OIF Open400ZR+ Interoperability White Paper
ECOC 2023 Plugfest

ABSTRACT: This paper presents the methodology and results of an interoperability study of OpenZR+ MSA QSFP-DD transceivers conducted during a ECOC 2023 plugfest. Ten 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 tested using 400GE traffic over a shortened optical line system link with a DWDM 75GHz fixed channel grid and a separate configuration to capture the transmitter EVM performance. The transceiver receiver OSNR performance is compared against the transceiver transmitter EVM performance for each vendor.

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. For this industry exhibition, we focused on the OpenZR+ application, released by the OpenZR+ Multi-Source Agreement (MSA). Both specifications aim to enable interoperable 400 Gbps solutions using dual-polarization (DP) 16-QAM coherent optical modulation with their own forward error correction (FEC) solution. The OIF-400ZR IA defines the structure of the concatenated FEC (C-FEC) and the OpenZR+ MSA uses the structure of the open source FEC (O-FEC) for higher performance. Previous OIF 400ZR interoperability white papers demonstrate a healthy 400ZR ecosystem with multiple vendors. This white paper follows the same approach for the OpenZR+ application.

To continue supporting the industry needs, the OIF conducts these plugfests to provide quantified measurements on the quality of the links between different 400 Gbps pluggable modules. We use the required optical signal to noise ratio (rOSNR) of the receiver as a performance metric.

We also want to support multiple standards bodies with their efforts to use the Error Vector Magnitude (EVM) of the module transmitter as a normative metric. EVM is the vector difference at a given time between the ideal reference signal and the measured signal (sum of individual impairments). EVM is the root-mean-square (RMS) value of the error vector over time at the instants of symbol clock transitions.

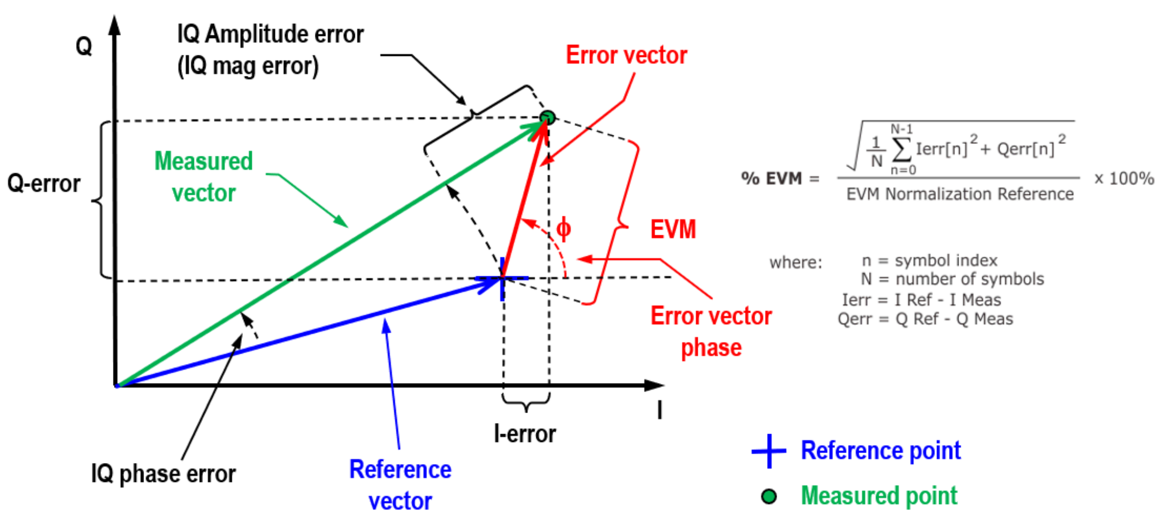

Figure 1 Error Vector and Error Vector Magnitude

In this white paper, we document results from multiple OpenZR+ MSA QSFP-DD modules using 400GE traffic. The key parameters measured during this event include the receiver rOSNR threshold and the transmitter EVM from each module. The rOSNR threshold was tested using the noise loaded short link under two test configurations. The transmitter EVM measurement was tested with two test equipment vendors. The goal of the event was to provide network operators insight into the OpenZR+ application following the same test methods previously applied to the OIF-400ZR application, including a new comparison between the receiver and transmitter performance.

2 Test Setup

The test setups utilized a combination of optical network equipment from different vendors displayed in Figures 2-5. The test setups cover four configurations: two noise loaded short links and two transmitter measurements. The noise loaded short links were re-configured into two variations to measure the loopback performance with a host router interface and to measure the interoperability performance using an optical switch.

The noise loaded short link test setups are displayed in Figure 2 (router interface) and Figure 3 (module interop). These test configurations utilize a reduced set of OLS equipment similar to the previous OIF interoperability tests, noted in the OIF OFC 2023 White paper. The OLS elements, provided by Cisco, ensured a 75 GHz channel was received by the module. The test equipment was provided by EXFO noted below.

The host router in Figure 2 was the Juniper PTX10001-36MR, using two additional QSFP-DD FR4 modules to carry 400 Gbps traffic from the EXFO tester into the router. The router configured a virtual connection (V-LAN) connection to enable bi-directional traffic between the client QSFP-DD FR4 module labeled “Module” in Figure 2 and the device under test (DUT) QSFP-DD OpenZR+ module labeled “DUT” in Figure 2. The JUNOS OS monitored the bi-direction traffic performance between both modules and the JUNOS OS controlled and monitored the status of both modules using the OIF CMIS protocols. The 400 Gbps traffic was unmodified by the router allowing the EXFO tester to evaluate the traffic link.

Both Figure 2 and Figure 3 use the EXFO LTB-8 mainframe and the EXFO DCO BERT application to generate and evaluated 400 Gbps traffic as documented in previous white papers. During the interoperability tests, an EXFO 8x8 low-loss optical switch was introduced to speed up the testing process. The optical switch was located between the EXFO host LTB-8 mainframe, and the noise loaded short link as labeled in Figure 3. Due to the insertion loss from the optical switch, the dynamic attenuator (in Figure 3) was adjusted to ensure the module input power was controlled to -10 dBm. Additionally, EXFO provided fiber inspection probes and cleaning equipment to ensure clean fiber connections between the module and optical links.

Figure 4 displays the Keysight transmitter test setup which used a Keysight BERT and a Keysight optical modulation analyzer (OMA). The module transmitter output was directly connected to a Keysight OMA. The Keysight OMA measured the EVM performance of each transmitter using the script referenced in the 400ZR IA.

Figure 5 displays the Quantifi Photonics transmitter test setup which used the Wilder module compliance board, a Quantifi Photonics receiver, an EDFA, and two Tektronix oscilloscopes. The module transmitter was connected to an EDFA that amplified the signal to a constant output power of +1.5dBm. The Quantifi Photonics receiver converted the optical signal into four electrical signals: X_i, X_q, Y_i, Y_q. These four signals were evaluated by two Tektronix oscilloscopes to calculate the EVM measurement, one oscilloscope for the X polarization and one oscilloscope for the Y polarization.

These test investigations were conducted during an OIF OpenZR+ plugfest hosted by LightRiver in Concord, CA. Additional testing was completed during the ECOC 2023 conference exhibition in Glasgow, Scotland.

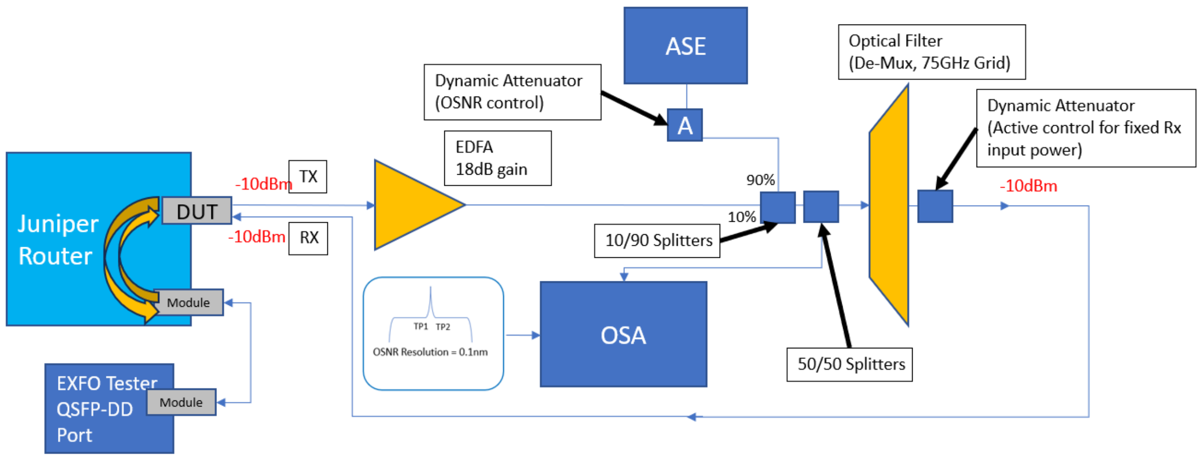

Figure 2 OpenZR+ plugfest setup for the noise loaded short link with a router interface.

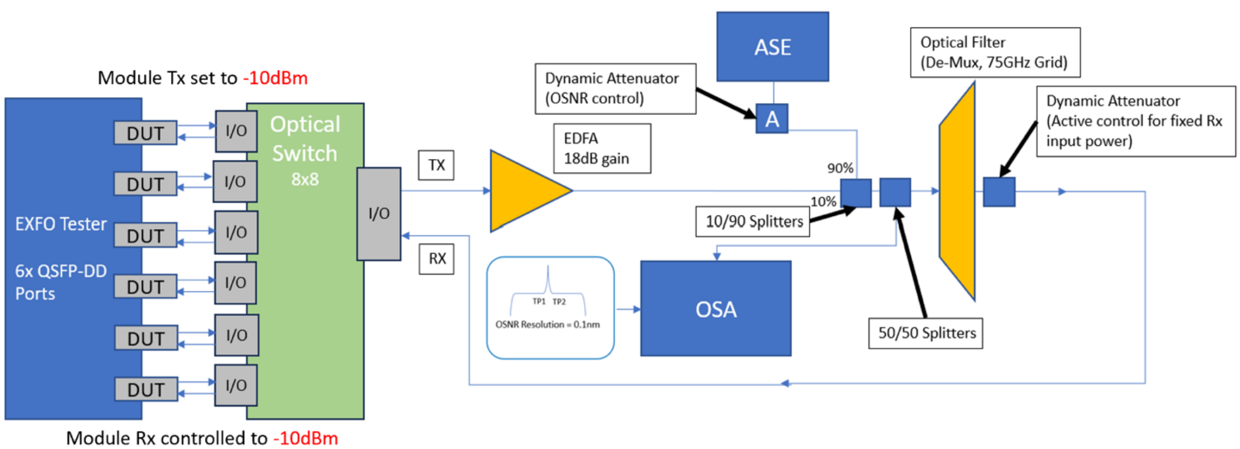

Figure 3 OpenZR+ plugfest test setup for the noise loaded short link for the rOSNR interop test.

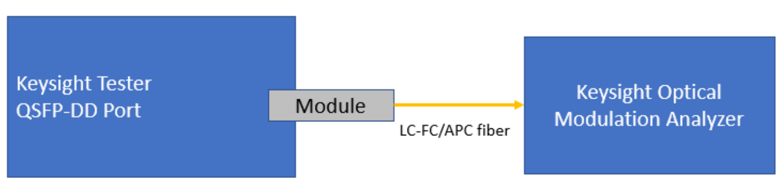

Figure 4 OpenZR+ plugfest test setup for the Keysight transmitter test.

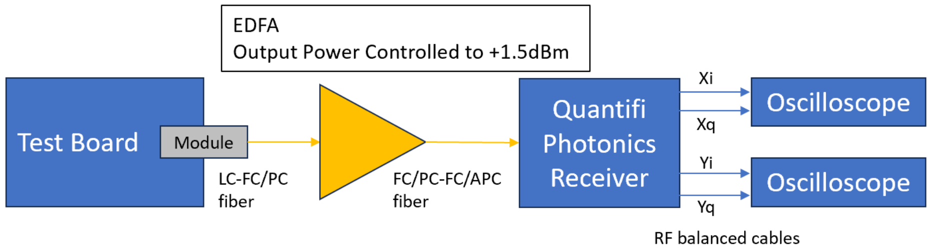

Figure 5 OpenZR+ plugfest test setup for the Quantifi Photonics transmitter test.

3 Test Procedure

The OIF plugfest compared the performance of different QSFP-DD OpenZR+ modules in four different test setups. In all test setups the modules were configured to the same setting by the tester or router using the CMIS registers. All modules were configured into the OpenZR+ Application (ZR400-OFEC-16QAM) with the 400GE client interface, tuned to optical channel 24 (193.7 THz), and set Tx output power to -10 dBm.

In the first test, the loopback performance used the short link setup with a router interface as displayed in Figure 2. All the OpenZR+ modules were tested one at a time. First all of the fibers connecting to the modules and the test setup were inspected with a fiber inspection probe (FIP) and cleaned if the FIP test failed. The Tx of the DUT module was connected to the input of the short link (input of the EDFA). The Rx of the DUT module 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 OpenZR+ loopback link was established. At this point the *rOSNR test process* began, which is defined in previous OIF 400ZR Interoperability papers. The traffic soak period for each measurement was 30 seconds and the noise steps were incremented by 0.1dB. After the *rOSNR test process* a *validation step* was taken to ensure "error free" traffic at a certain OSNR level. The *validation step* is the same process that was defined in previous OIF 400ZR Interoperability white papers. Finally, the module was removed and replaced with a different vendor's module until all modules were tested.

In the second test, the rOSNR interop measurement used the short link setup as displayed in Figure 3. Six QSFP-DD modules were configured at one time by the host tester as noted above. Again, all fiber connecting to the six modules were cleaned and inspected following the same steps as the first test. With the introduction of the optical switch, all six modules remained in the same configuration throughout the rOSNR interop test. First the loopback performance was tested by configuring the optical switch to allow one input/output (I/O) port from the Tx/Rx of one module to maintain a link with the noise loaded short link setup. Note, the return signal (to complete the OpenZR+ link) was routed through the optical switch I/O ports from the receiving DUT module to the transmitting DUT module, bypassing the noise loaded short link. Next the short link was configured to have a high OSNR (>30 dB) to ensure the OpenZR+ link was established. At this point the same exact *rOSNR test process* and *validation steps* were performed. At the end of the data collection, the optical switch was reconfigured to allow a new I/O port (and a new DUT module) to establish a link with the noise loaded short link setup. This process was repeated until all six DUT modules loopback performance was tested.

Next the rOSNR interop performance was measured between each Tx and Rx combination. The DUT modules would continue to remain in the same configuration. The optical switch was configured to pair

Tx and Rx from different DUT modules. The optical switch enabled the Tx from one DUT module to connect into the input of noise loaded short link through the I/O ports. The output signal from the noise loaded short link was configured into the Rx of another DUT module through the I/O ports. Again, the return signal (to complete the OpenZR+ link) was routed through the optical switch I/O ports from the receiving DUT module to the transmitting DUT module, bypassing the noise loaded short link. Next the noise loaded short link was configured to have a high OSNR (>30 dB) to ensure the OpenZR+ short link was established. At this point the same exact *rOSNR test process* and *validation steps* were performed as the first test and loopback test. At the end of the data collection, the optical switch was reconfigured to connect a new pair of DUT modules until all Tx-to-Rx combinations were tested.

After the loopback and all interop combinations were tested, the DUT modules were removed and replaced with a new set of six DUT modules. The same configuration, setup, and testing process was repeated for the new set of DUT modules. This process continued until all data points were captured.

In the third and fourth tests, all the modules were individually tested. All fiber connections were cleaned and inspected following the same steps as the first test. All modules were configured the same as the previous tests. The Keysight OMA provided the EVM metric using internal resources. The test data was saved, and the raw data files were saved for future analysis. The Quantifi Photonics test setup captured the raw measurements from each oscilloscope and the EVM metric was post processed. All test data and raw data files were saved for future analysis.

4 Test Data

We are presenting four parameters of our test data: rOSNR interop threshold, rOSNR self-loopback threshold, EVM, and the CMIS VDM reporting accuracy of the OpenZR+ module in a router. The letter code assignment for each vendor remains the same in all data sets.

Figure 6 displays the self-loopback rOSNR threshold results tested over the noise loaded short link when a router was hosting the QSFP-DD OpenZR+ modules. The data set includes the CMIS reported OSNR value and the OSA measured OSNR value after the 30 second period of error-free traffic. The delta is the difference between the two values. All loopback rOSNR threshold measurements meet the OpenZR+ MSA Rx OSNR tolerance requirement of ≤24 dB/0.1 nm. The delta between the reported value and the OSA measured value shows little variation. Figure 6 indicates that the variations in self-loopback rOSNR threshold are insignificant suggesting the router is a viable host platform network uses to simulate real applications.

Self-Loopback in Host Router			
Vendor	Router reading CMIS VDM registers (dB)	EXFO OSA (dB)	Delta (dB)
A	21.4	20.8	-0.6
B	20.9	20.9	0.0
C	21.5	21.5	0.0
D	21.9	21.8	-0.1
E	22.0	21.8	-0.2
F	21.9	21.9	0.0
G	22.0	22.0	0.0
H	22.1	22.0	-0.1
I	22.3	22.2	-0.1
J	22.6	22.7	0.1

Figure 6 OpenZR+ self-loopback rOSNR comparison between the router interface and OSA

Figure 7 displays the interop rOSNR threshold for each Tx paired with each Rx from the second test. The data in Figure 7 was measured by the OSA after the 30 second period of error-free traffic. The highlighted cells are the self-loopback test results from each vendor. The data shows variation in the loopback performance and interop performance. Just like the first test, all loopback rOSNR threshold measurements meet the OpenZR+ MSA Rx OSNR tolerance requirement of ≤24 dB/0.1 nm following the MSA conditions and comments. However, six Tx-to-Rx pairs exceeded the rOSNR tolerance limit with values ranging from 24.1 dB to 25.4 dB. Three test points were incomplete during the OIF plugfest because the Tx-to-Rx combination failed to establish an OpenZR+ link. After the OIF plugfest further troubleshooting was performed and both vendors could successfully interoperate.

Additionally, Figure 7 includes the module EVM measurements captured during the third and fourth tests. The data provides a comparison between the EVM measurements and the receiver rOSNR interop results. The module EVM performance varied between vendors with most values between 8% and 13%. The Keysight test setup could not capture the EVM measurement for Vendor D and Vendor E.

EXFO OSA rOSNR (dB)		Tx									
		Vendor A	Vendor B	Vendor C	Vendor D	Vendor E	Vendor F	Vendor G	Vendor H	Vendor I	Vendor J
Rx	A	20.8	20.9	20.7	21.5	21.6	21.5	22.1	21.5	21.3	21.2
	B	20.9	20.9	20.7	21.4	21.6	21.5	22.1	21.6	*	21.3
	C	21.9	*	21.5	22.6	22.5	22.2	22.0	22.5	23.0	24.6
	D	21.5	21.5	21.3	21.8	22.0	21.8	22.0	22.0	22.3	24.1
	E	21.3	21.2	21.0	21.9	21.8	21.7	21.9	21.8	22.2	24.0
	F	21.9	21.8	21.4	22.8	22.6	21.9	22.6	22.1	22.8	25.4
	G	21.5	21.4	21.0	21.9	21.9	21.6	22.0	21.8	22.3	24.3
	H	21.9	21.7	21.4	22.8	22.6	22.1	22.5	22.0	23.3	25.1
	I	21.9	*	21.6	23.2	23.7	22.5	23.3	22.4	22.2	21.9
	J	22.5	22.4	22.2	24.0	24.2	23.0	24.1	23.1	22.7	22.7
Keysight EVM (%rms, OIF, no-noise, 7 tap, 1000 pts)		12.1	12.0	12.8	*	*	11.8	12.4	11.7	12.0	11.5
Quantifi Photonics EVM (%rms, OIF, no-noise, 7 tap, 1000 pts)		9.5	8.6	8.5	11.9	12.8	12.7	10.7	13.0	12.5	12.1

Single Vendor rOSNR of RX

* While the Vendor B results indicate multiple failed links, these pairings were investigated and successfully interoperated since the Plugfest.

* Keysight EVM - two modules were unable to be measured.

Figure 7 OpenZR+ Interop rOSNR and EVM test results.

Figure 8 provides a visual representation of the interop rOSNR data by comparing each vendor's loopback performance against their interop rOSNR results. The x-axis represents the loopback rOSNR results. The y-axis represents the interop rOSNR results based on that loopback receiver being paired with different transmitters. An example, Vendor A has a loopback rOSNR threshold of 20.8 dB and that location is marked A on the x-axis. The column of data points above the mark A displays Vendor A's rOSNR interop performance when Vendor A's receiver was paired with the other transmitters. Each Vendor's transmitter is assigned a color code in the legend.

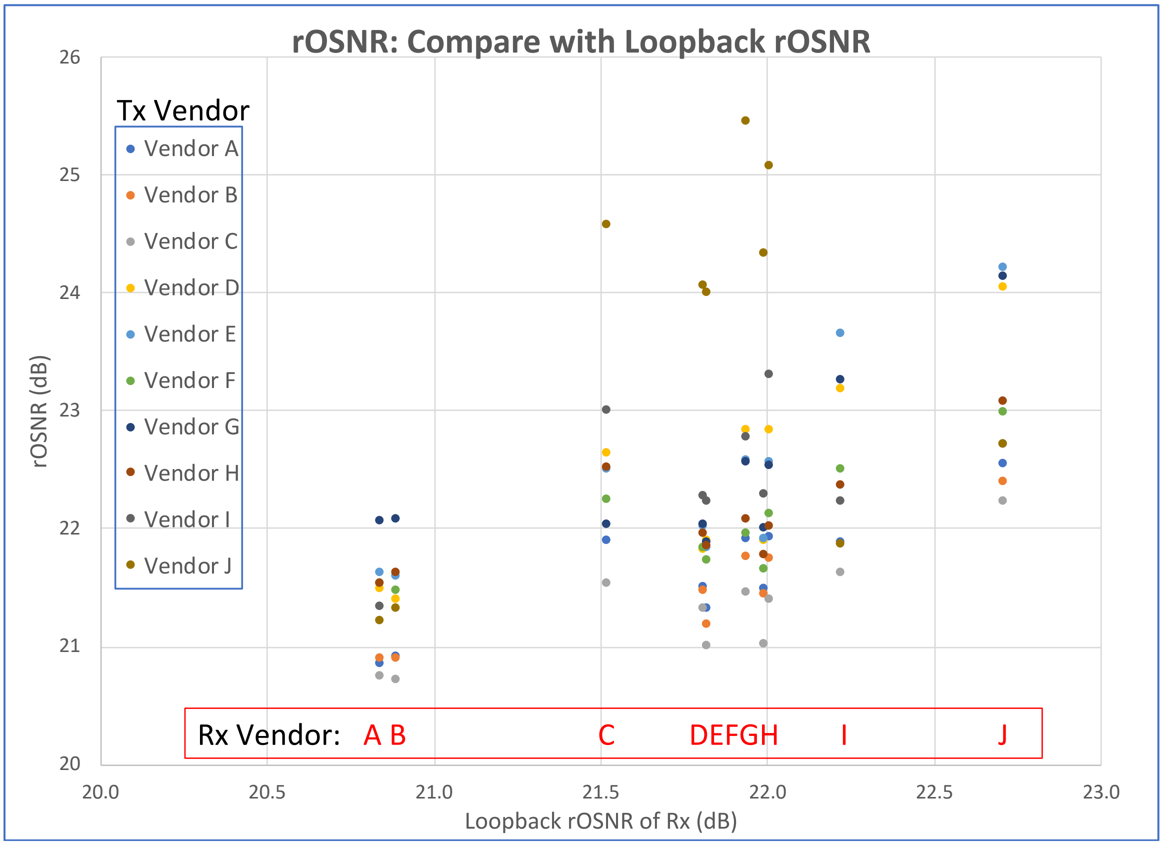

Figure 8 Loopback vs Interop rOSNR

5 Summary

The OIF QSFP-DD plugfest quantitatively demonstrates that all ten vendors can operate 400 Gbps traffic over a DWDM optical line system as defined in the OpenZR+ MSA.

The tests were once again limited in the time (traffic soak periods), but the results provide network operators guidance to perform their own in-depth evaluation. There was an observable difference in rOSNR performance between different combinations of OpenZR+ modules and three Tx-to-Rx combinations required further debugging for a successful link, suggesting additional testing is needed. Similar to the 400ZR Application, the OSNR value reported by the module can be used for basic guidance, but it is still recommended to use a high resolution OSA when measuring rOSNR. The addition of the 8x8 optical switch into the second test setup provided an option to speed-up testing of multiple modules by allowing modules to stay in a pre-configured ready state, reducing the re-configuration commands, and removing the module initialization time. Test groups must be pre-planned to take advantage of the optical switch.

The variation between the transmitter EVM measurements indicate additional investigation is warranted in both measurement methodology and post-processing.

This plugfest and subsequent demonstration further explores the 400Gbps ecosystem that includes the 400ZR and the OpenZR+ applications. However, during this interop investigation there were significant complications during the tests, including three interop links that required additional debugging and two missing transmitter measurements. While the OIF community strives to test and demonstrate pluggable interoperability, these tests suggest more work is needed.

Author	Doug Cattarusa
Company	Lumentum
Editor & 400ZR Lead	Karl Gass (for OIF)

---

6 References:

OIF, "OIF-400ZR-02.0 – Implementation Agreement 400ZR", created and approved November 3, 2023 https://www.oiforum.com/wp-content/uploads/OIF-400ZR-02.0.pdf

OIF, "400ZR+ Interoperability Demo ECOC 2023", https://www.oiforum.com/wp-content/uploads/400ZRplus_booth_slides_ECOC2023-9_30.pdf

OIF, "400ZR Interoperability White Paper OFC 2023 Plugfest", https://www.oiforum.com/wp-content/uploads/OIF_400ZR_OFC2023_Interop_WhitePaper_Plugfest.pdf

OIF, "OIF Update! Defining 800ZR, 800LR, and Random 400ZR Information", https://www.oiforum.com/wp-content/uploads/ECOC-2022-Market-Focus-Gass-final1.pdf

OIF, "400ZR Interoperability White Paper ECOC 2022 Plugfest", https://www.oiforum.com/wp-content/uploads/OIF_400ZR_Interop_WhitePaper_ECOC2022_Plugfest.pdf

OIF, "400ZR Interoperability Demo", presented at ECOC 2022 September 19-21 Basel, Switzerland https://www.oiforum.com/wp-content/uploads/OIF_ECOC_2022_400ZR_slidedeck_9_18_2022.pdf

OpenZR+ MSA, "OpenZR+ Specifications, v. 3.0", https://www.openzrplus.org/documents/

Keysight, "Making and Interpreting EVM Measurements" application note, https://www.keysight.com/us/en/assets/7018-01305/application-notes/5989-3144.pdf

SFF-8024 Module Management Reference Code Tables, https://members.snia.org/document/dl/26423

7 Appendix A: List of Contributors

Ciena - Gary Wang - WaveLogic 5 Nano 100G-400G Universal QSFP-DD

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

Coherent - Abdi Zolfaghari- 400G OpenZR+ QSFP-DD-DCO

EXFO - Jean-Marie Vilain, Louis Forget - Transmission & Optical Test Bench:

- 2x LTB-8 Mainframe
- 2x FTBx-88481 hosting QSFP-DD Single port with DCO BERT Application
- 2x FTBx-88480 hosting QSFP-DD Dual port with DCO BERT Application
- MXS-9100, 8x8 optical matrix switch
- FTBx-5255 optical spectrum analyzer
- 2x FTBx-3500-BI variable attenuator with embedded power monitoring
- 1x FTBx-9600-01-02-50E-EI utility module with integrated optical couplers and splitters
- 1x FTBx-9600-01-02-10S utility module with integrated optical couplers and splitters
- AEDFA-NS2380 ASE source
- FTBx-1750-031-4, high performance power meter
- FIP-430P/FIP-500 Fiber inspection probe

Fujitsu Optical Components - Yasujuki Atsuchi - 400ZR+ QSFP-DD

Hisense - Oliver Huang - QSFP-DD 400G ZR+

Juniper Networks - Jose Aris Dimabuyu (JAD), Charles Park - PTX10001-36MR, JUNOS OS, JCO400-QDD-ZR+

Keysight - Paul Forrest - A400GE Tester, M8292A Optical Modulation Analyzer (software release 5.8)

LightRiver - Javier Morena, Kevin Driscoll

Lumentum - Doug Cattarusa - 400G OpenZR+ QSFP-DD-DCO

NEC - Kumi Omori - 400G OpenZR+ QSFP-DD

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

Quantifi Photonics - Nicklaus Smith - Quantifi Photonics IQRX-1004

Source Photonics - Gurinder Parhar - 400ZR+ QSFP-DD

8 Appendix B: Glossary

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

400ZR+ - Digital Coherent Optical physical interface that is not defined across the ecosystem. The OpenZR+ MSA has defined specific applications and we have used the media interface code ZR400-OFEC-16QAM for this plugfest.

400GE – 400 Gigabit Ethernet defined by IEEE 802.3

ASE - Amplified spontaneous emission

BERT - Bit Error Rate Tester

C-FEC - Concatenated Forward Error Correction

O-FEC - Open Source Forward Error Correction

CMIS - Common Management Interface Specification

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

DUT – Device under test

DWDM - Dense Wavelength-Division Multiplexing

EDFA - Erbium-Doped Fiber Amplifier

EVM - Error Vector Magnitude

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

Gbps - Gigabit per second

IA - Implementation Agreement

OpenZR+ MSA - OpenZR+ Multi-Source Agreement that defines an extended optical reaches, including flexible Ethernet rates and modulation types

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

V-LAN – Virtual Local Area Network

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.

For additional information contact:

OIF, 5177 Brandin Ct

Fremont, CA 94538 USA

510-492-4040 info@oiforum.com www.oiforum.com