400ZR Interoperability White Paper
OFC 2023 Plugfest

ABSTRACT: This paper presents the methodology and results of an interoperability study of 400ZR transceivers conducted during a “pre-OFC 2023” plugfest. Twelve different transceivers were cross-connected in a matrix of transmitter-to-receiver combinations using a noise-loaded link to characterize the penalties associated with interoperability between suppliers. Individual transceiver performance was compared between a short self-loopback link to a reference optical line system link which included a 75 km fiber and DWDM 75GHz channel spacing. In addition, the accuracy of the module reported optical signal to noise ratio was compared with the value measured by reference test instrumentation to understand the reporting accuracy.

1 Introduction

The Optical Internetworking Forum (OIF) is serving the industry by driving the electrical, optical, and management interfaces that enable efficient and reliable optical networks. The OIF continues to play a key role in the standardization of coherent optics at the physical layer. The 400ZR implementation agreement (IA), OIF-400ZR IA, is one of the latest achievements that helps the industry to build 400 Gbps optical network ecosystems. The OIF-400ZR IA aims to enable interoperable and cost-effective 400 Gbps solutions by leveraging dual-polarization (DP) 16-QAM coherent optical modulation and defining the structure of the concatenated FEC (C-FEC). The industry has moved fast in the initial phase of testing the base functionality of 400ZR pluggable modules with QSFP-DD, OSFP, and CFP2 form-factors, which are widely available for network operators from multiple vendors thanks to the low-power DSP ASIC. Network operators are now seeking a healthy ecosystem where these pluggable modules can interoperate 400 Gbps traffic links between multiple vendors.

To meet such industry needs, the OIF investigated the performance of 400ZR pluggable modules through a multi-vendor interop environment at the OIF ECOC 2022 plugfest and published a "400ZR Interoperability White Paper". That investigation addressed the OSNR performance impact when seven different 400ZR QSFP-DD pluggable modules paired their transmitter (Tx) and receivers (Rx) together over a dense wavelength-division multiplexing (DWDM) optical line system (OLS). The noise level of the 400 Gbps link was controlled to find the required optical signal to noise ratio (rOSNR) threshold, which is the minimum optical signal to noise ratio to maintain a post-FEC error-free link. Additionally, the versatile diagnostic monitoring (VDM) reporting accuracy of each module was investigated by comparing the CMIS register values against the measurement of an optical spectrum analyzer (OSA). As a continuation of this effort, the OIF has extended its investigation to a second round of the 400ZR plugfest. The second plugfest focused on comparing verification methods of a respective 400ZR pluggable module to the OIF-400ZR IA and interoperability.

In this white paper, we have extended the test coverage to reflect industry voices collected by an OIF 400ZR survey. A total of 12 different 400ZR QSFP-DD vendors participated in the second plugfest, each submitting a single sample to test throughout the event. The same key parameters were measured under an extended set of test configurations compared to prior plugfest: the rOSNR threshold and the OSNR reporting (VDM) accuracy. The extended set of test configurations include a noise loaded short link and a DCI 75 km OLS link. Overall, the goal is to provide confidence to network operators that multi-vendor 400ZR environment continues to exist and continues to improve following the specifications in the OIF-400ZR IA.

2 Test Setup

The test setups utilized a combination of optical network equipment from different vendors displayed in Figures 1-3. The test setups cover three different configurations: two noise loaded short links and a data center interconnect (DCI) 75 km OLS link. The noise loaded short link was re-configured into two variations to measure the loopback performance and the interoperability performance.

The noise loaded short link test setups are displayed in Figure 1 (loopback) and Figure 2 (interop). These test configurations utilize a reduced set of OLS equipment compared to the 75 km optical line system. The optical line system elements were provided by Cisco which include a Cisco NCS 1001 DWDM erbium-doped fiber amplifier (EDFA) and a Cisco NCS 1001 DWDM 64-channel 75 GHz patch panel. The EDFA was operating in a constant gain mode of 18 dB. The DWDM 64-channel patch panel was used as an optical filter (demux) to ensure a 75 GHz channel was received by the module. The test equipment was provided by EXFO noted below.

The DCI 75 km OLS test configuration is displayed in Figure 3. The same optical line system elements were provided by Cisco. Two Cisco NCS 1001 DWDM 64-channel 75 GHz patch panels were used for the mux/demux and a Cisco NCS 1001 DWDM line system was used for the pre-EDFA gain and post-EDFA gain. Both amplifiers were operating in a constant gain mode of 18 dB. Juniper Networks provided the 75 km fiber spools that were connected between the pre- and post-EDFAs. Again, the same test equipment was provided by EXFO noted below.

The EXFO LTB-8 mainframe provided the host dual port interface for the QSFP-DD modules. The EXFO DCO BERT application generated and evaluated the 400 Gb/s traffic across the OIF-400ZR link in all the test setups. Per Figure 1 and 2, two 50/50 splitters were introduced in between the Cisco EDFA amplification gain and the optical filter (demux). Per Figure 3, the same two 50/50 splitters were introduced in between the Cisco post-EDFA amplification gain and the demux. One 50/50 splitter allowed control over the ASE source and the other splitter allowed OSNR measurements with the EXFO high resolution OSA (0.33 nm resolution for acquisition, OSNR normalized at 0.1 nm according to IEC 61280-2-9). The input signal into the module’s receiver was dynamically controlled to -10 dBm for all 400 Gb/s links through the EXFO BI-variable attenuator with embedded power monitoring. Additionally, EXFO provided fiber inspection probes and cleaning equipment to ensure clean fiber connections between the module and optical links.

This investigation was conducted during an OIF 400ZR plugfest hosted by Ciena in San Jose. The participating plugfest members supported the OFC 2023 OIF 400ZR trade show demo.

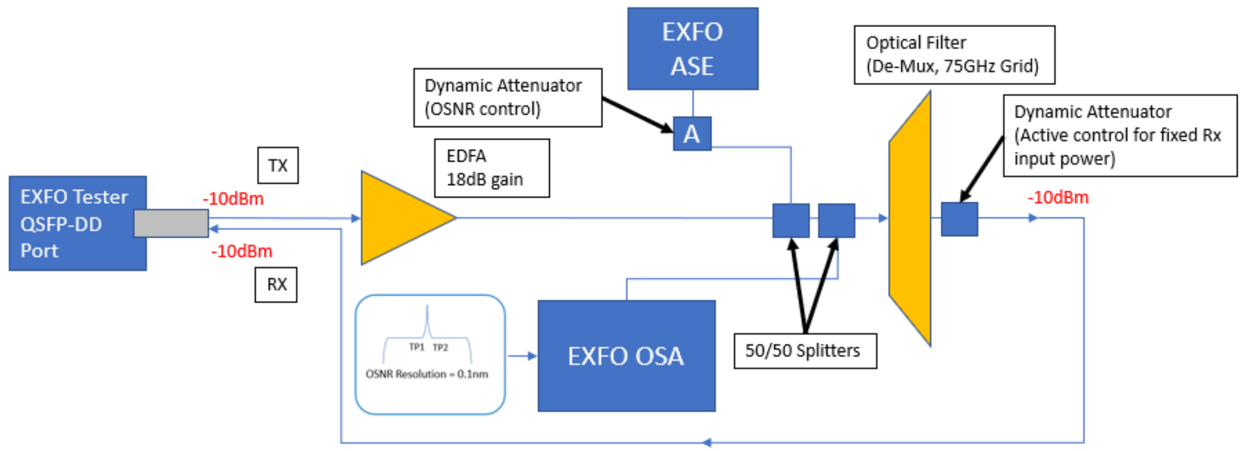

Figure 1 OIF 400ZR Plugfest Test Setup for the Noise Loaded Short Link rOSNR Loopback Test

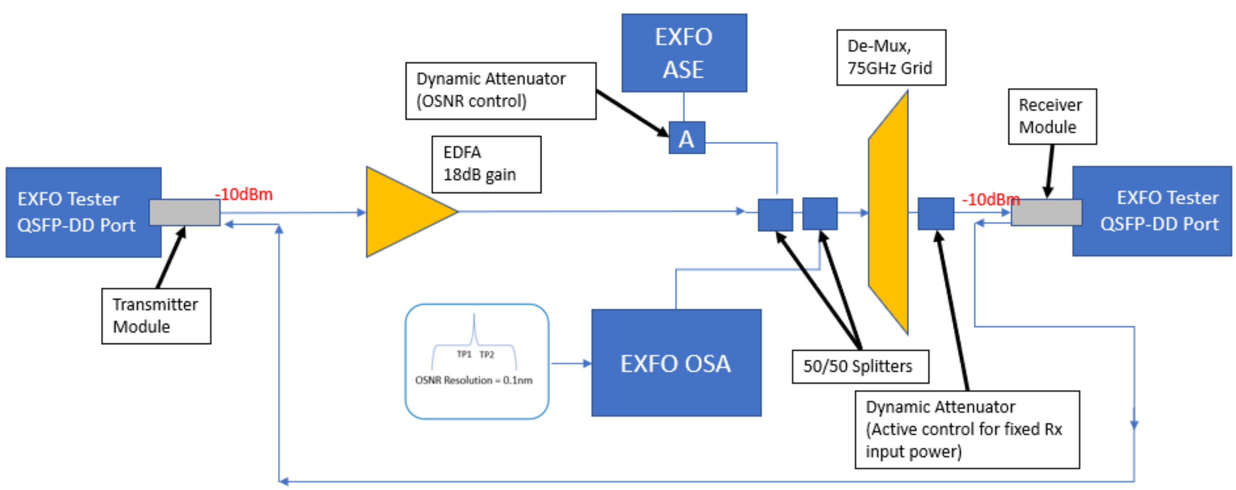

Figure 2 OIF 400ZR Plugfest Test Setup for the Noise Loaded Short Link rOSNR Interop Test

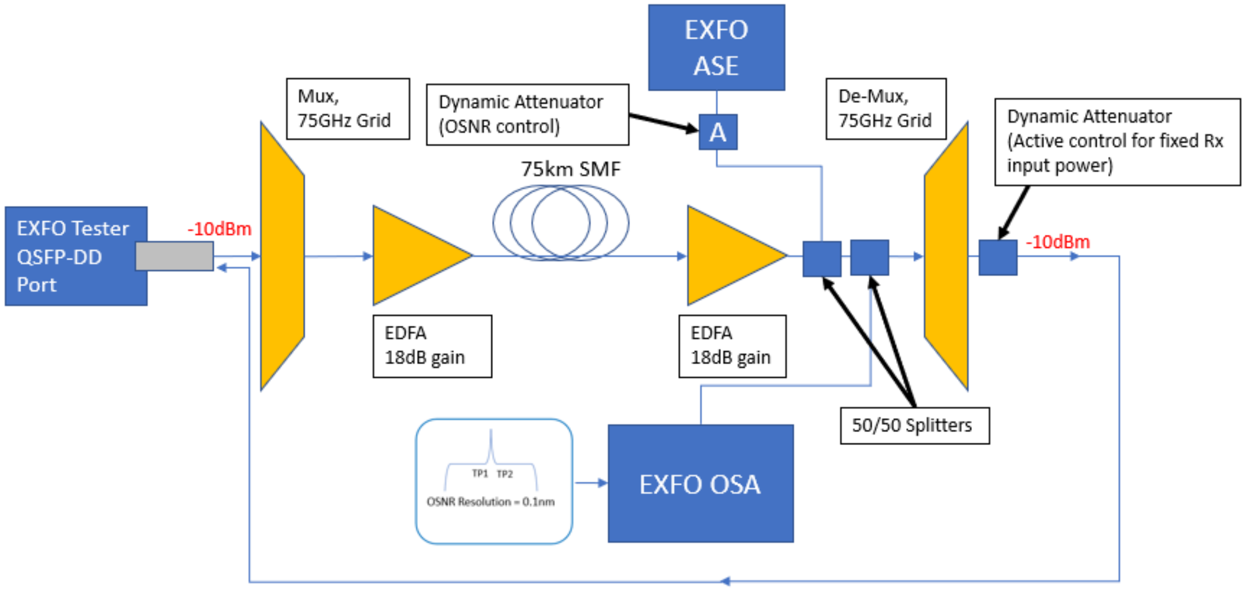

Figure 3 OIF 400ZR Plugfest Test Setup for the DCI 75 km OLS Link rOSNR Loopback Test

3 Test Procedure

The plugfest compares the performance of different QSFP-DD OIF-400ZR modules in three different test setups. In all three test setups the modules were configured in the same process by the host tester. The modules were initialized into a ready state, then the host configured the module to optical channel 24 (197.3 THz) and the output power to -10 dBm using the CMIS registers.

In the first test, the noise loaded short link loopback test (Figure 1), all the QSFP-DD OIF-400ZR modules were tested one at a time. First the fibers connecting to the modules were inspected with a fiber inspection probe (FIP) and the fibers were cleaned if the FIP test failed. The module transmitter was connected to the input of the short link (input of the EDFA). The module receiver was connected to the output of the short linked (the dynamic controlled attenuator).

Next the link was configured to have a high OSNR (>30 dB) to ensure the OIF-400ZR loopback link was established. At this point the *rOSNR test process* began, the OSNR was degraded using the EXFO ASE and attenuator, marked 'A' in Figure 1, in 0.1 dB steps until a post-FEC errors was reported by the host. At this state, the OSNR was increased by 0.1 dB and traffic was monitored for 30 seconds. If the traffic remained error free, then the module CMIS VDM data (OSNR and pre-FEC BER) was captured by the host. The line side OSNR level was measured and captured by the OSA. However, if a post-FEC error was reported by the host during the 30 second traffic soak, then the OSNR was increased by an additional 0.1 dB and traffic was monitored for new period of 30 seconds. This 0.1 dB increase in OSNR was repeated until the traffic remained post-FEC error-free for a 30 second period.

After, an additional *validation step* took place where the OSNR was decreased from the "error free" noise level by a 0.1 dB step and the traffic was soaked for new 30 second period. During this validation step post-FEC errors were expected to be reported by the host. At this post-FEC error state, the module CMIS VDM data (OSNR and pre-FEC BER) was captured by the host and the line side OSNR level was measured and captured by the OSA. However, if no errors were reported during this validation step, then the OSNR and CMIS VDM data points replaced the existing error-free traffic. Then *validation step* repeated until post-FEC errors were observed, and the post-FEC error state was captured. Finally, the module was removed and replaced with a different vendor's module until all modules were tested.

In the second test, the noise loaded short link interop test (Figure 2), two OIF-400ZR modules were tested at once time, a transmitter module and a receiver module. The first step was to inspect the fibers connecting to the modules with a FIP and the fibers were cleaned if the FIP test failed. Then transmitter module was plugged into the tester and configured by the host as noted above. The transmitter module would remain fixed in the same configuration while the receiver modules were connected and rotated among all other vendors. A back-to-back link was connected from the receiver module's Tx to the transmitter module's Rx to ensure an OIF-400ZR link was established between the two QSFP-DD 400ZR modules.

Next the link was configured to have a high OSNR (>30 dB) to ensure the OIF-400ZR short link was established. At this point the same exact *rOSNR test process* and *validation steps* were performed as the first test. At the end of the data collection, the receiver module was replaced with a new vendor until all receiver modules were tested. Then the transmitter module was replaced with a different vendor until all Tx-to-Rx link combinations were tested.

In the third test, the DCI 75 km OLS link loopback test (Figure 3), all the QSFP-DD OIF-400ZR modules were tested one at a time. First the fibers connecting to the modules were inspected with a FIP and the fibers were cleaned if the FIP test failed. The transmitter of the module was connected to the input of the DCI 75 km OLS link (input of the mux). The receiver of the module was connected to the output of the OSL (the dynamic controlled attenuator).

Next the OLS was configured to have a high OSNR (>30 dB) to ensure the OIF-400ZR OLS link was established. At this point the same exact *rOSNR test process* and *validation steps* were performed as the first test. At the end of the data collection, the module was removed and replaced with a different vendor's module until all modules were tested.

4 Test Data

The data presents three parameters; the rOSNR interop threshold, rOSNR self-loopback threshold, and the CMIS VDM reporting accuracy of the module. Figure 4 displays the rOSNR interop test results over the noise loaded short link between each transmitter paired with each receiver, recorded during the second test. The data in the table was measured by the OSA after the 30 second period of error-free traffic. The highlighted cells are the self-loopback rOSNR test results from each vendor, measured during the first test. Figure 5 provides a visual representation of the rOSNR interop data by comparing each vendor's loopback performance against their interop receiver results (x-axis being loopback rOSNR, y-axis being interop rOSNR based on one receiver being paired with different transmitters). The data shows variation in the loopback performance and interop performance. All loopback rOSNR measurements meet the OIF-400ZR IA Rx OSNR requirement of ≤26 dB following the IA conditions/comments. However, there were seven Tx-to-Rx pairs that exceeded the rOSNR limit with values ranging from 26.2 dB to 33.4 dB.

	Transmitter											
Receiver ⇩	Vendor A	Vendor B	Vendor C	Vendor D	Vendor E	Vendor F	Vendor G	Vendor H	Vendor I	Vendor J	Vendor K	Vendor L
A	22.4	22.3	23.1	22.4	22.4	22.6	22.8	23.0	24.1	24.1	22.6	22.9
B	22.5	22.5	23.5	22.7	22.7	23.0	23.2	23.3	24.3	24.2	22.9	23.3
C	23.0	23.1	22.9	22.7	22.7	23.1	23.2	23.3	23.3	23.7	24.0	23.6
D	23.3	23.3	23.7	23.0	22.9	24.2	23.8	23.8	24.2	24.2	26.2	24.6
E	23.5	23.7	23.5	23.2	23.1	23.5	23.7	23.8	24.1	24.3	33.4	24.6
F	23.0	23.1	23.5	23.1	22.9	23.7	23.8	23.9	24.1	24.1	24.3	24.3
G	23.6	23.4	23.6	23.4	23.1	24.0	23.8	24.0	24.1	24.4	27.1	25.0
H	23.5	23.4	23.5	23.5	23.0	24.1	23.7	23.9	24.0	24.4	26.5	24.9
I	23.3	23.5	23.5	23.3	23.2	24.3	23.7	23.8	24.0	24.2	26.6	24.7
J	23.7	23.6	23.4	23.4	23.0	24.0	23.7	23.9	24.2	24.2	27.1	24.9
K	23.8	23.6	24.9	23.8	23.5	24.9	24.2	24.2	25.2	25.9	24.3	25.4
L	23.5	23.5	23.5	23.3	23.0	24.2	23.8	24.0	24.1	24.2	29.8	25.3

Loopback rOSNR of RX

Figure 4 OIF 400ZR Interop rOSNR Test Results

[Loopback rOSNR of Rx values were measured per Figure 1 test configuration (highlighted),

Interop values were measured per Figure 2 test configuration]

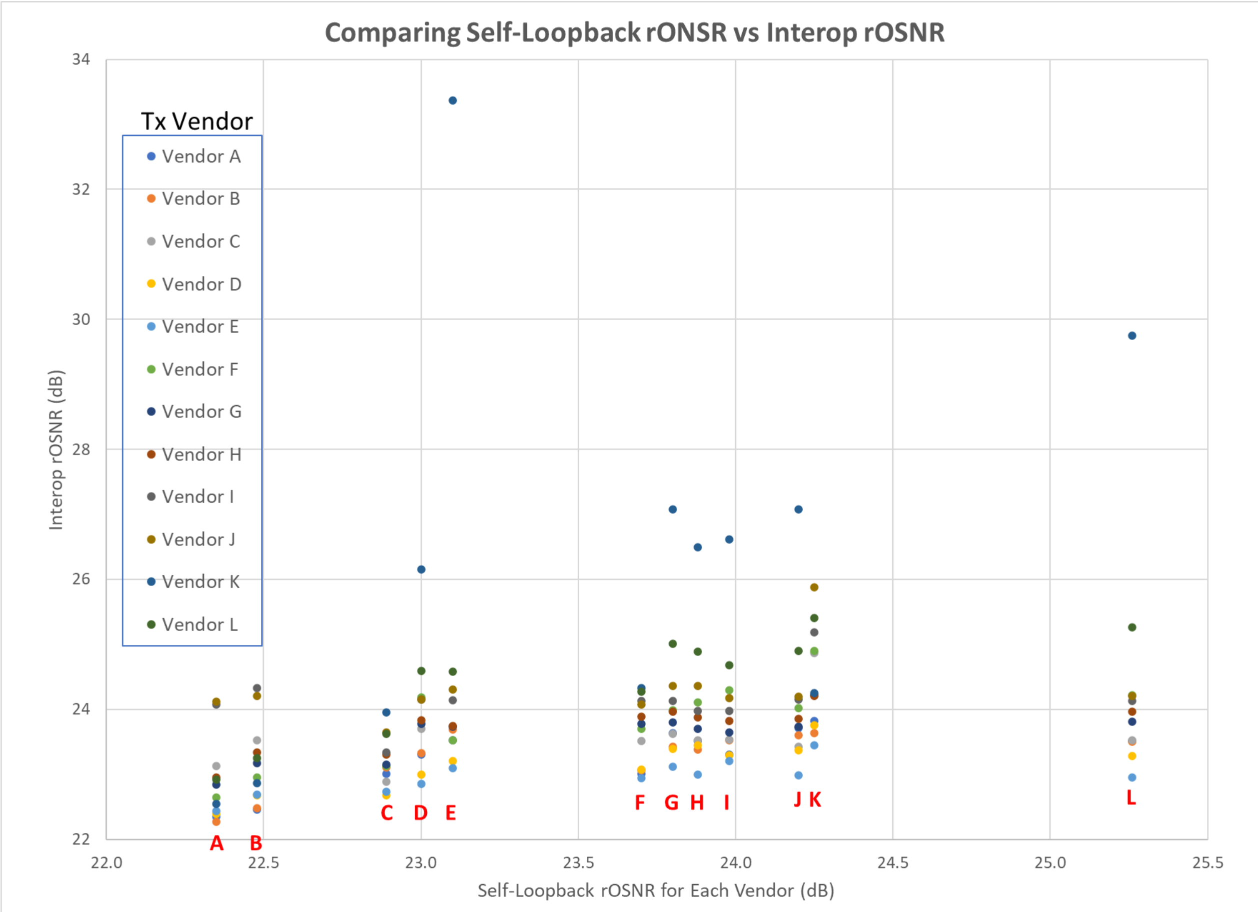

Figure 5 OIF 400ZR Visual Comparison of Self-Loopback rOSNR vs Interop rOSNR

[Same Data and Same Vendor ID as Figure 4, X-axis is each vendor's Loopback rONSR performance, Y-axis is the same vendor's rOSNR interop based their receiver being connected to different transmitters]

Figure 6 displays a comparison between two test setups of the self-loopback links, the noise loaded short link and the DCI 75 km OLS link. This comparison highlights the rOSNR performance impact with and without fiber (chromatic dispersion) in a 400ZR colored link. The rOSNR data was measured by the OSA after the 30 second period of error-free traffic. The delta between the two test configurations shows a minor variation in rOSNR performance with the delta ≤ 0.5 dB except for one case of a 0.8 dB delta. Additionally, in two cases the DCI 75 km OLS performed better than the noise loaded short link.

	Noise Loaded Short Link, rOSNR (dB)	DCI 75km OLS Link, rOSNR (dB)	Delta (dB)
A	22.3	22.5	0.2
B	22.4	22.8	0.4
C	22.8	23.2	0.4
D	23.0	23.2	0.2
E	23.1	23.0	-0.1
F	23.7	24.2	0.5
G	23.8	24.0	0.2
H	23.8	23.9	0.1
I	23.9	24.5	0.6
J	24.2	24.4	0.2
K	24.2	25.0	0.8
L	25.2	24.8	-0.4

Figure 6 OIF 400ZR Self-Loopback rOSNR Comparison Between Two Test Setups

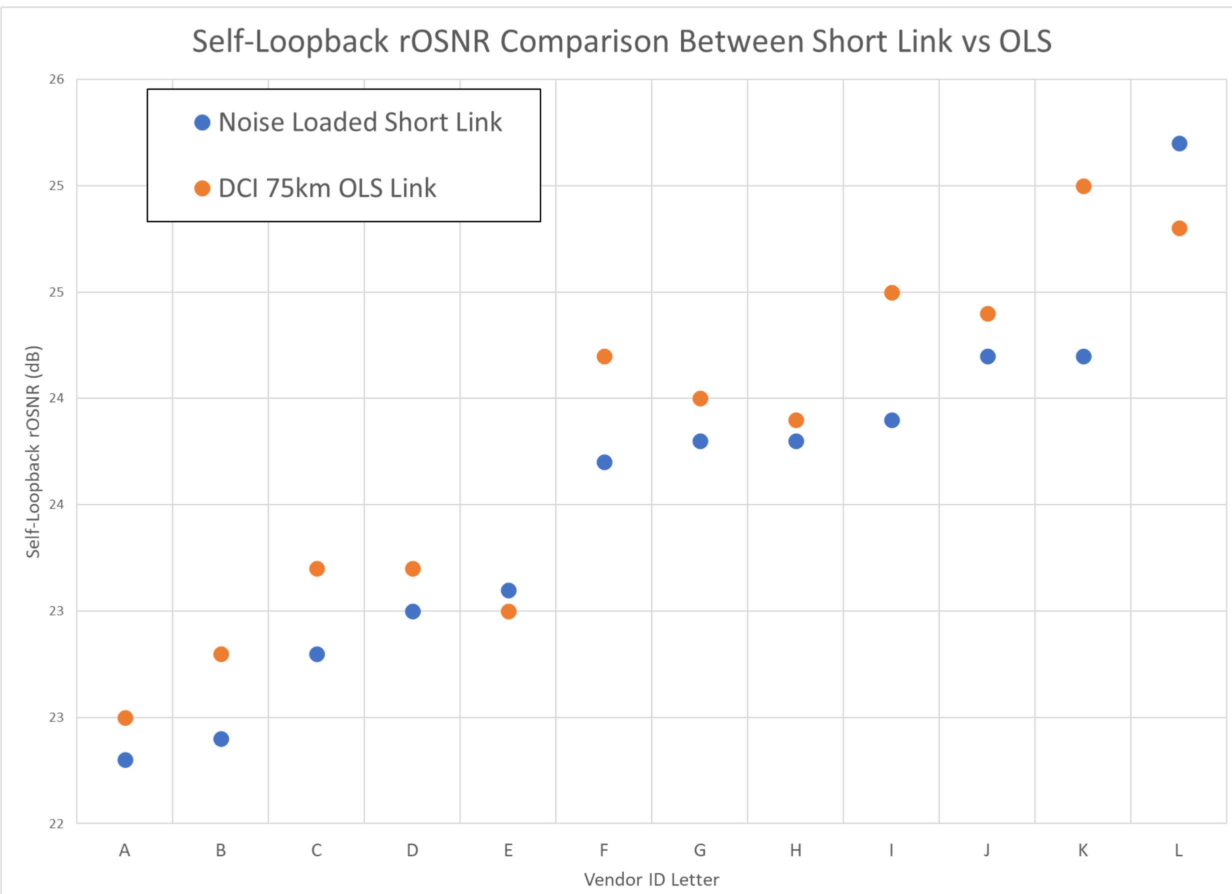

Figure 7 OIF 400ZR Self-Loopback rOSNR Visual Comparison Between Test Setups

Figure 8 provides a comparison between the measured OSNR value on the OSA and the reported OSNR value by module CMIS registers. The last table in Figure 8 highlights the difference between these OSNR values. There was a variation between the measured and reported OSNR values. The variation ranges between 0.0 dB to 8.8 dB, and in some cases the module was unable to report the Rx average OSNR values through the CMIS defined registers. Compared to the ECOC plugfest test, the overall delta performance has improved, with almost all vendors maintaining an average below 1.5 dB except for two cases.

OSNR Measured by OSA		Tx												Average OSNR for this Rx⇩
		Vendor A	Vendor B	Vendor C	Vendor D	Vendor E	Vendor F	Vendor G	Vendor H	Vendor I	Vendor J	Vendor K	Vendor L	
Rx (dB)	A	22.4	22.3	23.1	22.4	22.4	22.6	22.8	23.0	24.1	24.1	22.6	22.9	22.9
	B	22.5	22.5	23.5	22.7	22.7	23.0	23.2	23.3	24.3	24.2	22.9	23.3	23.2
	C	23.0	23.1	22.9	22.7	22.7	23.1	23.2	23.3	23.3	23.7	24.0	23.6	23.2
	D	23.3	23.3	23.7	23.0	22.9	24.2	23.8	23.8	24.2	24.2	26.2	24.6	23.9
	E	23.5	23.7	23.5	23.2	23.1	23.5	23.7	23.8	24.1	24.3	33.4	24.6	24.5
	F	23.0	23.1	23.5	23.1	22.9	23.7	23.8	23.9	24.1	24.1	24.3	24.3	23.6
	G	23.6	23.4	23.6	23.4	23.1	24.0	23.8	24.0	24.1	24.4	27.1	25.0	24.1
	H	23.5	23.4	23.5	23.5	23.0	24.1	23.7	23.9	24.0	24.4	26.5	24.9	24.0
	I	23.3	23.5	23.5	23.3	23.2	24.3	23.7	23.8	24.0	24.2	26.6	24.7	24.0
	J	23.7	23.6	23.4	23.4	23.0	24.0	23.7	23.9	24.2	24.2	27.1	24.9	24.1
	K	23.8	23.6	24.9	23.8	23.5	24.9	24.2	24.2	25.2	25.9	24.3	25.4	24.5
	L	23.5	23.5	23.5	23.3	23.0	24.2	23.8	24.0	24.1	24.2	29.8	25.3	24.3
	Average OSNR for this Tx⇨	23.3	23.3	23.6	23.1	23.0	23.8	23.6	23.7	24.1	24.3	26.2	24.4	Single Vendor OSNR of RX

Rx Average OSNR Reported by Module CMIS Registers (VDM)		Tx											
		Vendor A	Vendor B	Vendor C	Vendor D	Vendor E	Vendor F	Vendor G	Vendor H	Vendor I	Vendor J	Vendor K	Vendor L
Rx (dB)	A	26.8	25.1	31.9	25.1	24.4	31.2	-	24.4	22.8	25.4	-	25.4
	B	22.3	22.4	22.7	22.4	22.4	22.4	22.5	22.5	22.8	22.6	22.3	22.5
	C	22.9	22.4	22.2	22.4	21.8	22.4	22.4	22.9	22.4	22.8	23.4	22.9
	D	24.0	24.0	24.0	24.0	24.0	24.0	24.0	24.0	24.0	24.0	25.3	24.0
	E	24.7	24.9	24.4	24.8	20.8	24.3	24.4	24.4	24.5	24.7	34.4	25.2
	F	-	-	-	-	-	-	-	-	-	-	-	-
	G	24.0	23.8	23.4	23.5	23.8	23.6	23.7	24.0	23.6	24.0	26.2	24.4
	H	24.0	23.9	23.3	23.6	23.5	23.7	23.7	23.9	23.5	24.1	25.8	24.4
	I	23.9	24.2	24.0	24.0	24.0	24.0	23.9	24.2	23.9	23.9	26.7	24.4
	J	24.2	24.2	24.2	24.2	24.2	24.2	24.2	24.2	24.2	26.0	25.7	24.2
	K	23.1	23.0	23.0	23.0	23.0	23.0	23.0	23.0	23.0	23.1	23.4	23.2
	L	23.4	23.4	22.9	22.9	22.9	22.9	23.4	23.4	23.0	23.4	28.0	24.2

Delta		Tx												Average delta for this Rx⇩
		Vendor A	Vendor B	Vendor C	Vendor D	Vendor E	Vendor F	Vendor G	Vendor H	Vendor I	Vendor J	Vendor K	Vendor L	
Rx (dB)	A	4.5	2.8	8.8	2.7	2.0	8.6	-	1.5	1.3	1.3	-	2.5	3.6
	B	0.2	0.1	0.8	0.3	0.3	0.6	0.7	0.8	1.5	1.6	0.6	0.8	0.7
	C	0.1	0.7	0.7	0.3	0.9	0.7	0.8	0.4	0.9	0.8	0.6	0.7	0.6
	D	0.7	0.7	0.3	1.0	1.2	0.2	0.2	0.2	0.1	0.1	0.8	0.6	0.5
	E	1.2	1.2	0.9	1.6	2.3	0.8	0.7	0.6	0.4	0.4	1.0	0.6	1.0
	F	-	-	-	-	-	-	-	-	-	-	-	-	-
	G	0.4	0.4	0.2	0.1	0.7	0.4	0.1	0.0	0.5	0.4	0.9	0.6	0.4
	H	0.5	0.5	0.2	0.2	0.5	0.4	0.0	0.0	0.5	0.3	0.7	0.5	0.4
	I	0.6	0.7	0.5	0.7	0.8	0.3	0.3	0.4	0.1	0.3	0.1	0.3	0.4
	J	0.5	0.6	0.8	0.8	1.2	0.2	0.5	0.3	0.1	1.8	1.4	0.7	0.7
	K	0.7	0.6	1.9	0.8	0.4	1.9	1.2	1.2	2.2	2.8	0.9	2.2	1.4
	L	0.1	0.1	0.6	0.4	0.1	1.3	0.4	0.6	1.1	0.8	1.8	1.1	0.7

Figure 8 OIF 400ZR Reported CMIS VDM rOSNR Value Compared to Measured OSNR

5 Summary

The OIF 400ZR QSFP-DD plugfest shows that all twelve vendors can maintain 400 Gb/s traffic over a DWDM optical line system as defined in the OIF-400ZR IA and interop with the short link. Similar to the previous OIF plugfest, these tests were limited in scope of soak time, but the results can give network users confidence to perform their own in-depth evaluation with different vendors. There was an observable difference in rOSNR between different combination of 400ZR QSFP-DD modules so additional testing is still suggested. Additionally, during this plugfest there was a request to compare an optical line system link performance against a short link, which is referenced in the OIF-400ZR IA (13.1.330 OSNR Tolerance, Conditions/Comments). During this investigation there were minor differences observed between the two test setups. This suggests the noise loaded short link test setup (Figure 1 and Figure 2) is a good alternative to evaluate the module OSNR performance. The OIF-400ZR QSFP-DD modules can report an average OSNR values within a reasonable limit when linked in different combinations, with one exception. These CMIS OSNR values can be used for basic guidance, but it is recommended to use a high resolution OSA while testing the rOSNR performance of OIF-400ZR links.

The OIF 400ZR module market has transitioned from the initial phase of basic functionality into an interoperable 400ZR ecosystem.

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Author	Charles Park
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7 Appendix A: List of Contributors

Ciena - Gary Wang - WaveLogic 5 Nano 400ZR QSFP-DD

Cisco - Tuan Tran - 400ZR QSFP-DD, NCS 1001 DWDM Line System, NCS 1001 Mux/Demux Patch Panel

Coherent - Abdi Zolfaghari - 400ZR QSFP-DD

EXFO - Jean-Marie Vilain, Louis Forget, Gwenn Amice - End to End Transmission & Optical Test Bench:

- 2x LTB-8 Mainframe
- 2x FTBx-88460 hosting QSFP-DD Dual port with DCO Bert Application
- FTBx-5255 optical spectrum analyzer
- 2x FTBx-3500-BI variable attenuator with embedded power monitoring
- 2x FTBx-9600-01-02-50E-EI utility module with integrated optical couplers and splitters
- AEDFA-NS2380 ASE source
- FIP-430P/FIP-500 Fiber inspection probe

Innolight - Steven Shi - 400ZR QSFP-DD

Juniper Networks - Jose Aris Dimabuyu (JAD), Charles Park - JCO400-QDD-ZR, 75km Fiber Spool

Lumentum - Doug Cattarusa - 400ZR QSFP-DD-DCO

Marvell – Tingong Liu, Michael Bustamante - 400ZR QSFP-DD

Molex - Payam Rostami - 400ZR QSFP-DD

NEC – Kumi Omori, Thomas Hanes - 400ZR QSFP-DD

O-Net - Guochu Zhou, Wenwen Yu- 400ZR QSFP-DD

Precision OT - Pol Torres Compta - 400ZR QSFP-DD

Source Photonics - Gurinder Parhar, Frank Chang - 400ZR QSFP-DD

8 Appendix B: Glossary

400ZR - Digital Coherent Optical physical interface defined in the OIF-400ZR implementation agreement

BERT - Bit Error Rate Tester

C-FEC - Concatenated Forward Error Correction

CMIS - Common Management Interface Specification

DCI – Data Center Interconnect

DP-16QAM – Dual Polarization 16 state Quadrature Amplitude Modulation

DSP - Digital Signal Processor

DWDM - Dense Wavelength-Division Multiplexing

EDFA - Erbium-Doped Fiber Amplifier

FEC (post-FEC) - Forward Error Correction (after the Forward Error Correction process)

Gb/s - Gigi bit per second

IA - Implementation Agreement

OSA - Optical Spectrum Analyzer

OSNR - Optical Signal to Noise Ratio

QSFP-DD - Quad Small Form Factor Pluggable Double Density

rOSNR - required OSNR

Rx - Receiver

Tx - Transmitter

VDM - Versatile Diagnostic Monitoring

About the OIF:

For more than two decades, OIF has accelerated progressive transformation in optical networking by serving as the only global industry forum driving the electrical, optical and control interoperability that enables a more efficient and reliable network. Its active member ecosystem collaborates through a transparent and fast-paced process to develop, validate and publish Implementation Agreements (IAs) and technical white papers that are critical to accelerating market adoption of optical networking technologies.

Based on established methodologies including the documentation of industry requirements, bringing forward member-driven technical solutions, validation testing and free publishing, OIF's interoperability solutions are vital to the global network.

With more than 130 member companies spanning component suppliers to network operators, OIF members strive to identify the industry's needs and requirements and rapidly develop solutions that directly impact and facilitate global connectivity in the open network world. Information on the OIF can be found at http://www.oiforum.com.

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