization controller is stepped to another polarization state, a new waveform is captured, and the TWDP and EMBW are measured again. This continues until several fiber states have been captured.

For each transmitter/ fiber combination TWDP and EMBW are measured for each of several polarization settings. These measurements are plotted in Figure 4. Looking at the figure, we can then say that if all TWDP/EMBW values for any polarization state lie within the green region (TWDP less than the 4.2 dB defined at the receiver end of the link in the IEEE standard, and EMBW greater than the 500 MHz-km defined in the IEEE standard), the fiber under test is a realistic case link for 10GBASE-LRM application and representative of the worst real link on which an LRM-compliant transmitter and receiver is expected to operate. Conversely, if some of the points lie outside the rectangular area, the fiber is not part of the 99% of the installed multimode fiber base at 220 m which the IEEE defined for 10GBASE-LRM.

When full step-by-step characterization measurements have taken over fiber, the polarization controller or fiber shaker is then set to continuously sweep through all of the fiber states, and the requirement is that the optical transceiver is able to function error-free over all states of the fiber, including the worst case TWDP and EMBW points of the fiber.

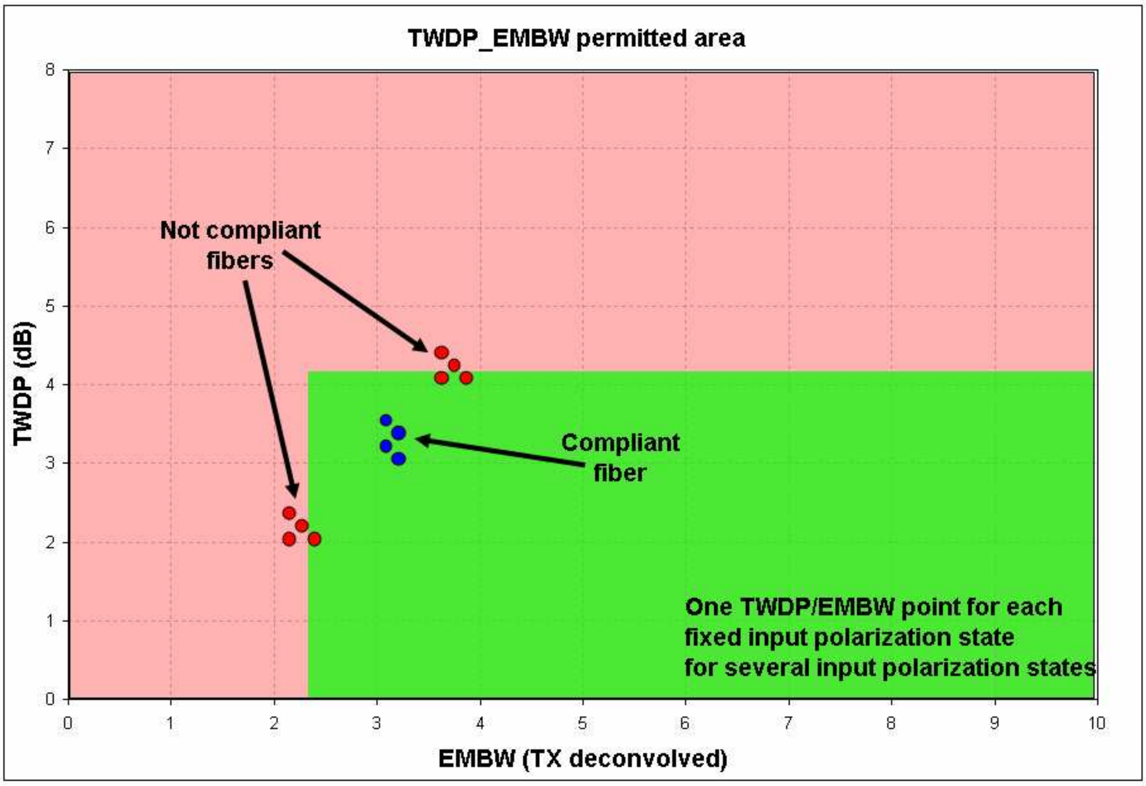

Figure 4: TWDP/EMBW permitted area for 10GBASE-LRM compliant fiber link

Experimental results from multi-vendor interoperability testing of 10GBASE-LRM

Recently seven optical transceiver vendors met under the umbrella of the Ethernet Alliance to demonstrate interoperability of 10GBASE-LRM optical interfaces in support of the IEEE Std. 802.3aq™-2006 standard. Various optical transceiver form factors (X2, XFP, and SFP+) were tested together over 220 meters of OM1 (62.5 µm) multimode fiber, and 260 meters of OM2 (50 µm) multimode fiber.

Two multimode fibers were selected for the interoperability testing based on the methodology described above. To verify the fiber characteristics with each optical transceiver transmitter, the effective modal bandwidth (EMBW) of the fiber and transmitter waveform dispersion penalty (TWDP) after transmission through the fiber were measured with each LRM transmitter participating in the tests. The back-to-back TWDP was also measured for each transmitter and de-convolved from the measurement to calculate only the characteristics of the fiber channel itself, in order to better evaluate EMBW. In the interests of time, no other transmit or receive parameters from the LRM standard were measured during the interoperability testing; each vendor was expected to run these prior to testing and verify that the participating parts were compliant to the LRM standard. Because of logistics and early development status, one transmitter was not fully verified beforehand as compliant to the standard.

Fiber TWDP and EMBW measurements

Two target fibers and launch conditions were proposed at the outset of the interoperability testing. The fiber characteristics and the proposed launch conditions are shown below.

ISO/IEC 11801: 2002 fiber type	Core diameter	Nominal bandwidth*	Launch	Length
OM1	62.5 µm	200/600	Offset	216 m
OM2	50 µm	700/680	Offset	260 m

*Each fiber type is identified by its core diameter followed by a pair of OFL bandwidth values separated by "/". The OFL bandwidths are in MHz.km and are for 850 nm and 1300 nm respectively

As outlined above, first the back-to-back transmitter TWDPs were measured for each vendor's transmitter; values are given below in Table 1, along with the transmitter extinction ratio (ER).

Vendor	ER	TX TWDP
A	4,1	3,8
B	3,6	4,7
C	4,2	4,2
D	5,2	4,0
E	4,0	4,3
F	4,3	4,1
G	5,6	4,7

Table 1: TX characteristics: extinction ratio and TWDP measurements

Note that some of the TWDP and ER values for the 10GBASE-LRM transmitters are very close to the minimum standard requirements; this implies that OMA sensitivity tests (BER observation for error-free condition) were expected to be particularly stressful when these transmitters were used in the interoperability demonstration.

The above sentence is true if the propagation across the fiber is similar for each tested transmitter: in a "real world", by example, what could happen is that a very marginal transmitter is connected to a particular "good" fiber if a particular MCP is used and then behave better then a well-margined transmitter connected to the same fiber, but with no MCP or with a different off-set launch condition (see reference).

Figure 5 and Figure 6, below, show plotted results of the fiber characterization. Again we followed the fiber characterization method outlined above; for both fibers, we plotted different TWDP/EMBW "clouds" over both OM1 and OM2 fiber (one point for each different state of polarization induced by the polarization controller), where each color corresponds to measured values with a different participant's transmitter.

As explained in page3, TWDP were calculated after propagation to verify the links.

All TWDP/EMBW values for every 10GBASE-LRM transmitter were inside the allowed region. From the TWDP/EMBW values over the two fibers, we expected the OM2 fiber to be more challenging than the OM1 for traffic test, since not only is the fiber length longer, but the measured EMBW is lower (3.9 GHz vs. 4.7 GHz) and the TWDP is higher (3.9 dB vs. 3.1 dB).

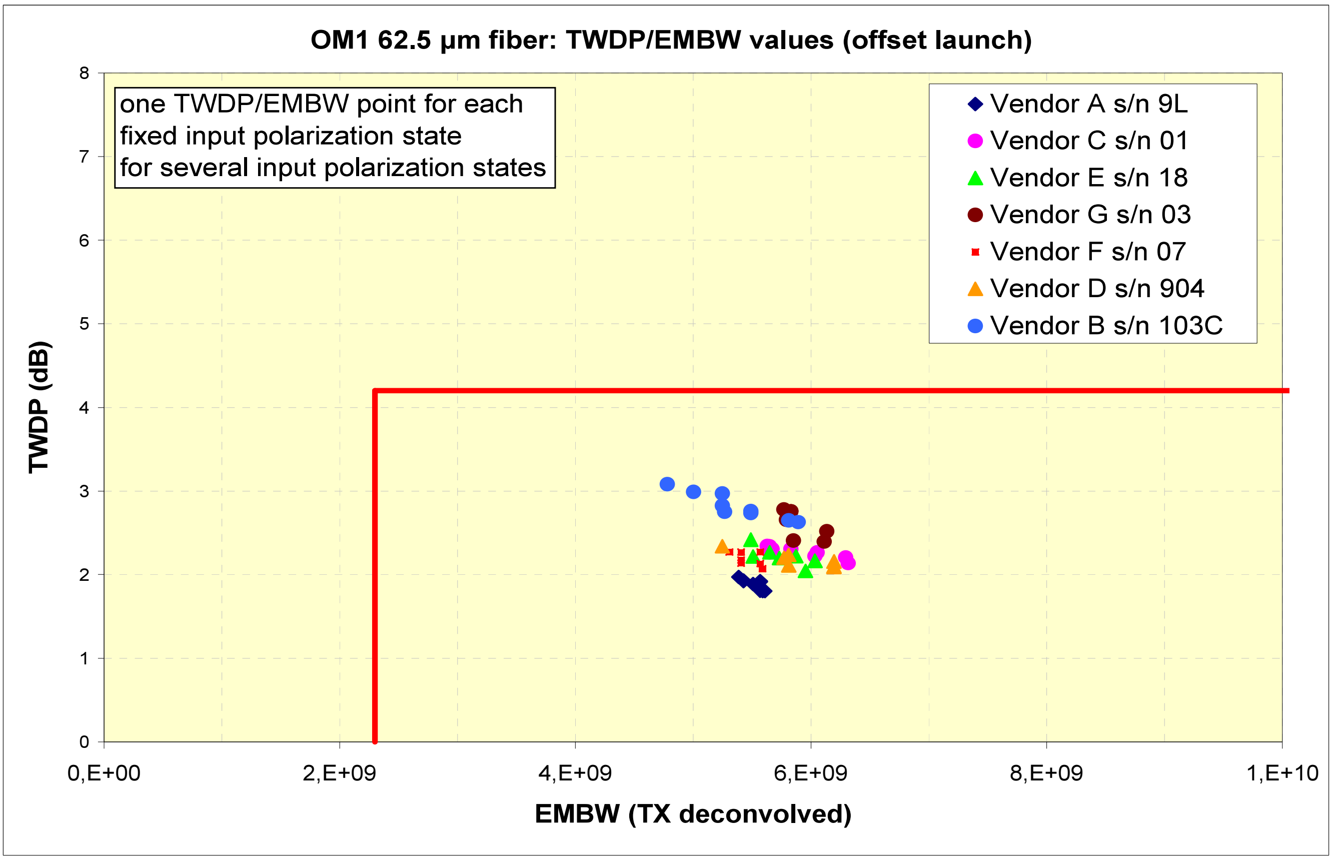

Figure 5: TWDP/EMBW values after propagation over 216m of OM1 fiber (offset launch)

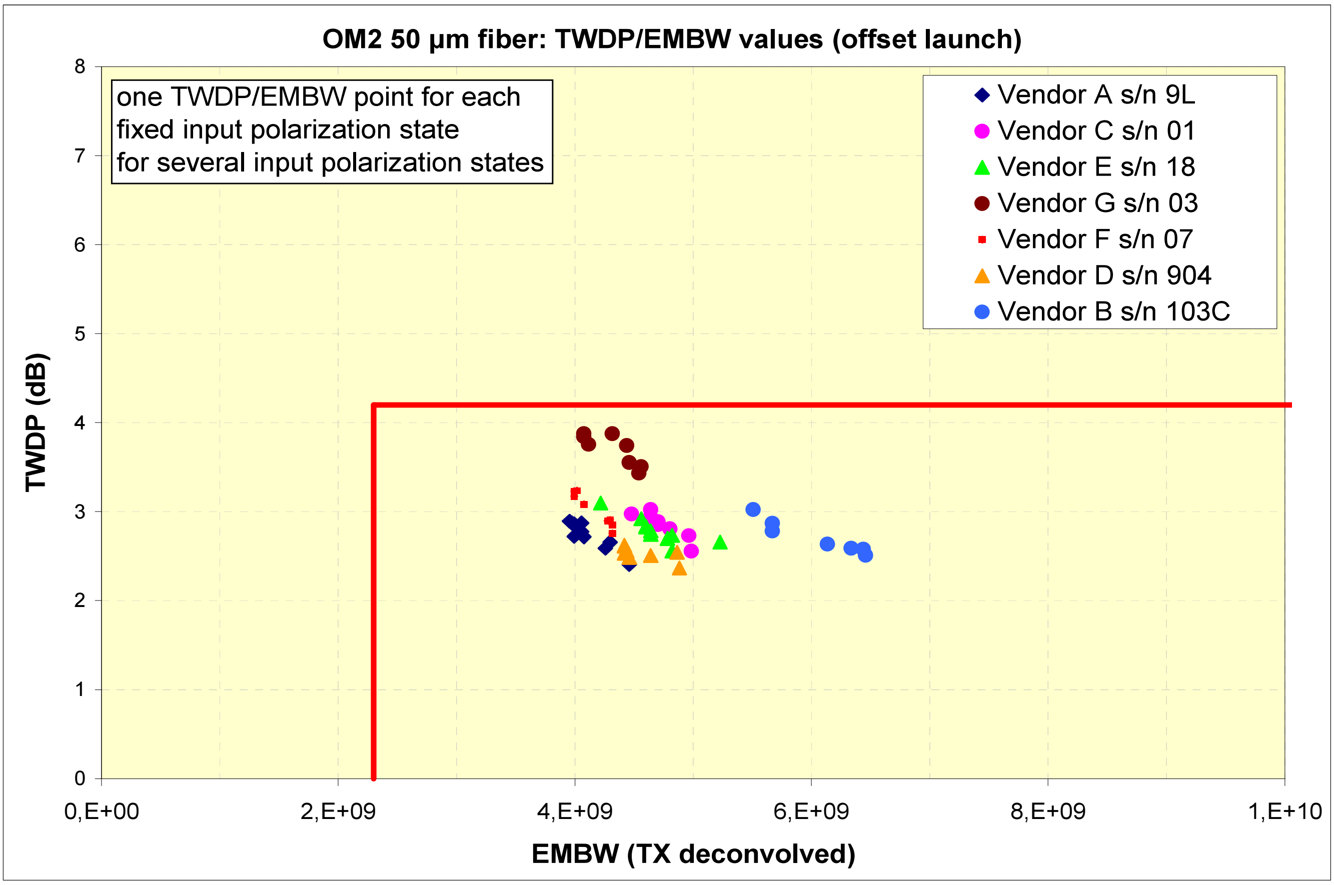

Figure 6: TWDP/EMBW values after propagation over 260m of OM2 fiber (offset launch)

Traffic Testing: Setup

After selecting the fibers over which interoperability would be tested, each LRM transmitter was connected to each receiver, in all possible combinations, and then tested together to verify error-free (1e-12) transmission performance.

During these tests the receiver input power was set at -6.5 dBm OMA (optical modulation amplitude), the minimum stressed receiver sensitivity level specified by the 10GBASE-LRM standard, to ensure testing at a worst-case corner. The input state of polarization was changed continuously throughout the transmission test, to ensure that all states of the fiber were covered including the worst-case stress for that fiber (this also has the side effect of simulating dynamic changes, to add more stress to the receiver). The measurement gating / acquisition time for error-free condition was set at 10 minutes, to guarantee a degree of confidence of around 99% in the measured bit error rates.

Other test conditions were chosen considering the large number of tests to be run (see note below) and the particular set-up:

- Tests were run at ambient temperature and nominal voltage.
- Since during traffic test a Cisco host Ethernet switch was used to generate traffic and check errors, with X2 modules plugged directly into the Cisco host.
- Bidirectional traffic was allowed on the Cisco host switch, so two propagation conditions could be tested at each time (e.g. Vendor A TX vs. Vendor B RX over Fiber1, and Vendor B TX vs. Vendor A RX over Fiber2).
- For the other mechanical formats, X2 modules were used as the “client” side to close traffic on Cisco host; in this case, only one test condition could be covered at a time.

Note: interoperability test cases grow according to the formula n(n-1), where n is the number of participants. In this case having seven participants and two fiber conditions we tested a total of 84 cases.*

The different set-up conditions are illustrated in Figure 1, Figure 2 and Figure 3.

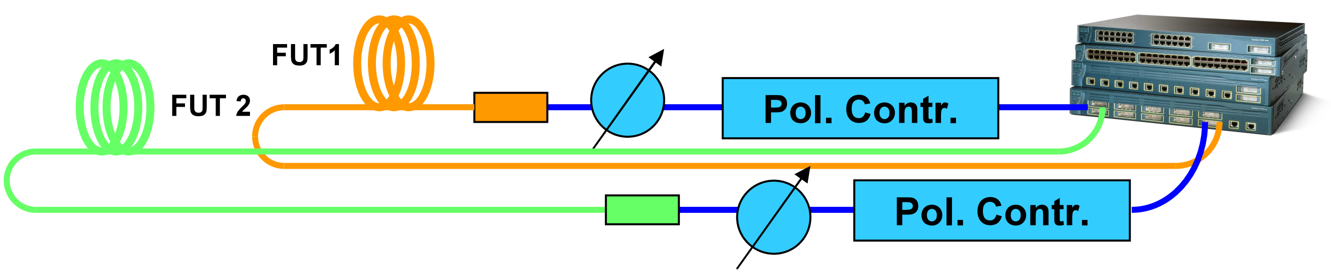

Figure 1: Traffic test using Cisco Ethernet switch; interoperability between X2 modules.

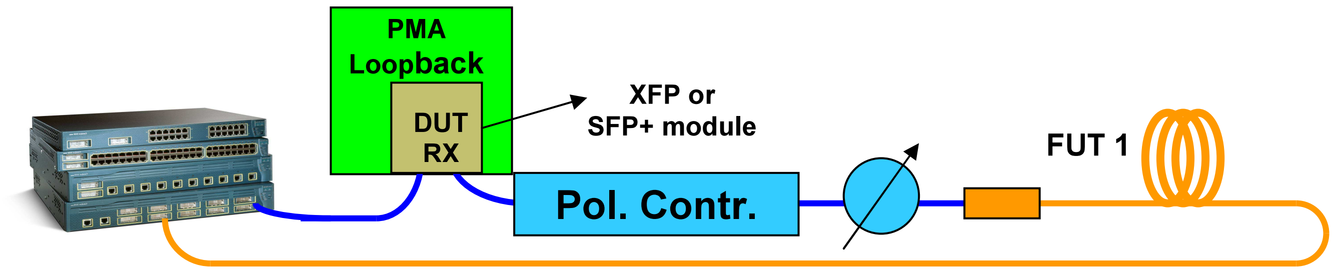

Figure 2: Traffic test using Cisco Ethernet switch; interoperability between XFP (or SFP+) transmitter and X2 receiver.

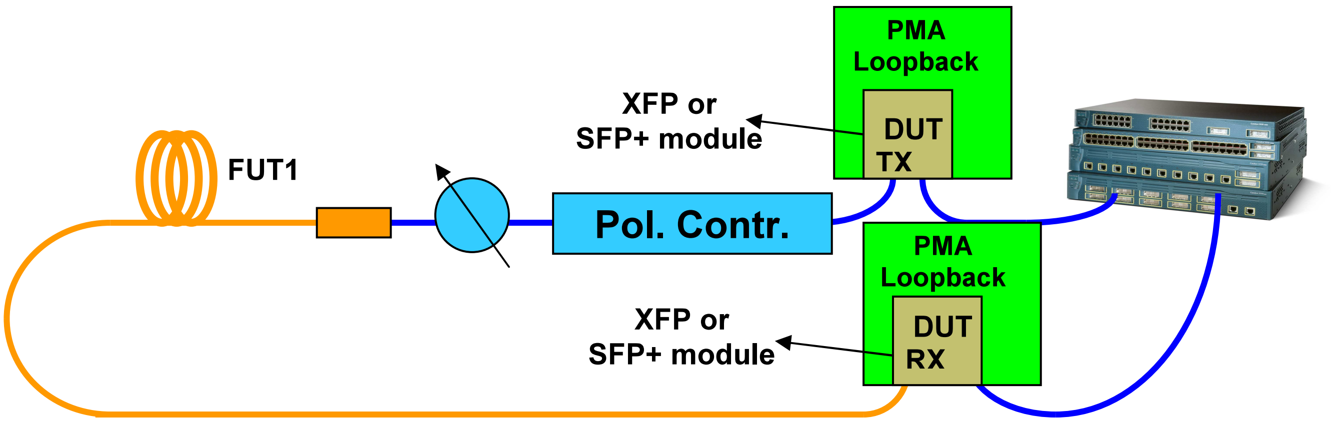

Figure 3: Traffic test using Cisco Ethernet switch; interoperability between XFP (or SFP+) transmitter and SFP+ (or XFP) receiver.

Traffic Testing: Results

Each vendor's transmitter and receiver were tested over both fibers with all of the other transmitters and receivers, and error-free transmission was verified. The overall results were collected into two different tables (one for each fiber), which are shown below. Check marks indicate error free performance for a given combination; if any errors were observed during a test, the bit error rate is given in the table instead.

OM1 fiber, 216m, offset launch

Vendor TX*RX*	*A*	*B*	*C*	*D*	*E*	*F*	*G*
A	n.a.	✓	✓	✓	✓	✓	✓
B	✓	n.a.	✓	✓	✓	✓	✓
C	✓	✓	n.a.	✓	✓	✓	✓
D	✓	✓	✓	n.a.	✓	✓	✓
E	✓	✓	✓	✓	n.a.	✓	✓
F	✓	✓	✓	✓	✓	n.a.	✓
G	✓	✓	✓	✓	✓	✓	n.a.

OM2 fiber, 260m, offset launch

Vendor TX*RX*	*A*	*B*	*C*	*D*	*E*	*F*	*G*
A	n.a.	✓	✓	✓	✓	✓	✓
B	1E-09	n.a.	✓	✓	✓	2E-11	6E-12
C	✓	✓	n.a.	✓	✓	✓	✓
D	✓	✓	✓	n.a.	✓	✓	✓
E	✓	✓	✓	✓	n.a.	✓	✓
F	✓	✓	✓	✓	✓	n.a.	✓
G	✓	✓	✓	✓	✓	✓	n.a.

Interoperability test results for the selected OM1 (62.5 um) fiber were completely error-free in every case, and in almost every case for the selected OM2 (50 um) fiber. The one exception was some low error rates for parts interoperating with one particular transmitter (as mentioned earlier, for various reason this transmitter was not fully verified to be compliant at the outset of testing).

This transmitter was the one which exhibits the lower ER (3.6) and the higher TWDP (4.7), as illustrated in Table 1.

Overall 96% of the test cases passed with no errors, effectively demonstrating interoperability between LRM optical transceivers from multiple vendors.

Conclusion

The new 10GBASE-LRM optical link has been standardized by the IEEE and is coming to market this year. This article discussed fiber test methodology and outlined results from an interoperability demonstration involving several vendors and demonstrating the robustness of LRM optical transceivers.

For More Information

A wealth of detailed research and technical information on the 10GBASE-LRM standard, its application space, and its enabling technologies is available at the IEEE 802.3 10Gb/s on FDDI-grade MM Fiber Study Group web page (http://www.ieee802.org/3/10GMMFSG/index.html) and the IEEE P802.3aq 10GBASE-LRM Task Force web page (http://www.ieee802.org/3/aq/index.html).

The multi-vendor interoperability test described in this article was sponsored by the Ethernet Alliance, an industry group dedicated to the expansion of Ethernet technology. For information about the Ethernet Alliance and its activities please visit http://www.ethernetalliance.org/.