White paper

Multi-Vendor 400G Coherent Optical Transceiver Interoperability Testing

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OpenZR+ MULTI-SOURCE AGREEMENT

www.openzrplus.org

Contents

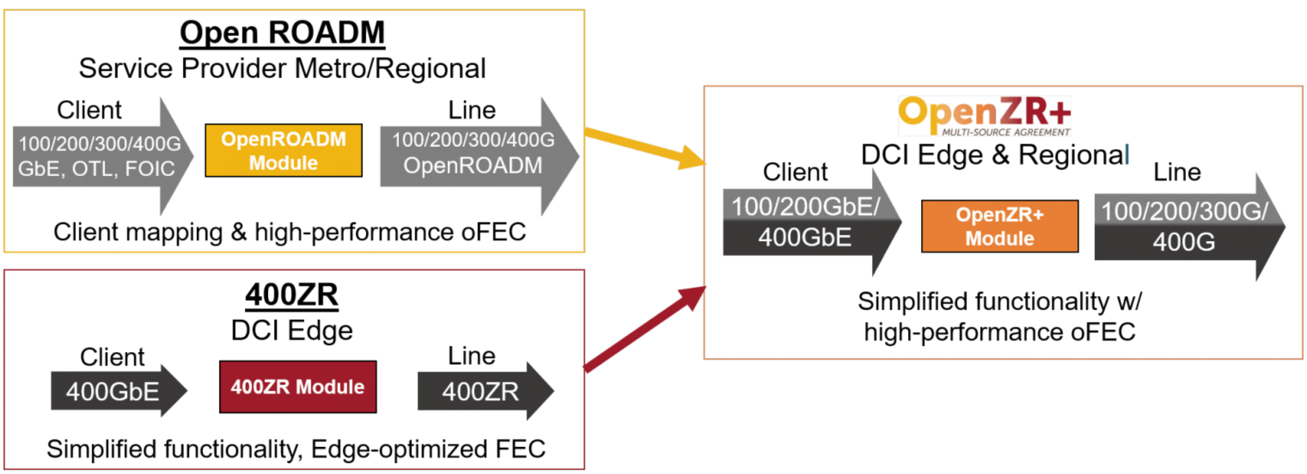
1. Introduction

Several years ago, hyperscale network operators saw an opportunity for coherent Dense Wavelength Division Multiplexing (DWDM) transport optics to plug directly into routers for 400 Gbps Data Center Interconnections (DCIs) with reaches up to 120km. This point-to-point, IP-over-DWDM architecture would eliminate the need for external optical transmission systems thus saving capital and operating expenses.

The Optical Internetworking Forum (OIF) started the 400ZR project in 2016 to standardize interoperable coherent interfaces with power consumption/dissipation to support small form-factors, such as QSFP-DD and OSFP, to plug into routers. Targeting a module power consumption/dissipation of 15 Watts, OIF standardized on the minimum features and performance to achieve the specific DCI use-case. The 400ZR standard was completed in 2020, vendors demonstrated interoperability to this standard, and the 400ZR solution was deployed in hyperscale DCI networks.

In parallel, system vendors demonstrated that improved thermal performance could be achieved for these small form-factors, which allowed digital signal processor (DSP) and module vendors to support additional functionality and higher performance. Building on the success of OIF, other standards bodies, such as Open ROADM, defined standards for applications beyond DCI that included additional features and higher performance. Open ROADM was designed for OTN-based networks that require support for additional protocols that can increase the ratio of overhead bits.

The OpenZR+ Multi-Source Agreement (MSA) defined interoperability specifications that expanded the applications for coherent optical transceivers in small form factor pluggable modules for longer-reach IP-over-DWDM links. OpenZR+ is a combination of the OIF 400ZR and Open ROADM industry standardization efforts:



Specifically, OpenZR+ combined the focus on ethernet traffic, higher performance, and multi-vendor interoperability to provide network operators with an operationally efficient solution for DCI and service provider applications with support for regional and long-haul reaches.

Multi-vendor interoperability is important in communications networks because, first, it promotes healthy competition in the industry, encouraging innovation and cost-efficiency. Furthermore, multi-vendor interoperability enhances network reliability and resilience. It allows network operators to mix and match equipment and services from different providers, reducing the risk of single points of failure and improving overall network stability. Additionally, interoperability simplifies network management and maintenance, as administrators can adopt the best-of-breed solutions, resulting in a more flexible and adaptable network infrastructure.

Achieving multi-vendor interoperability requires a couple steps. It is essential to define clear and comprehensive specifications and standards that all vendors must adhere to. Once specifications are established, rigorous interoperability testing should be conducted with products from different vendors to identify and resolve any compatibility issues. In line with this, the OpenZR+ group held two interoperability test events at LightRiver:

- Phase 1 (August 2023): Verification that optical transceiver QSFP-DD-DCO modules comply to the OpenZR+ multi-source agreement in router platforms through the OIF CMIS compliant interface in loopback mode. Also verify that optical transceiver QSFP-DD-DCO modules from different vendors interoperate over a Single-Span link with 75 km of fiber.
- Phase 2 (September 2023): Multi-vendor Interoperability and performance testing over multi-span optical line system (OLS).

The vendor participants were Cisco, Coherent, Fujitsu, Juniper Networks, and Lumentum on the coherent optical transceivers and Cisco and Juniper Networks on the routers.

This white paper describes the multifaceted interoperability test cases and the results.

2. Equipment List

Phase 1 Testing:

- 7x OpenZR+ 400G modules: 3x +0 dBm modules and 4x -10 dBm modules
- 1x Cisco 8201 router
- 1x Juniper Networks PTX10001-36MR router
- 2x Ciena EDFA
- 2x Lumentum Mux/Demux 75GHz
- 75km fiber spool
- 1x 50/50 fiber splitters
- 1x 90/10 fiber splitters
- 1x Attenuator
- 1x 10 dB fix attenuator (on +0 dBm modules)
- 1x EXFO Optical Spectrum Analyzer (OSA) EXFO FTBx-5235
- 1x EXFO Variable Attenuator
- 1x Viavi optical broadband light/noise source (Viavi OBS 550)
- 1x Viavi ONT 800 series optical network tester/traffic generator and analyzer
- Multiple fiber jump cables, ranging between 3m-10m

Phase 2 Testing:

- 7x OpenZR+ 400G modules: 3x +0 dBm modules and 4x -10 dBm modules
- 1x Cisco 8201 router
- 1x Juniper Networks PTX10001-36MR router
- 5x Fujitsu EDFA PN: L200
- 2x Fujitsu L100 open line systems
- 430km fiber spool, bi-directional link
- 1x Viavi ONT 800 series traffic generator and analyzer
- Multiple fiber jump cables, ranging between 3m-10m
- LightRiver's netFLEX™ Optical Domain Control Software solution

3. Phase 1 Testing: Interoperability over a Short Link and Single-Span Link with 75km of fiber

Phase 1 testing consisted of two different links: a Short Link and a Single-Span link. The purpose of the Short Link was to verify compatibility of the OpenZR+ optical transceiver modules from multiple vendors in routers from different vendors and to capture baseline performance of each OpenZR+ optical transceiver module looped back on itself. The purpose of the Single-Span Link was to confirm interoperability between OpenZR+ optical transceiver modules from multiple vendors and generate a performance matrix between the different modules.

Two different routers were used as hosts for the testing. The routers managed the OpenZR+ optical transceiver modules through the Common Management Interface specification (CMIS) defined by the OIF.

An optical spectrum analyzer (OSA) was used to measure the Actual optical signal-to-noise ratio (OSNR) during all testing. The resolution for acquisition was 0.33 nm and the OSNR was normalized at 0.1 nm according to IEC 61280-2-9.

Short-Link Test Setup:

In the Short-Link Test Setup, shown in

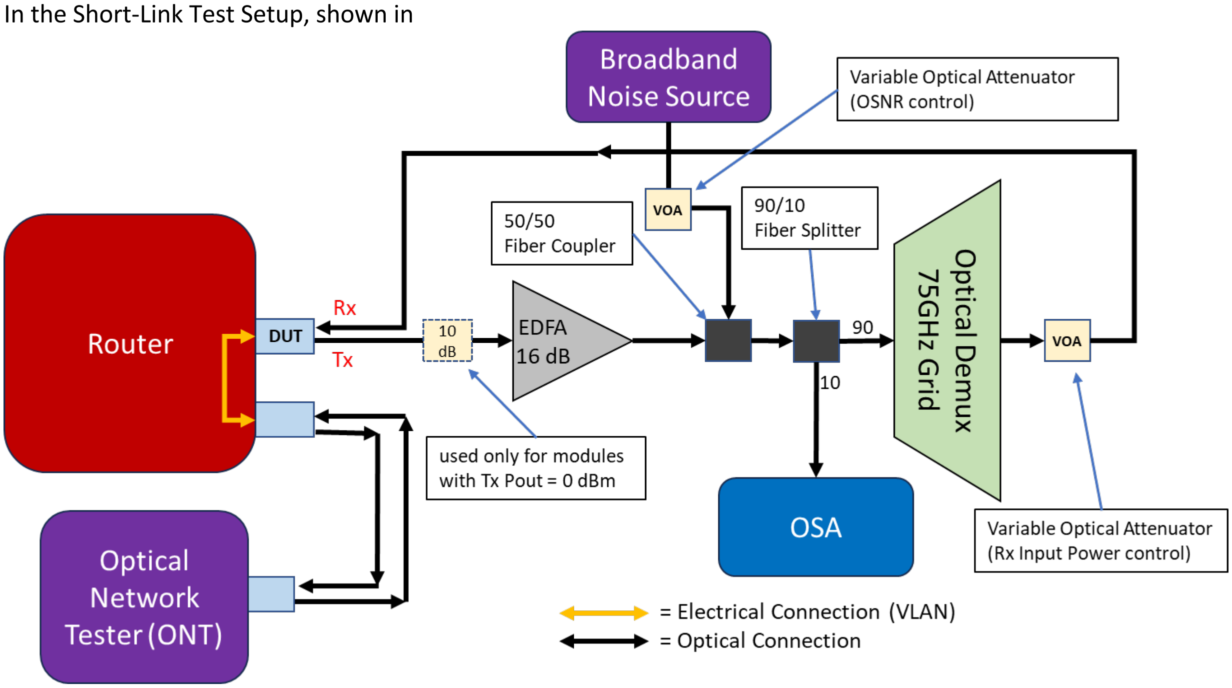


Figure 1, the OpenZR+ optical transceiver module (device under test or DUT) was plugged into a router and configured as follows: the client mode compliant to 1x400GE IEEE 802.3bs, frequency channel to the 193.7 THz, and transmit power to 0 dBm or -10 dBm. The transmitter port of the module was then connected with a fiber to an erbium-doped fiber amplifier (EDFA), and the EDFA was configured in the constant gain mode with a gain of 16 dB. The output of the EDFA was connected to one of the inputs of a 50/50 fiber coupler; an optical broadband noise source (BBS) with the level controlled by a variable optical attenuator was connected to the other input of the fiber coupler. The primary function of the BBS is to load noise into the link to decrease the OSNR until the link produces errors.

The output of the 50/50 fiber coupler was connected to a 90/10 fiber splitter: 90% of the optical signal was split to the input port of an optical demultiplexer (demux) while 10% was split to the OSA to measure the Actual OSNR of the optical signal into the receiver port of the DUT. The 193.7 THz output channel port for the demux was connected back into the DUT's RX port. A variable optical attenuator was placed between the demux channel port and the RX port of the module to set the optical input power to -10 dBm.

For all the test set ups in this white paper, 400 Gbps-framed traffic was generated by an optical network tester (ONT), and two additional 400G modules were used to transmit and receive traffic between the ONT and the router. From the traffic module, the router mapped a passive bi-directional, electrical connection to the DUT by creating a virtual local area network (V-LAN). Both the router and ONT analyzed the performance of the link by monitoring error rates in the traffic. Additionally, the router continuous monitored the CMIS registers from the module under test.

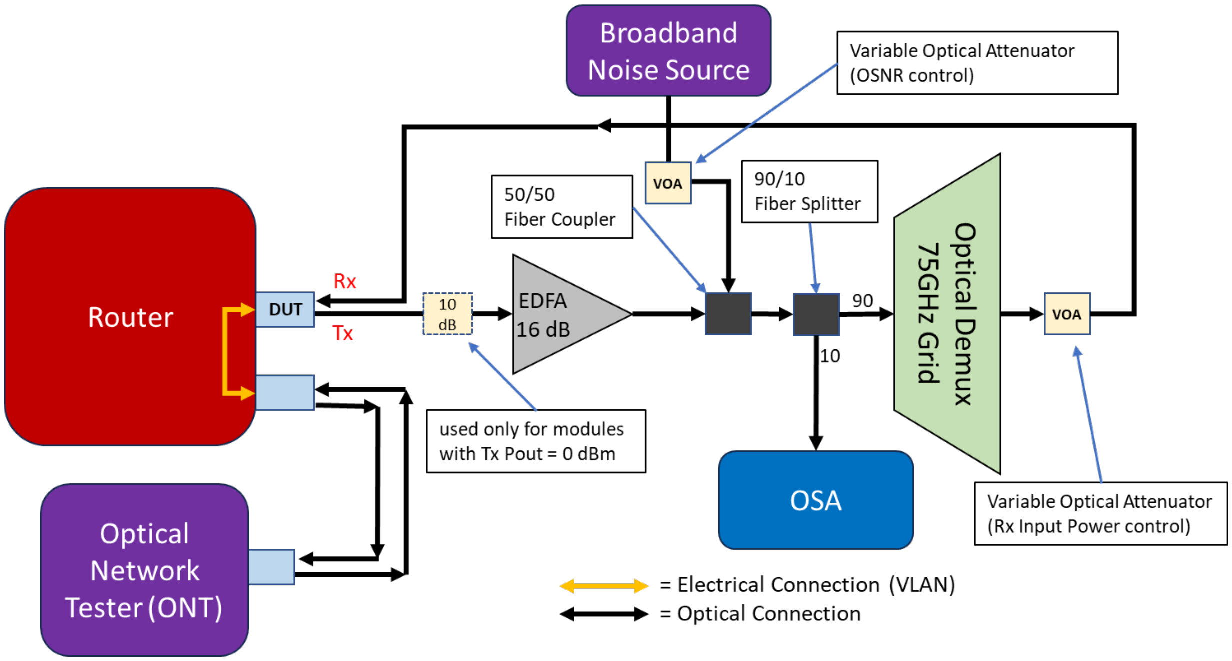


Figure 1: Short-Link Test Setup

Short-Link Test Procedure:

This is the test procedure for the Short-Link testing:

1. Insert module (DUT) in the router.
2. Configure the module into the OpenZR+ 400G application mode (Client 1x400GE mode).
3. Allow the module to power into the *ModuleReady* state.
4. Configure the module frequency to 193.7 THz.
5. Configure the optical output power to -10 dBm or +0 dBm, depending on the module type.
6. Connect the optical output signal of the module to the optical input of the EDFA. If the module supports Tx output power of +0 dBm, then connect a 10 dB attenuator between the module transmitter port and the EDFA.
7. Measure the output power from the optical demux and adjust the variable attenuator to achieve an output total power value from -9.5dBm to -10 dBm.
8. Connect the output of the line system (optical de-mux + attenuator) to the receiver port of the module.
9. Wait for the module to establish a bi-directional error-free link. This requires controlling the OSNR ratio on the line system by adjusting the attenuation between the broad band noise generator and the 50/50 coupler (the attenuator is marked ‘X’ in the test setup). Note: This attenuator ‘X’ is used throughout the test to control the line system’s OSNR.
10. Reduce the OSNR in 0.1dB steps until a post-FEC error is reported by the router and/or the Viavi ONT tester.
11. Increase the OSNR by 0.1dB until an error-free link is established.
12. Allow the traffic to pass between modules for 30 seconds. If a post-FEC error is reported by the router and/or the Viavi ONT tester, then repeat step #11. If no post-FEC error is reported by the router and Viavi ONT tester, then record the OSNR value as the OSNR tolerance.
13. Repeat steps 1-12 with a new module.

Short-Link Test Results & Observations:

The testing confirmed that OpenZR+ optical transceiver modules from multiple vendors were compatible in the routers from the two different vendors. Two OpenZR+ optical transceiver modules did not initialize in Router B.

Baseline OSNR tolerance was captured for each OpenZR+ optical transceiver module in each of the two different routers. **Error! Reference source not found.Error! Reference source not found.** lists the OSNR tolerance requirements specified in the OpenZR+ MSA; when operating in the 400G/16QAM mode, the module shall pass traffic without errors at a OSNR tolerance of 24 dB or less.

Ref.	Parameter	Mode	Min	Max	Unit	Conditions/Comments
11.1.330	OSNR tolerance	400G/16QAM	—	24	dB/0.1 nm	At OFEC threshold. Referenced to an optical bandwidth of 0.1 nm at 193.7 THz or 12.5 GHz.
		300G	—	21		
		200G	—	16		
		100G	—	12.5		

Table 1: OpenZR+ MSA OSNR tolerance requirement [ref]

The data for OSNR tolerance of each module in each two router platforms is listed in Table 2, with the Actual OSNR measured by the OSA and the Reported OSNR by the module versatile diagnostics monitoring (VDM). For Actual OSNR, the minimum value was 20.7 dB and maximum value was 21.7 dB. All modules complied to the OpenZR+ requirement with a minimum margin of 2.3 dB.

The Reported OSNR from the VDM in each module was recorded to observe the reporting accuracies compared to the Actual OSNR as measured by the OSA; the maximum difference was 1.2 dB. The accuracy of the Reported OSNR varied by the router platform: about 1 dB higher in Router A and from 0.2 dB to 0.8 dB lower in Router B.

OSNR Tolerance (dB)	Router A			Router B		
Vendor Module ID	**Actual (OSA)**	**Reported (Module VDM)**	**Delta**	**Actual (OSA)**	**Reported (Module VDM)**	**Delta**
A	21.3	22.2	-0.9	21.4	21.1	0.3
B	20.7	21.9	-1.2	21.7	20.9	0.8
C	21.1	22.3	-1.2	21.4	21.2	0.2
D	21.3	22.1	-0.8	21.8	21.5	0.3
E	21.0	21.9	-0.9			
F	21.0	22.2	-1.2			

Table 2: OSNR Tolerance of Modules in Loopback in Short Link

Single-Span Test Setup:

The Single-Span test setup modified the Short-Link test set up by adding an optical multiplexer (mux), a spool of 75km SMF-28 fiber, and a second EDFA. These three components were placed before the 50/50 fiber coupler. Note that testing was only performed in Router A. The router, ONT, V-LAN, and two additional modules retained the same configuration as the Short-Link test setup.

First, the baseline measurements were collected on each OpenZR+ optical transceiver module by looping it back on itself as shown in Figure 2. The testing procedure was the same as the procedure used for the Short-Link Test.

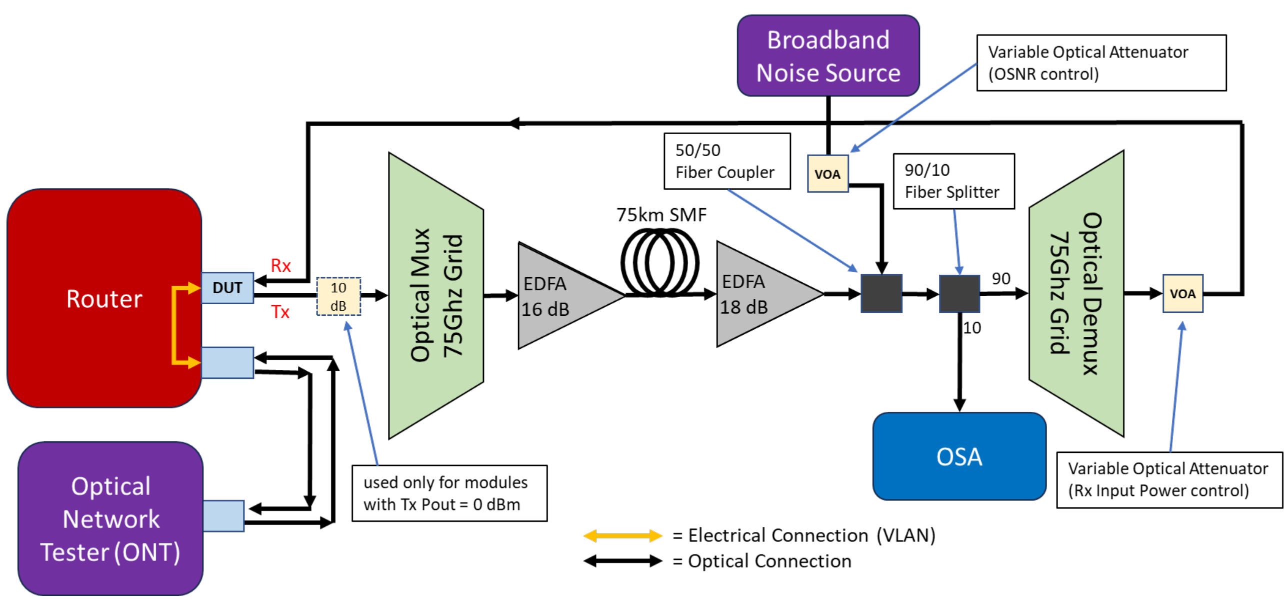


Figure 2: Single-Span 75km Link Test Setup, Loop-Back

Next, the test focused on interoperability between the different modules as shown in Figure 3. The Single-Span test setup was modified to include a second DUT module; one DUT was designated as transmitter (Tx-DUT) and the other DUT designated as receiver (Rx-DUT). Both DUTs were configured the same as in the Short-Link test setup. The transmitter port from the Tx-DUT was connected to the optical mux and the optical signal was transported through the entire link to the receiver port of Rx-DUT.

Additionally, the traffic path had to be modified to accommodate the second DUT by adding a third 400G traffic module and creating a second V-LAN connection. This enabled a return pathway by configuring the third traffic module in a self-loopback and connecting the transmitter from Rx-DUT optically to the receiver of the Tx-DUT. The router and ONT continued to analyze the traffic and link performance, and the router continued to monitor VDMs of both DUTs using CMIS.

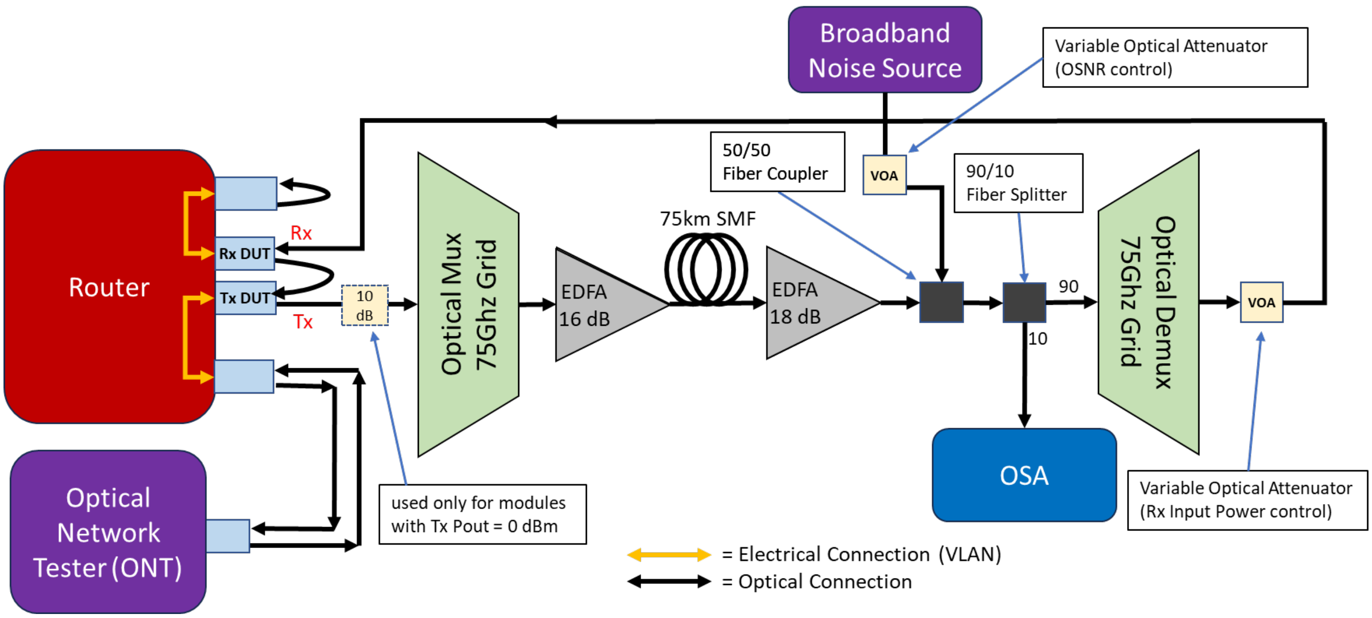


Figure 3: Single-Span 75km Link Test Setup, Module Interoperability

Single-Span Module Interoperability Test Procedure:

This is the test procedure for the interoperability testing over the Single-Span link :

1. Insert Tx-DUT module (#1) in the router.
2. Configure the Tx-DUT module into the OpenZR+ 400G application mode (Client 1x400GE mode).
3. Allow the module to power into the *ModuleReady* state.
4. Configure the module frequency to 193.7 THz.
5. Configure the optical output power to -10 dBm or +0 dBm, depending on the module type.
6. Connect the transmitter port of the module to the input of the line system (optical mux). If the module supports +0 dBm Tx output power, then connect a 10 dB attenuator between the module transmitter port and the optical mux.
7. Measure the output power from the optical demux and adjust the variable attenuator to achieve an output total power value from -9.5dBm to -10 dBm.
8. Insert Rx-DUT module (#2) in the router.
9. Configure the Rx-DUT module into the OpenZR+ 400G application mode (Client 1x400GE mode).
10. Allow the module to power into the *ModuleReady* state.
11. Configure the module frequency to 193.7THz.
12. Connect the output of the line system (optical de-mux + attenuator) to receiver port of the Rx-DUT module.

13. Wait for the modules to establish a bi-directional error-free link. This requires controlling the OSNR ratio on the line system by adjusting the attenuation between the broad band noise generator and the 50/50 coupler.
14. Reduce the OSNR in 0.1dB steps until a post-FEC error is reported by the Router and/or the Viavi ONT tester.
15. Increase the OSNR by 0.1dB until you reestablish a bi-directional error-free link.
16. Allow the traffic to pass between modules for 30 seconds. If a post-FEC error is reported by the router and/or the Viavi ONT tester, then repeat step #15. If no post-FEC error is reported by the Router and Viavi ONT tester, then record the OSNR value as the OSNR tolerance.
17. Repeat steps 8-12 with a new Rx-DUT module from the OpenZR+ MSA interoperability group.
18. Repeat steps 1-12 with a new Tx-DUT module from the OpenZR+ MSA interoperability group.

Single-Span Test Results & Observations:

All the OpenZR+ optical transceiver modules from multiple vendors interoperated with each other in the Single-Span testing. Due to time constraints, only Router A was used for the testing.

The data for the Actual OSNR tolerance, as measured by the OSA, for all combinations of modules is listed in Table 3 which shows a minimum value of 20.6 dB and maximum value of 22.9 dB. All combinations complied to the OpenZR+ requirement of 24 dB or less with a minimum margin of 1.1 dB. The baseline measurements with the modules looped back on themselves are highlighted in bold format. Compared to the Short-Link test results, these values were 0.0 dB to 0.7 dB worse (higher).

Table 4 provides the statistics of Actual OSNR tolerance by transmitter and receiver of each module. All transmitters had a variation of about 1 dB when measured with the receivers of the other modules, except for the transmitter of Module B which had values that varied by 2.1 dB. The receivers varied from 1.0 dB to 1.5 dB when measured with the transmitters of the other modules.

OSNR Tolerance (dB)	**Tx-DUT Module ID**					
Rx-DUT Vendor Module ID	**A**	**B**	**C**	**D**	**E**	**F**
A	**21.3**	22.5	21.3	22.2	22.4	22.8
B	20.8	**21.3**	20.6	21.3	21.7	21.8
C	21.6	22.7	**21.5**	22.3	22.7	22.9
D	21.1	22.0	21.0	**21.6**	22.2	22.0
E	20.7	20.6	21.4	21.4	**21.6**	21.6
F	20.6	20.6	21.5	21.7	21.6	**21.7**

Table 3: OSNR Tolerance in Single-Span Link Interoperability Testing

OSNR Tolerance (dB)	Statistics by vendor Transmitter across all Receivers				Statistics by vendor Receiver across all Transmitters			
Vendor Module ID	**median**	**max**	**min**	**range**	**median**	**max**	**min**	**range**
A	21.0	21.6	20.6	1.0	22.3	22.8	21.3	1.5
B	21.7	22.7	20.6	2.1	21.3	21.8	20.6	1.2
C	21.4	21.5	20.6	0.9	22.5	22.9	21.5	1.4
D	21.7	22.3	21.3	1.0	21.8	22.2	21.0	1.2
E	22.0	22.7	21.6	1.1	21.4	21.6	20.6	1.0
F	21.9	22.9	21.6	1.3	21.6	21.7	20.6	1.1

Table 4: Statistics of OSNR Tolerance by Module ID in Single-Span Link Interoperability Testing

The data for Reported OSNR tolerance is listed in Table 5 for all combinations of modules. The minimum value was 21.1 dB and maximum value was 22.7 dB. All combinations complied to the OpenZR+ requirement of 24 dB or less and the minimum margin was 1.3 dB. The baseline measurements with the modules looped back on themselves are highlighted in bold format; compared to the Short-Link test results, these values varied from -0.5 dB to 0.3 dB.

Reported OSNR Tolerance (dB)	Tx-DUT Module ID					
Rx-DUT Vendor Module ID	**A**	**B**	**C**	**D**	**E**	**F**
A	**22.3**	21.7	22.2	21.7	21.6	21.9
B	22.2	**21.9**	22.2	22.7	22.4	22.2
C	22.5	22.0	**22.6**	22.1	22.1	22.2
D	22.0	22.0	22.0	**22.2**	22.3	22.1
E	21.4	21.1	21.4	21.9	**21.4**	21.4
F	22.2	21.9	22.2	22.4	22.4	**22.4**

Table 5: Reported OSNR Tolerance in Single-Span Link Interoperability Testing

Table 6 provides the statistics of Reported OSNR tolerance by transmitter and receiver of each module. All transmitters had a variation of about 1 dB when measured with the receivers of the other modules. The receivers varied from 0.3 dB to 0.8 dB when measured with the transmitters of the other modules.

Reported OSNR Tolerance (dB)	**Statistics by vendor Transmitter across all Receivers**				**Statistics by vendor Receiver across all Transmitters**			
Vendor Module ID	**median**	**max**	**min**	**range**	**median**	**max**	**min**	**range**
A	22.2	22.5	21.4	1.1	21.8	22.3	21.6	0.7
B	21.9	22.0	21.1	0.9	22.2	22.7	21.9	0.8
C	22.2	22.6	21.4	1.2	22.2	22.6	22.0	0.6
D	22.2	22.7	21.7	1.0	22.1	22.3	22.0	0.3
E	22.2	22.4	21.4	1.0	21.4	21.9	21.1	0.8
F	22.2	22.4	21.4	1.0	22.3	22.4	21.9	0.5

Table 6: Statistics of Reported OSNR Tolerance by Module ID in Single-Span Link Interoperability Testing

Table 7 provides the difference between the Actual OSNR and the Reported OSNR for all combinations of modules. Most combinations had an accuracy of 1 dB or less except for a handful of data points.

Delta Actual vs. Reported OSNR Tolerance (dB)	**Tx-DUT Module ID**					
Rx-DUT Module Vendor ID	**A**	**B**	**C**	**D**	**E**	**F**
A	**-1.0**	0.8	-0.9	0.5	0.8	0.9
B	-1.4	**-0.6**	-1.6	-1.4	-0.7	-0.4
C	-0.9	0.7	**-1.1**	0.2	0.6	0.7
D	-0.9	0.0	-1.0	**-0.6**	-0.1	-0.1
E	-0.7	-0.5	0.0	-0.5	**0.2**	0.2
F	-1.6	-1.3	-0.7	-0.7	-0.8	**-0.7**

Table 7: Statistics of Reported OSNR Tolerance by Module ID in Single-Span Link Interoperability Testing

4. Phase 2 Testing: Interoperability over a Multi-Span Optical Line System with 430km of fiber

Multi-Span Link Test Setup:

The Phase 2 test focused on interoperability between OpenZR+ optical transceiver modules from multiple vendors over an optical line system (OLS) with multiple spans. The test set up is shown in **Error! Reference source not found.**Figure 4. The Fujitsu OLS consisted of a ROADM node on one end of the link, five Intermediate Line Amplifier (ILA) nodes, and another ROADM node on the other end. Spools of SMF-28 fiber, with distances shown in Table 8, were between the nodes. Routers from two vendors hosted multiple OpenZR+ modules (DUTs) at the same time. The modules were daisy-chained to each other to create one large 400G traffic link. This was accomplished through multiple V-LAN connections. Similar to the Single-Span interoperability test, the final module in the daisy-chain link was a third 400G traffic module in Router B, which had a self-loopback optical connection to return the 400G traffic link. The optical ports on the OpenZR+ modules were connected directly to the ROADM's channel ports with short fiber jumper cables.

Again, the router and ONT continued to analyze the traffic and link performance, and the router continued to monitor VDMs of both DUTs using CMIS.

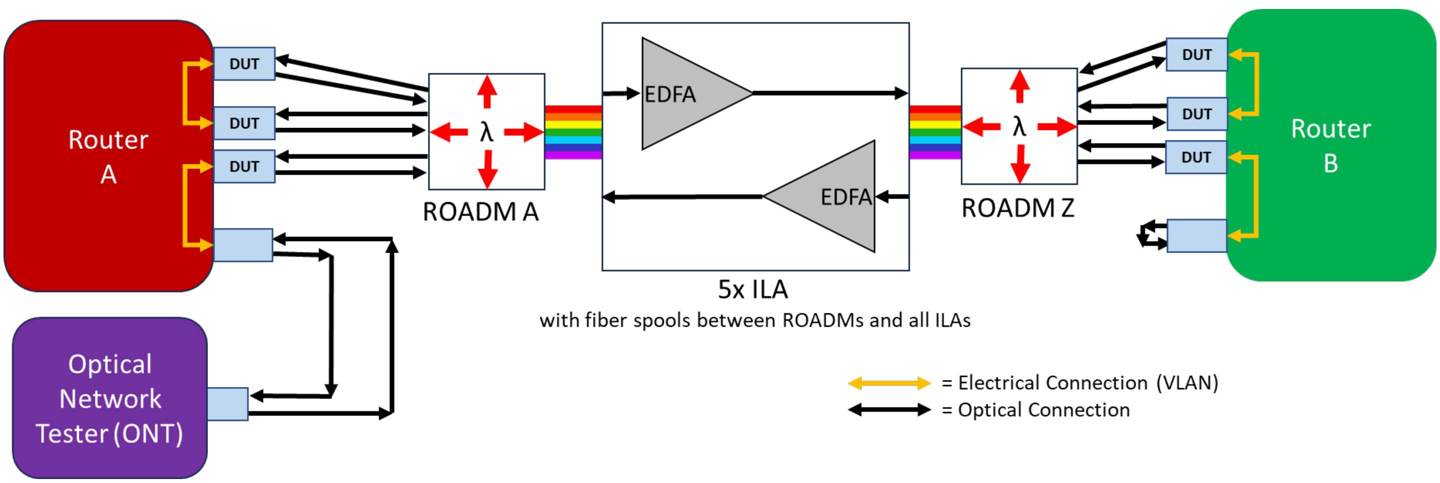


Figure 4: Multi-Span 430km Optical Line System Setup

Node-Node Link	Fiber Length
ROADM A to ILA1	105 km
ILA1 to ILA2	75 km
ILA2 to ILA3	50 km
ILA3 to ILA4	50 km
ILA4 to ILA5	50 km
ILA5 to ROADM Z	100 km
Total Fiber Distance	430 km

Table 8. Fiber Lengths between each Node in Multi-Span OLS testing

LightRiver's netFLEX™ Optical Domain Control Software solution was utilized to provision, control, and monitor the entire disaggregated network. It captured the data on the OpenZR+ optical transceiver modules, such as optical levels and OSNR.

Multi-Span Test Procedure:

This was the test strategy:

- Split the OpenZR+ optical transceiver module into two groups by transmitter optical output power:
- Module Group I: -10 dBm (4 vendors with 2 modules each)
- Module Group II: 0 dBm (3 vendors with 2 modules each)
- Test each group at the lower, center, and upper frequency ranges of the C-Band spectrum to measure performance across the entire wavelength range.
- For each frequency range, provision the modules to use three or four neighboring, adjacent frequencies spaced at 75 GHz, as shown in Figure 5, in order to include interference from out-of-band noise during the testing.
- Bookend each module with a module from a different vendor to test interoperability between modules.

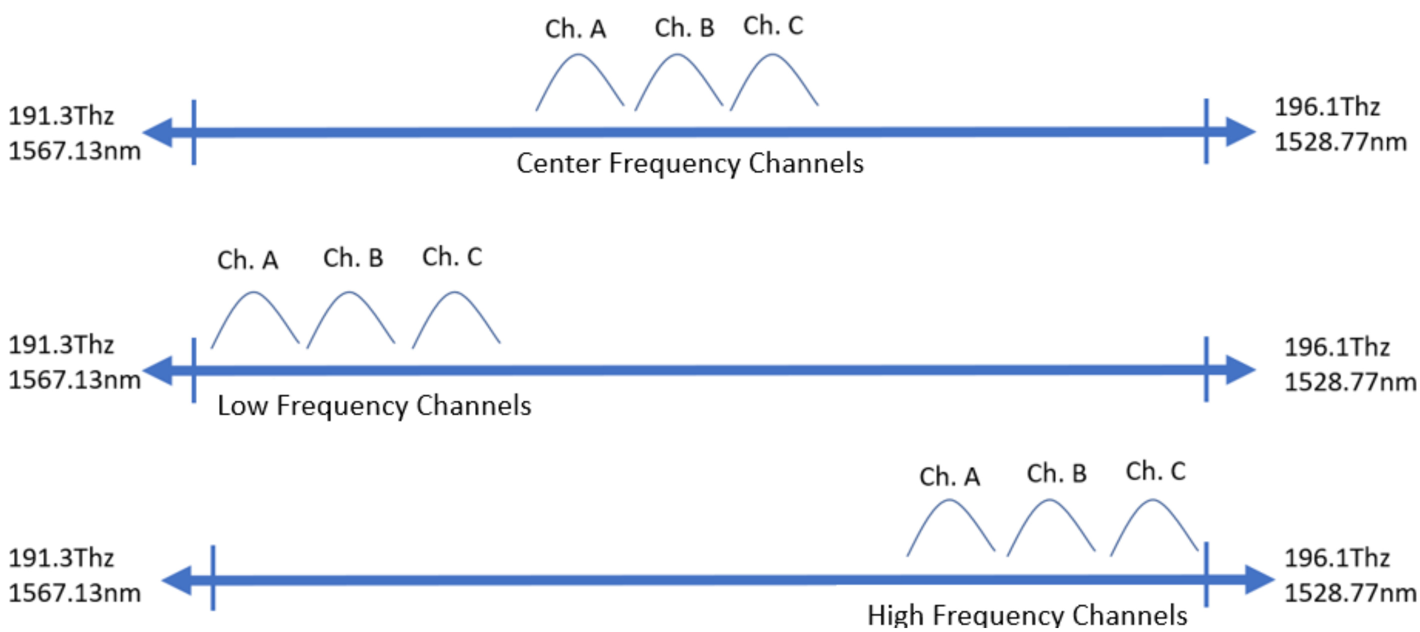


Figure 5: Frequency Ranges for Multi-Span Link Testing showing three adjacent channels

This is the test procedure for the testing over the Multi-Span link:

1. Insert modules from Module Group I into the routers.
2. Configure the modules into the OpenZR+ 400G application mode (Client 1x400GE mode).
3. Allow the module to power into the *ModuleReady* state.
4. Configure pairs of the modules to operate over four or three neighboring, adjacent frequencies in the center frequency range.
5. Configure the optical output power to -10 dBm for Group I modules or 0 dBm for Group II modules.
6. Connect the transmitter port of each module to the appropriate ROADM node of the Optical Line System.
7. Connect the receiver port of each module to the appropriate ROADM node of the Optical Line System.
8. Wait for the modules to establish a bi-directional error-free links.
9. Allow the traffic to pass between modules for 30 seconds. If no post-FEC error is reported by a router and/or the Viavi ONT tester, capture the performance metrics using LightRiver's netFLEX™.
10. Wait 15 minutes.

11. Capture performance metrics again using LightRiver's netFLEX™.
12. Repeat steps 4-11 at the low frequency range and then the high frequency range.
13. Repeat steps 1-11 with the modules from Module Group II.

Multi-Span Link Test Results & Observation:

400G client traffic was successfully transported on four or three optical channels simultaneously over the Multi-Span OLS network with 430 km of fiber with no post-FEC errors at center, low, and high frequency ranges for Module Groups I and II.

The reported optical power levels at the modules and the ROADM nodes for Module Group I tested at the center frequency range are shown in **Error! Reference source not found.**. The reported optical power level for the transmitters varied from –8.8 dBm to –11.8 dBm; the ROADM nodes balanced the actual power levels to transport over the OLS.

Router A			ROADM A		ROADM Z		Router B		
Module Vendor ID	**Port**	**Module Optical Level**	**Optical Channel Level**	**Composite Optical Level**	**Composite Optical Level**	**Optical Channel Level**	**Module Optical Level**	**Port**	**Module Vendor ID**
A	**TX**	-11.1	-9.0	TX: 8.7 RX: -19.1	TX: 7.9 RX: -9.3	-10.1	-8.8	**RX**	**C**
	RX	-8.9	-11.3			-9.0	-10.1	**TX**	
B	**TX**	-8.8	-8.9			-11.1	-8.5	**RX**	**D**
	RX	-9.1	-10.5			-9.0	-10.0	**TX**	
C	**TX**	-10.0	-8.9			-10.1	-9.3	**RX**	**B**
	RX	-9.0	-8.4			-9.0	-11.8	**TX**	
D	**TX**	-10.0	-9.0			-11.3	-9.2	**RX**	**A**
	RX	-8.3	-10.7			-9.2	-10.8	**TX**	

Table 9. Reported Optical Power Levels (dBm) for Module Group I for Multi-Span Link at center frequency range

The reported values for receiver OSNR, receiver pre-FEC BER, and chromatic dispersion for Module Group I tested at the center frequency range are shown in Table 10.

Router A					Router B			
Module Vendor ID	Port	Rx OSNR (dB)	Rx pre-FEC BER	Chromatic Dispersion (ps/nm)	Rx pre-FEC BER	Rx OSNR	Port	Module Vendor ID
A	TX				3.50E-03	25.3	RX	C
	RX	23.2	1.09E-02	7274			TX	
B	TX				1.20E-02	23.1	RX	D
	RX	23.4	8.76E-03	7250			TX	
C	TX				6.80E-03	24.4	RX	B
	RX	23.5	8.75E-03	7250			TX	
D	TX				1.20E-02	23.2	RX	A
	RX	25	6.95E-03	7255			TX	

Table 10. Reported Rx OSNR, pre-FEC BER, and CD for Module Group I for Multi-Span Link at center frequency range

Compared to the Single-Span Link, the OSNR degraded through the Multi-Span Link due to the additional EDFAs and out-of-band noise from the adjacent optical signals. Five out of the eight of the modules reported receiver OSNR that was even lower than the OSNR tolerance of 24 dB as required in the OpenZR+ specification, but the links still passed traffic with no post-FEC errors. Here are two of these cases:

- The module from Vendor ID A in Router A reported a receiver OSNR of 23.2 dB and pre-FEC BER of 1.09E-02
- The module from Vendor ID D in Router B reported a receiver OSNR of 23.1 dB and pre-FEC BER of 1.20E-02

Both reported pre-FEC BER values are just below the breakdown threshold of 2.0E-02 for oFEC.

The reported chromatic dispersion by all the modules in Router A was about 7250 ps/nm which correlated well with the total fiber length of 430 km used in the link.

The reported receiver OSNR and receiver pre-FEC BER for Module Group I at the low, center, and high frequency ranges are shown in Table 11.

	Router A						Router B						
Module Vendor ID	Low Freq Range		Center Freq Range		High Freq Range		Low Freq Range		Center Freq Range		High Freq Range		Module Vendor ID
	Rx OSNR (dB)	Rx pre-FEC BER	Rx OSNR (dB)	Rx pre-FEC BER	Rx OSNR (dB)	Rx pre-FEC BER	Rx OSNR (dB)	Rx pre-FEC BER	Rx OSNR (dB)	Rx pre-FEC BER	Rx OSNR (dB)	Rx pre-FEC BER	
A	23.3	1.06E-02	23.2	1.09E-02	22.4	1.58E-02	25.3	3.40E-03	25.3	3.50E-03	25.1	3.60E-03	C
B	22.9	5.39E-03	23.4	8.76E-03	21.4	1.50E-02	23.1	1.20E-02	23.1	1.20E-02	23.0	1.20E-03	D
C	23.7	7.75E-03	23.5	8.75E-03	22.8	1.05E-02	24.4	6.70E-03	24.4	6.80E-03	24.5	6.20E-03	B
D	23.1	1.17E-02	25.0	6.95E-03	22.9	1.30E-02	23.2	1.20E-02	23.2	1.20E-02	23.0	1.20E-02	A

Table 11. Reported Rx OSNR and pre-FEC BER for Module Group I for Multi-Span Link at low, center, and high frequency ranges

The values at low and high frequency ranges were compared to the center frequency range. In general, the values were approximately the same, except at the high frequency range in Router A which showed noticeably worse values for reported Rx OSNR and pre-FEC BER. Even with these degraded values, the links still passed traffic with no post-FEC errors; the reported pre-FEC BER values were still below the breakdown threshold of 2.0E-02 for oFEC.

The reported receiver OSNR and receiver pre-FEC BER for Module Group II at the low and center frequency ranges are shown in Table 12. Testing was not completed at the high frequency range.

	Router A						Router B						
Module Vendor ID	Low Freq Range		Center Freq Range		High Freq Range		Low Freq Range		Center Freq Range		High Freq Range		Module Vendor ID
	Rx OSNR (dB)	Rx pre-FEC BER	Rx OSNR (dB)	Rx pre-FEC BER	Rx OSNR (dB)	Rx pre-FEC BER	Rx OSNR (dB)	Rx pre-FEC BER	Rx OSNR (dB)	Rx pre-FEC BER	Rx OSNR (dB)	Rx pre-FEC BER	
E	22.7	1.38E-02	23.7	8.62E-03	n/a	n/a	24.4	6.80E-03	24.2	6.70E-03	n/a	n/a	F
F	26.7	3.89E-03	26.2	4.56E-03	n/a	n/a	23.2	1.10E-02	23.0	1.20E-02	n/a	n/a	G
G	22.4	1.43E-02	22.5	1.34E-02	n/a	n/a	27.4	3.20-E03	26.7	3.50E-03	n/a	n/a	E

Table 12. Reported Rx OSNR and pre-FEC BER for Module Group II at low, center, and high frequency ranges

5. Conclusion

A core principle of OpenZR+ is to foster multi-vendor interoperability to cultivate healthy competition in the industry. This not only bolsters network reliability and resilience, but also facilitates the creation of a more versatile and adaptive network infrastructure. Additionally, OpenZR+ is dedicated to specify solutions that operate in real-world scenarios. To validate the efficacy of the 400G OpenZR+ solution, the OpenZR+ MSA group conducted Phase 1 and Phase 2 test events at LightRiver. The test results were successful in showing compatibility to the OpenZR+ specification and interoperability between optical transceiver modules from different vendors in two different routers by transporting 400 Gb/s traffic over various optical links.

In the Short-Link Test in Phase 1, all optical transceiver modules operated in the two different routers which included communication using the CMIS interface compliant to the OIF standard. When in loop-back, all optical transceiver modules transported 400G traffic to the OpenZR+ requirement of a receiver OSNR of 24 dB/0.1 nm, with at least 2.3 dB of margin. The reported OSNR by the module was compared to the actual OSNR as measured by the OSA; the reported OSNR was about 1 dB higher in Router A and about 0.8 dB lower in Router B.

The Single-Span testing over 75 km of fiber in Phase 1 focused on interoperability of optical transceiver modules in a DCI use-case. All the modules from multiple vendors successfully interoperated with each other. All optical links transported 400G traffic to the OpenZR+ requirement of a receiver OSNR of 24 dB/0.1 nm, with at least 1.1 dB of margin. For most combinations, the reported OSNR by the modules in Router A was about 1 dB higher than the actual OSNR.

Phase 2 testing was over a Multi-Span Optical Line System with 430km of fiber to emulate a metro network use-case. The Fujitsu OLS consisted of a ROADM node on one end of the link, five Intermediate Line Amplifier (ILA) nodes, and another ROADM node on the other end. Three or four optical signals on adjacent frequency channels from transceiver modules were simultaneously transported over the network; these groups were tested in three different frequency ranges in the C-band: center, low, and high. All optical links transported 400G traffic with no post-FEC bit errors over all test conditions.

In summary, the interoperability testing was successful in showing the following:

- 400G OpenZR+ optical transceiver modules from multiple vendors operated in different routers
- All 400G OpenZR+ optical transceiver modules transported traffic with no post-FEC bit errors at receiver OSNR of 24 dB or less
- 400G OpenZR+ optical transceiver modules from five different vendors interoperated with each other
- 400G traffic was transported over a typical DCI use-case with 75 km of fiber and a typical metro use-case with multi-spans over 430 km of fiber.

Appendix A: Contributors and Participants

Cisco – MSA member: QSFP-DD 400G OpenZR+ module, 8201 Router

Coherent – MSA Member: QSFP-DD 400G OpenZR+ module

EXFO – Partner Company: FTBx-5235 Optical Spectrum Analyzer

Fujitsu – MSA Member: QSFP-DD 400G OpenZR+ module, L100 Open Line Systems, L200 EDFA

Juniper Networks – MSA Member: QSFP-DD 400G OpenZR+ module, PTX10001-36MR Router

LightRiver – Event Host and Partner Company: netFLEX Management Software

Lumentum – MSA Member: QSFP-DD 400G OpenZR+ module, Optical Mux/Demux

NTT Innovative Devices - MSA Member: fiber spools

Viavi – Partner Company: 800 Series Optical Network Tester, 550 Broad Band Noise Source

Appendix B: Acronyms

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, often it is referenced as the 400G application from the OpenZR+ MSA specification

BER – Bit Error Rate

OIF - Optical Internetworking Forum

CMIS - Common Management Interface Specification

DCI – Data Center Interconnect

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)

Gbps - Gigabits per second

ILA – In-Line Amplifier

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

ONT – Optical Network Tester traffic generator and analyzer

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

OSA - Optical Spectrum Analyzer

OSNR - Optical Signal-to-Noise Ratio

Pre-FEC BER – Bit Error Rate before the Forward Error Correction process

QSFP-DD - Quad Small Form Factor Pluggable Double Density

rOSNR - required OSNR

Rx – Receiver

ROADM - Reconfigurable Optical Add-drop Multiplexer

Tx – Transmitter

V-LAN – Virtual Local Area Network

VDM - Versatile Diagnostic Monitoring