Juniper 400G Optical Transceivers and Cables Guide

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About This Guide

Use this guide to learn about the Juniper Networks® 400G optical transceivers and cables, their specifications, and how to install, remove, and maintain these transceivers.

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CHAPTER

400G Optical Transceivers Overview

IN THIS CHAPTER

Know Your 400G Transceiver

IN THIS SECTION

400 Gigabit Ethernet (400G) transceivers are optical modules capable of handling data rates of 400 Gbps. With a transmission rate of up to 400 Gbps, 400G transceivers offer double the capacity of their predecessor (200G transceivers). Juniper's 400G transceivers use the QSFP-DD form factor. 400G transceivers are ideal for:

- Any host platform with 400G ports
- Networks with 400 Gbps data transmission
- Data center deployments

A 400G transceiver uses multiple lanes of optical signals and advanced modulation techniques to achieve higher capacities. 400G transceivers can employ multiplexing using multiple fibers, parallel optics, or optical multiplexing techniques. Many implementations employ wavelength multiplexing to transmit optical signals efficiently.

400 Gigabit Ethernet (400G) optical transceivers commonly feature an eight-lane architecture, with each lane operating at 50 Gbps. The 400G transceivers use Pulse Amplitude Modulation 4-level (PAM4). This modulation scheme enables doubling the data rate per lane compared to traditional NRZ, thereby making 400G transmission feasible with fewer lanes and fibers.

400G transceivers support multiple transmission rates and breakout modes to ensure compatibility with various network transport requirements. This flexibility allows a single physical transceiver to be logically divided into multiple lower-speed Ethernet ports, adapting to different deployment scenarios:

- 4x100G—The transceiver can break out into four separate 100G ports. For 400G optics with a 400GAUI-8 electrical interface, a gearbox Digital Signal Processor (DSP) is employed to manage the conversion. The gearbox converts pairs of 50 Gbps (2x50 Gbps) electrical lanes into a single 100 Gbps (1x100 Gbps) electrical lanes. The conversion occurs entirely at the electrical level. It is different from the optical lane conversion that occurs in the optical modulator. The DSP typically features multiple gearboxes with independent clock and data recovery (CDR) circuits. This helps to handle the complete signal distribution efficiently, thereby converting all 8x50G lanes into 4x100G lanes.

- 2x200G—The breakout cable provides the port as two separate 200G ports to achieve a total capacity of 400 Gbps.
- 1x400G—The transceiver functions as a single 400G port, combining all eight 50G lanes to deliver a total capacity of 400 Gbps.

Bit Rate and Symbol Rate

Understanding the fundamental concepts of bit rate and symbol rate is necessary to understand how 400G optics function.

Bit Rate—Refers to the total number of bits transmitted per second. 400G optics in the industry always operate at the 400G Ethernet bit rate. For 400G optics, the effective bit rate is 425 Gbps, when accounting for overheads as defined by the standard IEEE 802.3.

Symbol Rate (Baud Rate)—The rate at which symbols (signal changes or modulation events) are transmitted. In 400G optics using PAM4 modulation, each symbol represents 2 bits. Therefore, a 53.125 Gbaud rate correlates to a 106.25 Gbps bit rate per lane for configurations using 4 lanes. A 26.5625 Gbaud rate correlates to a 53.125 Gbps bit rate per lane for configurations using 8 lanes.

NOTE: The Juniper 400 Gigabit Optical Transceivers and Cables Guide refers to 50G, 100G, 200G, and 400G bit rates for simplicity. It is intended to align with standard industry terminology without implying specific overhead inclusions each time.

400G Optical Transceiver Flavors

You can have various 400G optical transceiver flavors, depending on their electrical interface and optical interface configurations.

Electrical interfaces

- 4-Lane Electrical Interface (400GAUI-4)
  - The 400GAUI-4 electrical interface utilizes four high-speed lanes.
  - Supported by PFE ASICs such as Express-5 (BX), Tomahawk-5, and the upcoming Trio-7 (XT).
  - These ASICs use 100G SERDES for native 800G support. However, they also support 400G by using 4x100G as the electrical interface between the host and the pluggable optic.
  - Typically used with QSFP112 optics.
- 8-Lane Electrical Interface (400GAUI-8)

    - Incorporates eight electrical lanes to handle data transmission.
    - Supported by PFE ASICs like Trio-6 (YT), Express-4 (BT), and Tomahawk-3 and 4.
    - All these ASICs employ 50G SERDES for native 400G support. Hence, the 8x50G electrical interface between the host and the pluggable optic is necessary.
    - Typically used with QSFP56-DD or QSFP-DD optics.

Optical interfaces

- Single-Lane Optical Interface (for example, 400ZR and 400ZR+)
    - Application—Designed for long-distance data center interconnects, as well as metro and regional networks.
    - Characteristics
        - Utilizes tunable DWDM optical technology for long-range communication.
        - Supports distances typically up to 80 km.
        - 400ZR (and especially 400G ZR+) optics can be used over considerably longer distances (hundreds of kilometers) when combined with a DWDM transmission platform using periodic optical amplification.
- 4-Lane Optical Interface (for example, DR4, FR4, LR4, or ER4-30)
    - Application—Suited for intermediate distance applications such as those within data center environments and campus networks.
    - Characteristics
        - DR4—Uses parallel single-mode cables with 8 fibers and has a maximum reach of up to 500 meters. DR4 is used within data center environments.
        - FR4—Uses duplex single-mode fiber and has a maximum reach of up to 2 kilometers.
        - LR4—Uses duplex single-mode fiber and has a maximum reach of up to 10 kilometers.
        - ER4-30—Uses duplex single-mode fiber and has a maximum reach of up to 30 kilometers.
- 8-Lane Optical Interface (for example, SR8 or LR8)
    - Application—Ideal for high-density environments or applications requiring extensive data aggregation and reach. An 8-Lane optical interface is suitable predominantly when cost sensitivity is a concern, and higher lane speeds are not fully matured for the specific application.
    - Characteristics

- SR8—Primarily focused on short-reach applications using multi-mode fibers. As the technology for 400G SR4 is comparatively new, SR8 is a more popular and cost-effective choice in the current market.
- LR8—Extends reach up to 10 km, suitable for longer links. However, it is considered legacy technology now.

NOTE: We recommend that you transition to 400G LR4 optics that offers better performance and is industry-relevant.

400G tunable DWDM optics support Wavelength Division Multiplexing (WDM) systems, such as Dense Wavelength Division Multiplexing (DWDM), to further enhance data transmission capacity by permitting multiple wavelengths to be transmitted over a single fiber. For example, client interfaces such as 400G FR4 or 400G LR4 also use WDM to multiplex four wavelengths into a single fiber. Hence, 400G tunable DWDM optics are also referred to as tunable DWDM optics. See "Dense Wavelength Division Multiplexing" on page 17.

Table 1: Comparison of 800G and 400G Optical Transceivers

Feature	800G	400G
Optical lane speed	8 lanes at 100 Gbps each, 53.125 Gbaud with PAM4	4 lanes at 100 Gbps each, 53.125 Gbaud per lane with PAM4 through gearbox **NOTE**: The configuration of 8 lanes at 50 Gbps each (26.5625 Gbaud per lane with PAM4, direct modulation) is not a standard configuration for Juniper's 400G optical transceivers. The 400G SR8 optical transceiver is an exception.
Electrical lane speed/Interface	800GAUI-8 (8 lanes), 106.25 Gbps per lane, 53.125 Gbaud per lane with PAM4	400GAUI-8 (8 lanes), 53.125 Gbps per lane, 26.5625 Gbaud per lane with PAM4 400GAUI-4 (4 lanes), 106.25 Gbps per lane, 53.125 Gbaud per lane with PAM4

Table 1: Comparison of 800G and 400G Optical Transceivers *(Continued)*

Feature	800G	400G
Total bandwidth	800 Gbps	400 Gbps
Fiber count	16 Tx+Rx fibers (8 Tx, 8 Rx) for parallel single-mode (MPO-16) **NOTE**: Each optical lane operates at 100 Gbps using PAM4 modulation. 2 Tx+Rx fibers (1 Tx, 1 Rx) for 4-wavelength WDM (Dual Duplex LC) **NOTE**: For 800G, each wavelength carries 200 Gbps, resulting in 4 wavelengths per fiber.	16 Tx+Rx fibers (8 Tx, 8 Rx) for parallel single-mode (MPO-16) **NOTE**: 400G SR8 transceiver uses MPO-16 connectors and 400G LR8 transceiver uses duplex LC connector. 8 Tx+Rx fibers (4 Tx, 4 Rx) for parallel single-mode (MPO-12) **NOTE**: For 400G transceivers with MPO-12 connectors, 8 out of the 12 fiber channels are used, and 4 remain unused. 2 Tx+Rx fibers (1 Tx, 1 Rx) for 4-wavelength WDM (Dual Duplex LC) **NOTE**: For 400G, each wavelength carries 100 Gbps, resulting in 4 wavelengths per fiber.
Connector type	Dual Duplex LC Dual MPO-12 Dual Duplex CS MPO-16	Duplex LC MPO-12 MPO-16 (supports 400G SR8 optical transceivers)
Form factor	QSFP-DD or OSFP	QSFP-DD
Standards	IEEE 802.3df-2024	IEEE 802.3-2022 IEEE 802.3cd (for 50 Gbps signaling using PAM4 modulation)

Table 1: Comparison of 800G and 400G Optical Transceivers *(Continued)*

Feature	800G	400G
Symbol rate (baud rate)	~53.125 GBd for 100G PAM4 lanes	~26.5625 GBd for 50G PAM4 lanes; ~53.125 GBd for 100G PAM4 lanes

Modulation Methods

- Pulse Amplitude Modulation 4-level (PAM4)—PAM4 is a four-level modulation format. There are four distinct amplitude levels within an electrical or optical data lane or channel such that each amplitude level represents two bits of data. As a result, PAM-4 modulation can transmit twice the amount of data without a significant increase in the speed of optical components. However, the use of PAM4 modulation that uses 4 signal levels considerably reduces the signal-to-noise ratio (SNR). SNR is reduced as the distance between two signal levels is just one-third compared to binary NRZ modulation. This results in a theoretical SNR difference of ~10 dB, or to be exact 20 x log10(1/3). It is because of this difference in SNR that both DSP and FEC are mandatory in combination with PAM4 modulation.

  Forward error correction (FEC) is a channel coding technique to handle signal integrity. FEC transmits data with redundancies. It is designed such that information need not be retransmitted to correct errors detected at the receiving end of the link. FEC is enabled by default on Juniper's optical transceivers.

  FECs are implemented through FEC algorithms. FEC algorithms are specific mathematical techniques or coding schemes. FEC algorithms detect and correct errors in transmitted data without requiring retransmission. The FEC process involves two steps:

  - Encoding (at the Tx or transmitter)—The FEC algorithm processes the original data and adds redundant bits or parity bits based on a specific mathematical rule. The encoded data is then transmitted over the communication channel.

  - Decoding (at the Rx or Receiver)—The receiver uses the FEC algorithm to analyze the received data, including the redundant bits. If errors are detected, the algorithm attempts to correct them based on the redundancy.

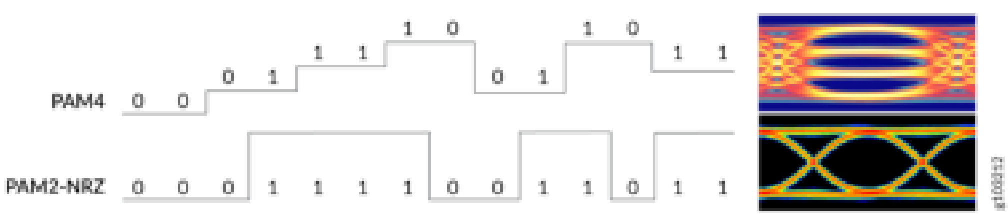
  The error correction capability of FEC depends on the specific algorithm used and the amount of redundancy added. For 400G optical transceivers, the industry standardized FEC code is known as FEC119 or RS(544, 514). This code is defined in IEEE 802.3-2022 Clause 119, and consists of a forward error correction code from the Reed-Solomon (RS) family of codes that can correct up to 15 symbol errors within a single codeword. This FEC code is sometimes referred to as **KP4** as it was first used in a 100G standard for copper backplanes, known as 100GBASE-KP4. Once the number of symbol errors exceed 15 in a single codeword, it can no longer be corrected by the FEC decoding algorithm, resulting in an Uncorrected Code Word (UCW).

Figure 1: FEC 119 in 400G Optics

Both the transmitter and receiver ends of a communication link that uses 400G optical transceivers has FEC. The FEC algorithm encodes data before transmission and decodes and corrects the errors in data upon reception. In summary, PAM4 enables efficient short distance data transmission, but it demands more signal processing and error correction.

- Non-return to Zero (NRZ or PAM2) modulation—NRZ is a two-level binary modulation format. There are two distinct amplitude levels within an electrical or optical data channel. The signal does not return to baseline rest between bits. Instead, it fluctuates between **1** that represents a higher value of power and **0** that represents a lower value.

Figure 2: Comparison of PAM4 and NRZ Modulation



Some of the other technologies that the 400G optics use are:

- Advanced Digital Signal Processing (DSP) techniques—Enhances signal integrity and extend the reach of 400G transceivers over optical fiber. All 400G optical transceivers uses DSP. Functions such as Feed-Forward Equalization (FFE), Decision Feedback Equalization (DFE) and Clock Data Recovery (CDR) are used in all 400G optics. Tunable DWDM optics (ZR and ZR+) use advanced DSP functions. DSP involves several components such as:

    - SerDes (Serializer/Deserializer)—SerDes converts data between serial and parallel forms, enabling efficient and high-speed data transfer within the optic. It works closely with the DSP to manage data flow and conversion. For more information, see "Serializer/Deserializer (SerDes)" on page 12.

    - FFE (Feed-forward Equalization) and DFE (Decision Feedback Equalization)—FFE and DFE mitigate inter-symbol interference (ISI) and enhancing signal clarity. FFE addresses linear distortions before a decision is made. DFE helps correct errors based on previously received symbols, working dynamically to improve overall signal quality.

- Clock Data Recovery (CDR)—Extracts timing information from a data signal and ensures accurate data retrieval and transmission in an optic network.

See the Hardware Compatibility Tool for the list of transceivers, their specifications, and the list of devices supported by the transceivers.

Key Characteristics

The following are the key design considerations for an 400G transceiver:

- Form Factor—Juniper's 400G optical transceivers incorporate the Quad Small Form-factor Pluggable Double Density (QSFP-DD) form factor to meet high power and thermal requirements for 400 Gbps data transmission. QSFP-DD is the dominant form factor for 400G optics in the industry.

  NOTE: For 400G optical transceivers, Juniper does not currently support the OSFP form factor.

- Fiber type and reach—The fiber type specifies the type of optical fiber (single-mode or multimode) compatible with 400G transceivers. The reach provides the maximum supported distance or range for an optical transceiver. It helps you to select the appropriate optical transceiver for different applications, such as inter-data center, intra-data center, long-haul networks, and so on.

- Lane Distribution—IEEE 802.3ba defines lane distribution. Lane distribution happens in the PCS, and lanes are then multiplexed to 1, 4 or 8 lanes in the PMD depending on the exact optics type. The types of lane distribution include:

    - Single lane—In a single-lane configuration, the entire Ethernet signal is conveyed through one optical lane or channel.

    - Multiple lanes—Multiple lane distribution leverages parallel optical transmission by stripping Ethernet signals into multiple low rate lanes. The low rate lanes map into optical lanes or channels. This results in a more optimal cost per bit, fewer points of failure and interfaces, and lower power and heating.

400G optics support only the 400G lane rate. However, with breakout, Juniper's 400G optics can be split into multiple sub-interfaces, ensuring that the total bandwidth is 400G. The breakout ports of lower speeds are fully independent and can run on separate time domains, enabling higher density applications.

Figure 3: 4x100G Solution Using Four Wavelengths

Juniper Optical Product Numbers

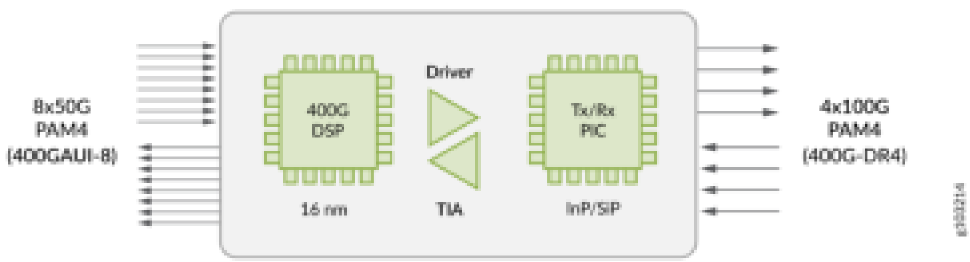
Juniper's optical components such as transceivers, cables, and connectors follow a naming convention. Each element in the product name corresponds to a specification. It helps you to better understand and select the optical component that you need. For example:

- JCO400-QDD-ZR
  - JCO—It denotes Juniper coherent optical (JCO) transceivers or tunable DWDM optical transceivers. JCO is a core component of the Juniper Converged Optical Routing Architecture (CORA). It offers industry-leading power efficiency, operational simplicity, an open architecture, and an integrated DWDM design. The 400 in JCO400 indicates that the transceiver is capable of handling transmission speeds of 400 Gbps.
  - QDD—Short for QSFP-DD. It identifies the form-factor of the transceiver.
  - ZR—ZR is a standard developed by the Optical Internetworking Forum (OIF). It is offered in either ZR and ZR+ specifications. JCO400-QDD-ZR supports ZR that is capable of transmitting data over distances of up to 120 kilometers.
- QDD-400G-DR4

- QDD—Short for QSFP-DD. It identifies the form-factor of the transceiver.
- 400G—Indicates that the transceiver is capable of data transfer rates of 400 Gbps.
- DR4—Stands for 400GBase-DR4. It is a specific standard that uses four parallel lanes of 100 Gbps to deliver 400 Gbps.

NOTE: You can distinguish the Juniper optical cables from transceivers using the product numbers. For example, QDD-400G-AOC-3M and QDD-8x50G-1M (Juniper cables) specify the cable type (AOC or DAC) and distance range (3 meter or 1 meter) in their product names.

400G (X8) Transceiver Architecture



The industry-standard and most widely deployed design for 400G transceivers uses an eight-lane 8x50G PAM4 electrical interface (400GAUI-8) on the host side. X8 denotes the eight-lane electrical interface. The host side represents the part of the transceiver that connects to the switch, router, or any other host device. On the line side, the 400G transceivers uses a four-lane 4x100G PAM4 optical interface (400G-DR4). The line side represents the part of the transceiver that transmits and receives data over fiber cables to the network.

This architecture is used in 400G transceiver form factors like QSFP-DD. The following are the different components of a 400G transceiver architecture:

- 400G platform—The Juniper device (switch or router) that supports the 400G architecture.
- 8x50 Gbps electrical—The electrical interface between the switch and the transceiver components. It can transmit data over eight separate 50 Gbps electrical lanes.
- 4x100 Gbps optical—The optical interface between the transceiver and the network. It can transmit data over four separate 100 Gbps optical lanes.
- Digital Signal Processor (DSP)—The 400G DSP (Digital Signal Processor) performs signal conditioning and conversion between the 8x50G electrical lanes and the 4x100G optical lanes. PAM4 effectively

doubles the amount of data that you can transmit. The CDR is responsible for re-timing incoming data to reduce jitter. The DSP handles functions like equalization, error correction, and other signal processing tasks.

- Driver—Drivers are electronic components that amplify the electrical signal. The x8 transceiver architecture has eight drivers. Each driver corresponds to a 50G lane.

- Directly modulated lasers—Modulated lasers convert the amplified electrical signals into optical signals. It includes Vertical-Cavity Surface-Emitting Lasers (VCSELs) for multimode applications and Directly Modulated Lasers (DMLs) for single-mode applications.

- Transimpedance Amplifiers (TIA)—TIA is the receiving end of an optical transmission. It converts the electrical current output of a photodiode to a specific voltage level. It can operate with very low signal levels that are typical for long-distance optical communication.

- Photo-Detector—It works in tandem with the TIA to convert the optical information back into electrical form.

Some 400G optical transceivers, such as SR8 modules, use eight parallel lanes each running at 50G PAM4, directly converting electrical to optical signals. Some 400G optical transceivers use a gearbox to convert 8×50G electrical lanes into 4×100G optical lanes. For example, FR4 and LR4 modules use an 8:4 gearbox, where the eight electrical lanes at 50G PAM4 are converted into four optical lanes at 100G PAM4. This reduces the number of optical lanes and fibers required, simplifying cabling and connectors. For example, an 8×100G architecture requires eight fibers for its eight lanes, often using MPO connectors or multiple duplex LC connectors. However, a 400G module such as FR4 or LR4 that uses 4×100G optical lanes requires only four fibers (two duplex LC connectors) to transmit and receive signals.

Serializer/Deserializer (SerDes)

A SerDes consists of an integrated circuit (IC or chip) transceiver. An IC can hold multiple SerDes. Each SerDes within an IC can have multiple lanes. Each of these lanes in a SerDes can handle input and output traffic. The two functional units or blocks within a SerDes are:

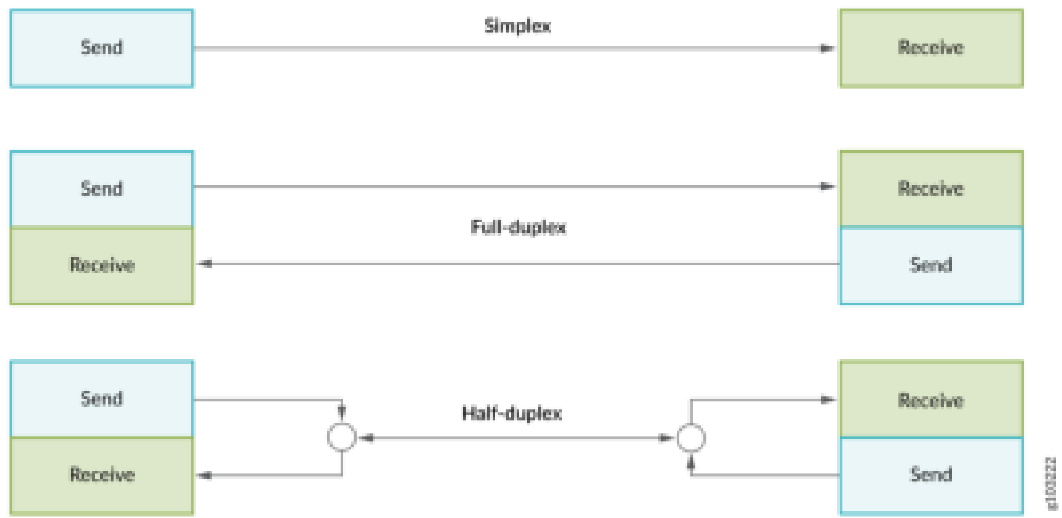
- Parallel in serial out (PISO) or the Serializer—Converts parallel data into serial data. The transmitter section of the transceiver functions as a parallel-to-serial converter that converts parallel data to serial data.

- Serial in parallel out (SIPO) or the Deserializer—Converts serial data into parallel data. The receiver section of the transceiver serves as a serial-to-parallel converter that converts the serial data back to parallel data.

SerDes devices support multiple operational modes between two points:

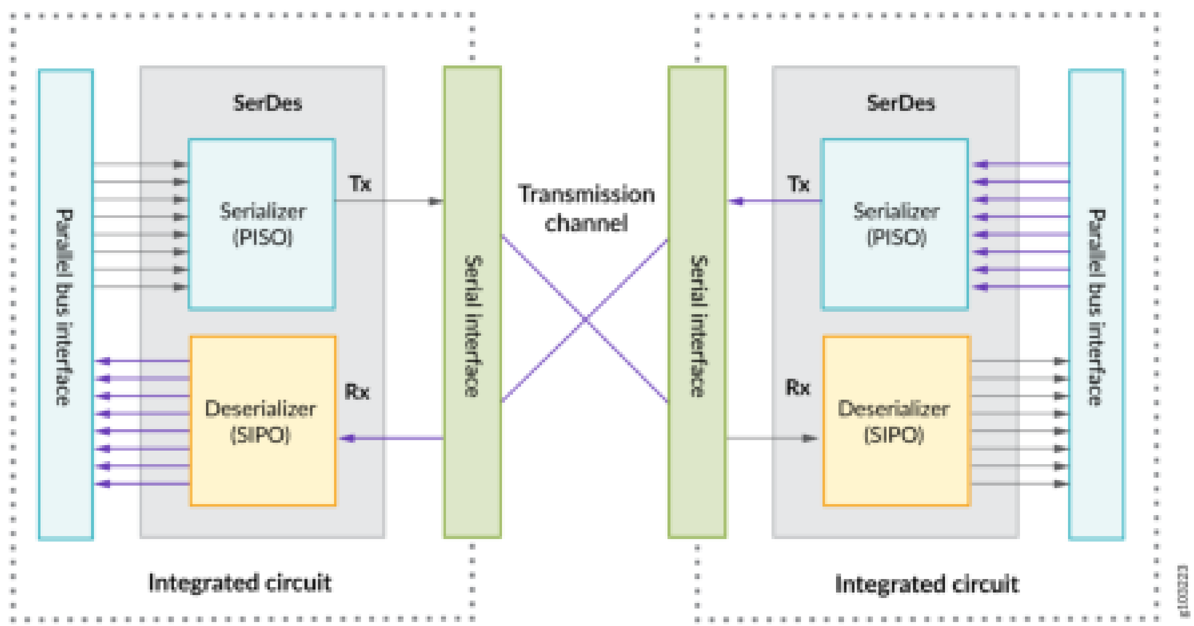
- Simplex operations—Allows data conversion to occur only in one direction.
- Full-duplex operations—Allows data conversion to occur in both directions simultaneously.
- Half-duplex operations—Allows data conversion to occur in both directions, but not simultaneously.

Figure 4: Transmission Modes in SerDes Devices



SerDes reduces the number of data paths and connecting pins or wires needed to transmit data. It counters the common issues associated with parallel power transmission such as increased power consumption, electromagnetic interference, and clock timing errors. Using SerDes, you can efficiently transmit the data signals from a port through its multiple breakout channels into the optic network and vice versa.

Figure 5: Data Exchange in SerDes Chips



Tunable DWDM Optics

Traditional optical transceivers often utilize On-Off Keying (OOK), where binary values are encoded into light pulses for fiber communication. While OOK can efficiently transmit data, it is limited by bandwidth capacity. In contrast, tunable Dense Wavelength Division Multiplexing (DWDM) optics use advanced modulation and equalization techniques through Digital Signal Processors (DSPs) to handle transmission impairments more effectively and encode more data onto light waves.

Modulation Techniques in Tunable DWDM Optics

Tunable DWDM optics and modulation formats are independent of each other. 10G tunable DWDM optics are widely deployed and use simple OOK modulation. 400G tunable DWDM optics use only Quadrature Amplitude Modulation (QAM). QAM adds amplitude variation to phase states, allowing higher data rates. Higher-order QAM (for example, 16-QAM) increases data capacity but requires high signal-to-noise ratios.

The 16-QAM modulation uses 4-level modulation of both the in-phase and quadrature component of the optical field to encode 4 bits per symbol. This is then again doubled with polarization multiplexing to 8 bits/symbol. For 400G tunable DWDM modules, more advanced modulation such as DP-16QAM is also used. DP-16QAM makes it possible to encode 400G onto a single wavelength.

NOTE: PSK modulation is not used with tunable DWDM optics. Instead, QAM is more prevalent.

Table 2: QAM Guidance

Modulation	Bits per symbol	Symbol rate
4QAM	2	1/2 x bit rate
8QAM	3	1/3 x bit rate
16QAM	4	1/4 x bit rate

Tunable DWDM optics adhere to the ZR and OpenZR+ standards. The ZR standard is developed by the Optical Internetworking Forum (OIF). In contrast, OpenZR+ is standardized by the OpenZR+ Multi-Source Agreement (MSA) and builds upon the capabilities of the original ZR standards. The ZR and OpenZR+ Tunable DWDM optics from Juniper comply with these standards.

Packet Optical Integration

Packet-optical integration is a network architecture that seamlessly combines Dense Wavelength Division Multiplexing (DWDM) with routing and switching functions into a unified system. By integrating these elements, packet-optical architectures eliminate the need for separate, external third-party DWDM transponders, resulting in a streamlined approach to network management. This integration not only simplifies operations but also significantly reduces capital expenditures (CAPEX) and operating expenses (OPEX).

Juniper's 400G Tunable DWDM optics models such as JCO400 adhere to the Converged Optical Routing Architecture (CORA). CORA is a comprehensive solution that directly integrates IP routing and Dense Wavelength Division Multiplexing (DWDM) into a single converged architecture, known as IP-over-DWDM (IPoDWDM). With IPoDWDM, CORA enables IP traffic to be sent directly over DWDM networks using Juniper's Tunable DWDM optical transceivers (JCO400 pluggables) that plug directly into device ports. In summary, CORA helps to eliminate multiple network elements and simplifies the network by converging IP routing and optical transport layers into one system. With CORA, you do not need separate DWDM transponders traditionally used to convert IP traffic into optical signals for transport over fiber networks.

The DWDM-based ZR and OpenZR+ optical transceivers from Juniper for 400G transmission are as follows:

- JCO400-QDD-ZR
- JCO400-QDD-ZR-M
- JCO400-QDD-ZR-M-HP
- QDD-400G-ZR
- QDD-400G-ZR-M
- QDD-400G-ZR-M-HP

Comparison of ZR, ZR-M, and ZR-M-HP

- 400ZR optics are standardized in the OIF 400ZR implementation agreement and are primarily used for single-span applications. 400ZR optics have a limited chromatic dispersion specification of up to 2400 picoseconds per nanometer in order to minimize the power consumption of the optic. 400ZR optics uses a FEC code known as concatenated forward error correction (CFEC). CFEC concatenates two FEC codes with each other, an inner soft-decision Hamming (128,119) code and an outer Staircase BCH (255, 239) hard-decision outer code. The concatenation helps to obtain the optical performance as specified in the OIF 400ZR implementation agreement. Hence, such optics are suitable for distances of approximately 120 kilometers. CFEC is the sole FEC method used in ZR optics.
- ZR+ or ZR-M optics are typically used for multi-span applications in metro and regional networks. This is possible through more advanced digital signal processing, including a higher chromatic dispersion compensation specification and more advanced FEC. 400G ZR+ (or ZR-M) optics uses an FEC code known as open forward error correction (OFEC). OFEC consists of a Turbo Product Code (TPC) using an Extended BCH(256, 239) code with 3-iteration soft-decision de-coding. The improved performance of OFEC compared to CFEC is critical to achieve the higher optical performance as specified in the OpenZR+ MSA. The OpenZR+ MSA defines OFEC for 400G OpenZR+ optics such as ZR-M and ZR-M-HP. OFEC is the sole FEC method used in ZR-M and ZR-M-HP optics.
- ZR-M-HP optics are the same as ZR-M but with higher transmission (Tx) or output power. These optics are also great for unamplified links due to their higher Tx power.

NOTE: The 400G ZR/ZR+ optical transceivers can have 0 dBm tunable DWDM capabilities. In optical terms, 0 dBm indicates the optical signal power level. It represents a power level of 1 milliwatt. The ZR+ optics with a 0 dB TX output power (ZR-M-HP) are used for backward compatibility with existing transport DWDM platforms, especially reconfigurable optical add-drop multiplexers (ROADMs). In addition, the high TX output power is also important for dark fiber links to cross longer distances.

Here's a summary of the FEC methods used in 400G optics, including tunable DWDM optics:

Table 3: FEC Techniques in 400G Optics

FEC Technique	Usage	Standard	Application
Concatenated Forward Error Correction (CFEC)	Used in ZR optics	Optical Internetworking Forum 400ZR (OIF 400ZR)	Supports unamplified links up to 40 kilometers and single-span data center interconnect up to 120 kilometers
Open Forward Error Correction (OFEC)	Used in ZR+ or ZR-M and ZR-M-HP optics	Defined by OpenZR+ Multi-Source Agreement (MSA)	Supports metro and regional networks with a maximum distance of hundreds of kilometers over DWDM transport platforms with periodic in-line amplification
FEC119	Primarily used in 400G gray optics	Defined by IEEE 802.3 family of standards. 119 refers to the 119th clause in IEEE 802.3 standard. Utilizes Reed-Solomon coding RS(544, 514)	Supports client optics with a maximum distance of up to 40 kilometers (in case of 400G ER4-30 optics)

Dense Wavelength Division Multiplexing

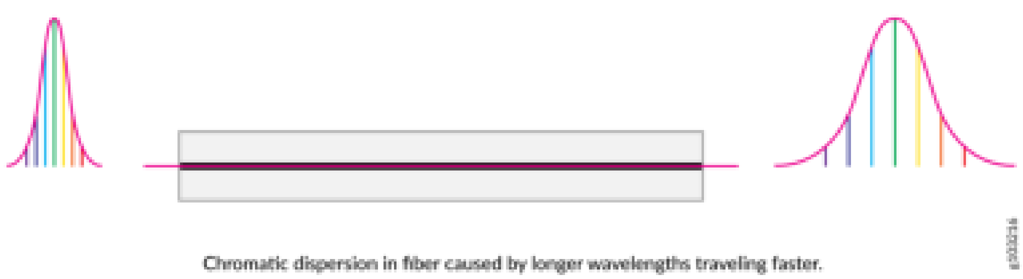
Tunable DWDM optics uses Dense Wavelength Division Multiplexing (DWDM). This technology increases the amount of data that can be transmitted over a single optical fiber. DWDM achieves this by using multiple light wavelengths or channels. The two types of DWDM connections used by Juniper's 400G Tunable DWDM optics are:

- Unamplified link (limited optical power)—In an unamplified link, the optical signal is sent through the fiber without any amplification. In this type of Tunable DWDM optics, the maximum transmission distance is limited by the natural loss of optical power as the signal travels through the fiber. Without amplification, the light signal gradually weakens, restricting the distance it can travel. Hence, an unamplified link is more suitable for shorter distances and is often referred to as a power-limited optical signal.

- Amplified link (limited optical signal-to-noise ratio and chromatic dispersion)—In an amplified link, the optical signal strength is boosted using optical amplifiers. As you boost the signal strength in amplified link, the signal can travel long distances. However, it can also introduce noise or loss in signal quality. The noise is more prominent if you are using Erbium-Doped Fiber Amplifier (EDFAs). Optical signal-to-noise ratio (OSNR) refers to the signal quality of the signal. A high OSNR value ensures that the noise is low and the signal quality is acceptable.

  Chromatic dispersion occurs because different wavelengths of light travel at different speeds through the fiber. This can cause signal distortion, especially over long distances. During optical transmission, short-duration input optical signals composed of multiple wavelengths or colors are incident on the optic fiber. The colored lines within the optical signal correspond to different wavelengths. These varied wavelengths in the optic signal enter the optical fiber simultaneously but propagate at different velocities due to their unique refractive indices. After traveling through the optical fiber, the output optical signal broadens and the different colors or wavelengths spread apart. This indicates that longer wavelengths have traveled at a different speed than shorter wavelengths.

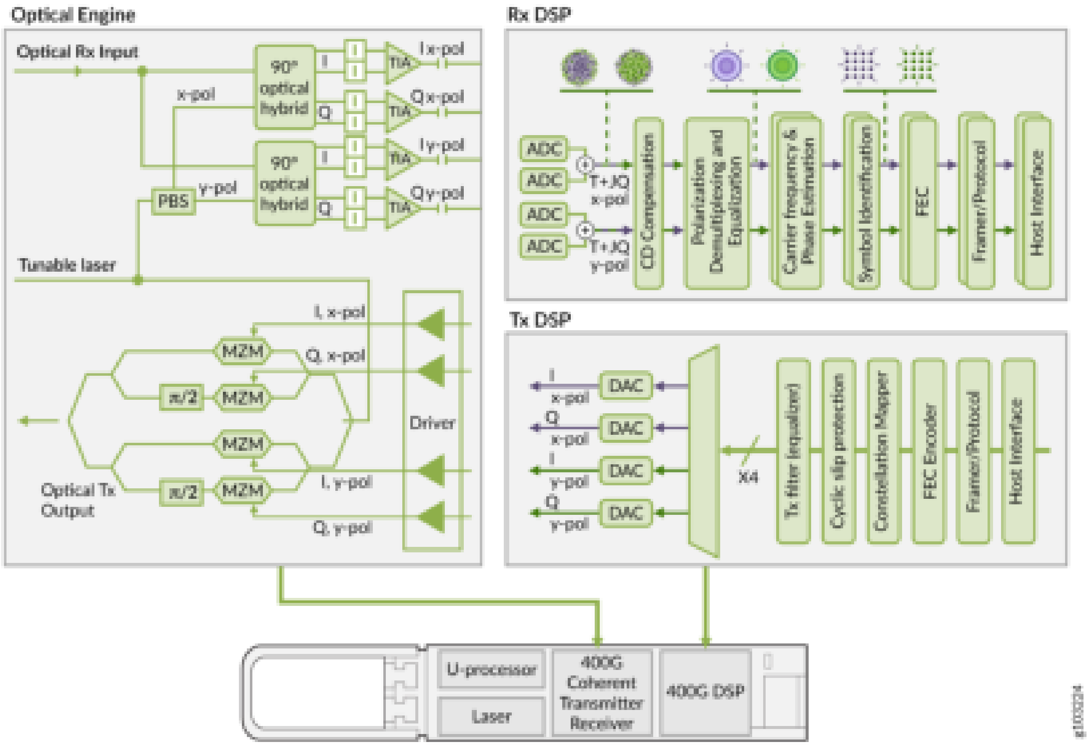
Figure 6: Chromatic Dispersion



> **NOTE**: To overcome the OSNR limitation, a RAMAN amplifier can be used. RAMAN amplifiers have lower effective noise figure as they amplify the signal along the fiber.

For maximum chromatic dispersion and minimum rOSNR values, see Hardware Compatibility Tool.

Figure 7: Tunable DWDM Optics Architecture



2

CHAPTER

400G Optical Transceivers Specifications

IN THIS CHAPTER

Form Factor

SUMMARY

Juniper's 400G transceivers cater to the growing demand for bandwidth in metro, edge, core, and data center networks. To support the multivendor network environment, Juniper 400G transceivers adhere to key industry standards.

IN THIS SECTION

Form factor refers to the physical dimensions and shape of a transceiver. Form factor includes aspects like the size, shape, connector type, and other physical characteristics. It determines how the transceiver fits into networking equipment like switches, routers, or servers.

Juniper supports the QSFP-DD (Quad Small Form Factor Pluggable Double Density) form factor for 400G transceivers. QSFP-DD uses an 8x50G electrical interface to achieve a total bandwidth of 400Gbps. The QSFP-DD form-factor is defined by the QSFP-DD MSA industry consortium. Juniper is a founding member of the consortium. QSFP-DD can accommodate more ports per unit area than other form factors. Hence, QSFP-DD form factor is ideal for networks that require high-density port layouts such as a data center.

The QSFP-DD host cage design supports backward compatibility with QSFP28 and QSFP. You do not need any external mechanical adapter to support legacy transceivers. QSFP-DD is both forward and backward compatible.

NOTE: Juniper does not currently support OSFP (Octal Small Form-Factor Pluggable) for 400G transceivers. However, OSFP transceivers used in third-party platforms can be interoperable with Juniper's QSFP-DD transceivers in a 400 Gbps network. If you are using third-party OSFP transceivers in your network, the IEEE standard (DR4, LR4, FR4 and so on) of the transceivers must be consistent.

NOTE: The OSFP optical transceiver does not fit into a QSFP-DD port.

Quad Small Form Factor Pluggable Double Density (QSFP-DD)

QSFP-DD ports are smaller in size than ports with OSFP form factor. Hence, you can accommodate more ports per unit area. QSFP-DD form factor is ideal for networks that require high-density port layouts. QSFP-DD is compatible with QSFP56, QSFP28, and QSFP+ modules.

Table 4: Features of QSFP-DD Form Factor

Feature	QSFP-DD	Notes
Size	Small	
Heat sink	Standard heat sink limited by size constraints. Supports a riding heat sink	
Connector style	Small connector with 76 connector pins (16 differential pairs, the remaining pins being power, ground, status and control pins.)	The connectors are designed for high-density connections.
Power consumption	Gray optics: up to 14 W	
	ZR/ZR+ tunable DWDM optics: 18 W through 23 W	
Thermal requirements	• Standard: 0 through 70° C • High power modules: 75° C to 80° C	Transceiver modules with QSFP-DD form factors are designed to operate within the case temperature ranges provided.
Backward compatibility	Compatible with some of the other QSFP transceiver module ports such as QSFP56, QSFP28, and QSFP+.	Backward compatibility with the existing hardware ensures smooth transition, upgrade, operational flexibility, and cost savings.

Juniper 400G Transceivers

IN THIS SECTION

Juniper's 400G transceivers cater to data center and AI-ML cluster applications for routing and switching solutions. The 400G ZR/ZR+ and 0dBm tunable DWDM pluggable optical transceivers from Juniper are essential for metro network modernization. To support the multi-vendor network environment, Juniper 400G transceivers adhere to key industry standards.

Juniper's 400G transceivers use the QSFP-DD form factor. For a list of all 400G optics and their supported platforms, see Hardware Compatibility Tool.

Platform Support for 400G Transceivers

Juniper's 400G transceivers support multiple Juniper platforms. For information about the Juniper platforms that 400G transceivers support, see the Supported Platforms tab for 400G transceivers in Hardware Compatibility Tool.

Connector Types

Optical connectors ensure efficient and reliable connections between fiber optic cables. Connectors are designed to minimize insertion loss and back reflection, ensuring high-quality signal transmission.

400G transceivers support the following connector types:

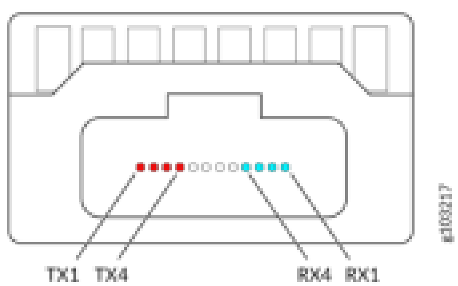
- MPO-12/APC and MPO-12 BiDi/UPC—A multifiber push-on (MPO-12) has a single row of connectors with 12 optical fiber channels or lanes. An MPO-12 connector contains four transmission (TX) channels and four reception (RX) channels that is used to transmit and receive signals. Four optic fiber channels are unused or reserved in MPO-12 connectors used with 400G optical transceivers. In a standard deployment, the four unused channels or lanes are those located in the center of the row.

  - APC—Angled physical contact (APC) denotes an optical fiber endface that is polished at an eight-degree angle. APC reduces back reflection by directing reflected light into the fiber cladding rather than back toward the source.

  - BiDi/UPC—Ultra physical contact (UPC) denotes a rounded optical fiber endface that is polished to maintain a very smooth, slightly curved surface (nearly zero degrees). UPC helps to improve contact quality and reduce back reflection compared to other physical contact connectors. BiDi (bidirectional) indicates bidirectional optical transmission over a single fiber strand or fiber pair. This allows simultaneous transmission and reception on the same fiber using different wavelengths.

  MPO-12 APC is used for parallel single-mode optics such as 400G DR4. MPO-12 Bidi UPC is used for parallel multi-mode BiDi optics such as 400G SR4.2.

  Figure 8: MPO-12 Connector



  The image represents the channel or lane allocation for a 400G optical transceiver using an MPO-12 connector:

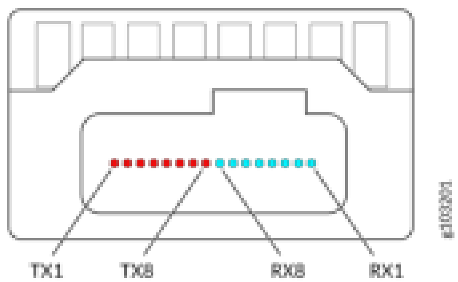
  - Red (TX): Fibers 1 through 4, named TX1, TX2, TX3, and TX4 respectively.

  - White (unused): Fibers 5 through 8.

  - Blue (RX): Fibers 9 through 12, named RX4, RX3, RX2, and RX1 respectively.

- MPO-16/APC—A multi-fiber push-on 16 (MPO-16) connector has 16 optical fibers in a single connector. For example, the 400G-SR8 transceiver uses all 16 fibers of the MPO-16 connector. Eight fibers are used as TX (transmit) channels and eight fibers are used as RX (receipt) channels. Each fiber carries a 50G PAM4 channel, totaling eight parallel channels for 400G aggregate bandwidth. With angled physical contact (APC), the connector minimizes back reflection and ensure better signal integrity. MPO connectors offer high-density connections and support multiple fibers in a single connector. MPO connectors are often used in data centers.

Figure 9: MPO-16 Connector



The connector has 16 fiber channels arranged in a single row. TX (transmit) is handled by eight channels and the RX (receive) is handled by the other eight. The image represents the channel or lane allocation for a 400G optical transceiver using MPO-16 connector:

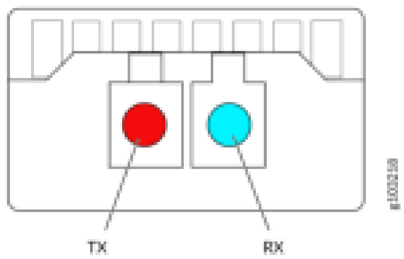
- Duplex LC—A duplex LC connector is a type of lucent connector (LC) that has small form factor and high-density design. The term duplex indicates that the connector houses two separate fiber optic channels or lanes within a single unit. One channel is for transmission (TX) and the other is for reception (RX). The TX and RX channels enable full-duplex, bidirectional communication over a single connector. The typical LC interface is half the size of the traditional standard connector (SC). The smaller size allows greater port density in patch panels and transceivers. Like other optical connectors, the duplex LC connector is color-coded. This helps maintain correct polarity and simplifies installation and troubleshooting.

  Duplex LC/UPC is a duplex LC connector where each fiber end-face is polished using the ultra physical contact (UPC) method. For example, QDD-400G-ER4-30 use duplex LC/UPC connectors.

  NOTE: All 400G optical transceivers with duplex LC connectors are UPC.

  NOTE: Tunable DWDM 400G optical transceivers such as QDD-400G-ZR, QDD-400G-ZR-M, and QDD-400G-ZR-M-HP use Duplex LC connectors for their optical connections.

Figure 10: Duplex LC Connector



The image represents the channel or lane allocation for a 400G optical transceiver using duplex LC connector:

- Red (TX)
- Blue (RX)

Cable Types and Length

IN THIS SECTION

Cables are the physical medium that transmit optical and electrical signals. Juniper offers a broad variety of high-performance and cost-effective cables. These optical and electrical cables are available in various dimensions, distance ranges, and speeds. Cables offer a wide selection of breakout configurations that enable you to operate at lower Ethernet speeds. It helps to effectively interconnect devices and increase port density. For more information, see Optical and Electrical Cables.

The two broad types of cables are:

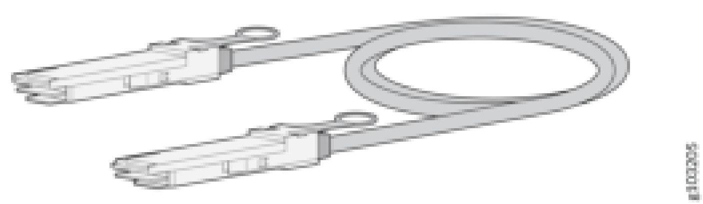
- Direct attach copper cables (DAC)

- Active optical cables (AOC)

Direct Attach Copper Cables (DAC)

Made of Twinax copper, the primary type of DAC cable is known as Twinax Cable. It is ideal for ultra short-range connections. DAC supports high-speed connections between servers, switches, and storage devices. DAC cables are lower cost. It is more durable than optical fibers. Also, it is less susceptible to dust and environmental disturbances.

Figure 11: 400G DAC Cable



DAC cables can be of two types:

- Passive DAC cables—Passive DAC cables transmit signals without the use of electrical components to boost or regenerate the signal. The network equipment's host handles signal amplification and conditioning. Typically, passive DAC cables are limited to a maximum length of two and a half meters, as their performance diminishes over longer distances.
- Active DAC cables—Active DAC cables, in contrast, include an additional driving chip that conditions the signal, enhancing transmission quality over longer distances. These cables share the same setup as passive DAC cables but provide signal boosting through built-in electronics. Active DAC cables can typically extend up to 10 meters or more, offering a longer reach in compare with passive DAC cables. By offering both passive and active options, DAC cables provide flexible solutions for various network environments, balancing signal integrity with distance requirements.

The 400G Juniper DAC cables that you can use include:

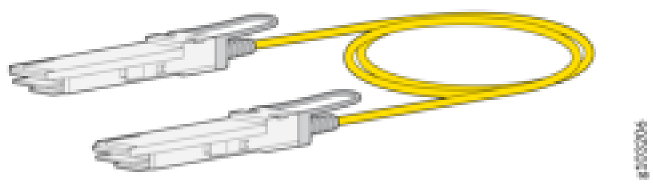
- 1x400G DAC cables
- 2x200G DAC cables
- 4x100G DAC cables
- 8x50G DAC cables

For more information, see Hardware Compatibility Tool.

Active Optical Cable (AOC)

AOC consists of duplex optical fibers with connectors on both ends. AOC utilizes fiber optic transceivers within the connectors, making it more complex and costly in comparison with DAC cables. The external interface of an AOC is always electrical, not optical. Therefore, unlike passive cables, AOCs require external power to convert electrical signals to optical signals and vice versa. The use of fiber optics in AOC allows for extended reach, supporting longer distances. It makes AOC an ideal choice for high-performance networking where longer cable runs are necessary.

Figure 12: 400G AOC Cable



AOC is lightweight in design in comparison with DAC cables. AOCs are immune to electromagnetic interference. It has higher throughput at longer distances in comparison with DACs. With AOCs, you can select your cabling solution considering a variety of form factors, breakout cables and speed options.

AOC cables can be of two types:

- Single-Mode fiber (SMF)—It has a core diameter of 9 microns and supports higher data rates and longer distances with minimal dispersion. The applications include long-distance communication and high-bandwidth transmission.

  NOTE: Active Optical Cables (AOCs) typically use multi-mode fiber and optics due to cost considerations. Using single-mode fiber in AOCs is generally much more expensive.

- Multimode fiber (MMF)—It has a core diameter of 62.5 microns. It is easier to install and align but has higher attenuation and dispersion than SMF, making it suitable for shorter distances. The applications include short to medium-distance communication, typically within buildings or campuses.

The 400G Juniper AOC cables that you can use include:

- 1x400G AOC cables
- 2x200G AOC cables

For more information, see Hardware Compatibility Tool.

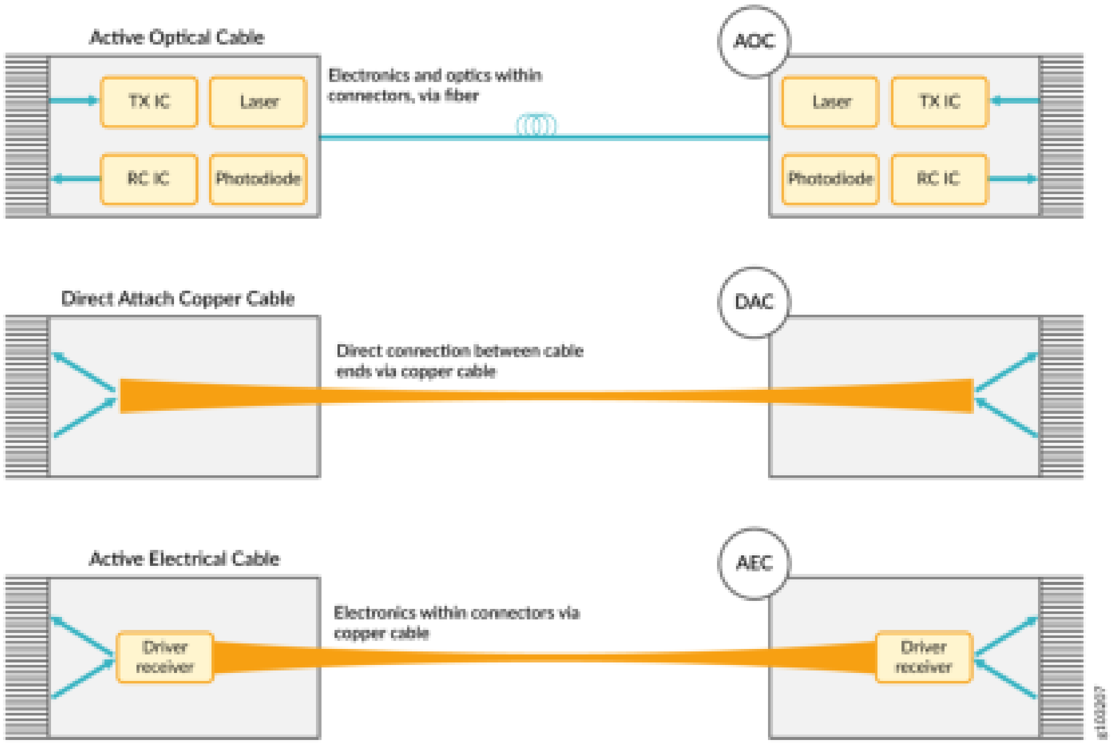
NOTE: Most of the DAC and AOC cables used along with 400G optical transceivers do not have connectors. The optical transceivers are permanently attached to the cables.

Architecture of AOC and DAC Cables

AOC and DAC each use distinct architectures, resulting in different operational characteristics. DAC cables, both active and passive, use copper wires to transmit electrical signals. Passive DAC cables directly transmit signals without any conditioning. Active DAC cables incorporate a driving chip within the transceivers to enhance and condition the signals.

In contrast, AOC cables transform electrical signals into optical signals using fiber optics, requiring external power for this conversion. The optical signals are then converted back to electrical signals at the receiving end. This architecture enables AOC cables to maintain high signal integrity over longer distances.

Figure 13: Architecture of AOC and DAC Cables



Cable Length or Range

Juniper 400G transceivers support varying cable lengths to meet specific needs. For more information about the specific distance range of individual transceivers, see Hardware Compatibility Tool.

Breakout Capability

IN THIS SECTION

Due to the rise of flat data center architecture models, breakout of high-speed ports has become a critical requirement. A flat data center architecture is a network and storage design approach that minimizes or eliminates the hierarchical layers traditionally found in data centers. By doing so, flat data centers create a simplified, scalable, and high-performance infrastructure, which leverages breakout capability to optimize network resources.

Breakout capability is the ability to split a high-capacity optical link into multiple lower-capacity links. This is typically achieved using breakout cables with suitable connectors that divide a single high-speed port into multiple lower-speed connections. Breakout capability is crucial for optimizing the use of available bandwidth and physical infrastructure in various networking scenarios. For a 400G transceiver, breakout capability allows a single high-speed 400 Gbps port to be split into multiple lower-speed ports.

Breakout relies on the concept of channelization to accomplish the split. Channelization involves splitting a high-speed physical port into multiple lower-speed lanes at the hardware level, using Serializer/Deserializer (SerDes) technology. In other words, breakout is the practical application of channelization to create multiple lower-speed ports from one high-speed port. Channelization can be configured at the level of an individual port, a block of ports, or a quad of ports. A block of ports is a group of ports that share hardware resources within a Juniper switch or router. For blocks that support breakout capability, SerDes technology enables the flexible allocation and operation of these lanes. For more information, see Port Speed Channelization.

Channelization is performed at the physical layer and involves splitting a high-speed port into multiple lanes. Channelization is different from Ethernet port channels or link aggregation (LAG). LAG combines multiple physical links into a single logical link at Layer 2 or Layer 3.

Port speed configuration can be performed at either the chassis level or the interface level. At the chassis level, port speed configuration offers three main options:

- Channelize individual port—Configure an individual port to operate at a specific channel speed. You must specify a port number and channel speed.
- Channelize block of ports—Configure a range of ports (a block) to operate at the same channel speed. You must specify the port range and the channel speed.
- Configure speed per quad—Configure port speeds in groups of four ports (quads), not individually. You must specify the speed for the first port in the quad. All four ports operate at the speed that you specified for the first port.

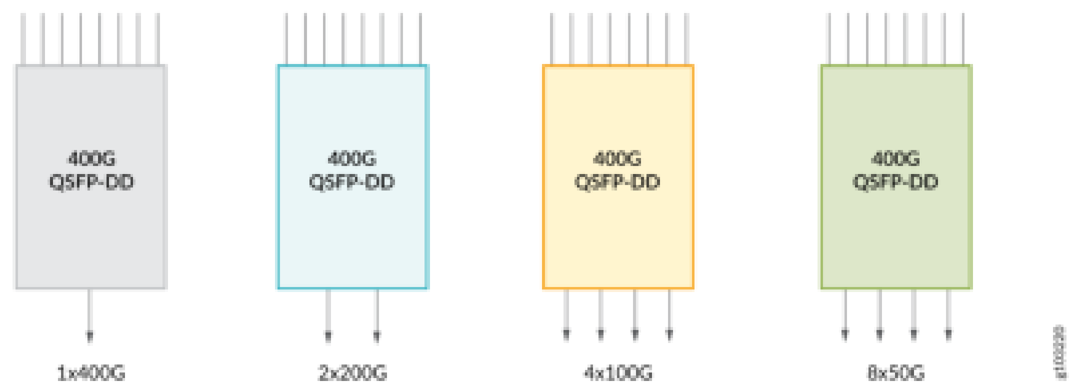
At the interface level, you must configure the speed for individual logical interfaces derived from the physical ports. It is useful for managing breakout interfaces after chassis-level speed settings are applied. For information about interface-level configuration, see Configure Speed at Interfaces Level.

Juniper supports the following breakout speed or mode options for its 400 Gbps ports:

- 8x50G
- 4x100G

- 2x200G
- 1x400G (no breakout)

Figure 14: Breakout Options in 400G Optical Transceivers



Breakout capability enables a network architect to configure a single port to support standardized 50 Gbps, 100 Gbps, 200 Gbps, or 400 Gbps data, depending on the network requirement. For more information about the breakout configuration that you can use in your Juniper device, use Port Checker.

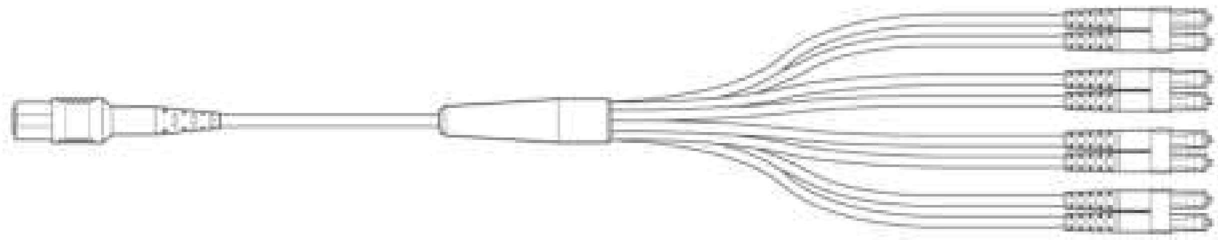
As 400G transceivers use PAM4 modulation, they aren't directly compatible with legacy, single-wavelength optics such as 100G optical transceivers and line cards. However, you can use breakout cables that can connect with legacy 100G optics. Thus, breakout capability enables 400G optical transceivers to be backward compatible with 100G line cards and platforms deployed in your network.

Breakout Cables

Breakout cables have a single transceiver at an end and multiple transceivers at the other end. You can use the breakout cables to channelize a port and increase the number of interfaces. To channelize the network ports on your Juniper device, connect the breakout cables and configure the recommended CLI commands. For more information, see Port Settings.

Breakout cables have one transceiver preattached to one end and more than one transceiver preattached to the other end. For information on how to maintain a breakout cable, see Maintain Breakout Cables.

Figure 15: Breakout Cable for 4x100G Optical Transceivers



The inclusion of APC connectors helps to minimize reflection loss and ensure high precision. To connect two transceivers of the same type, you can use the a variety of cables with the suitable connector. Breakout cables are use-specific. Depending on port channelization and the type of connectors, some of the breakout cables are:

- 12-Fiber Ribbon Patch Cables with MPO-12/APC Connectors.
- 12-Fiber Ribbon Breakout Cables with MPO-12/APC-to-LC Duplex Connectors.
- Table 5 on page 33
- Patch cables with LC duplex connectors.

Table 5: 12-Ribbon Patch and Breakout Cables Available from Juniper Networks

Juniper Model Number	Cable Type	Connector Type	Fiber Type	Cable Length
MTP-4LC-S10M	12-ribbon breakout cable	MTP to 4xLC pairs	SMF	10 m
MTP-4LC-S1M	12-ribbon breakout cable	MTP to 4xLC pairs	SMF	1 m
MTP-4LC-S3M	12-ribbon breakout cable	MTP to 4xLC pairs	SMF	3 m
MTP-4LC-S5M	12-ribbon breakout cable	MTP to 4xLC pairs	SMF	5 m
MTP12-FF-S10M	12-ribbon patch cable	MTP 12 fiber	SMF	10 m

Table 5: 12-Ribbon Patch and Breakout Cables Available from Juniper Networks *(Continued)*

Juniper Model Number	Cable Type	Connector Type	Fiber Type	Cable Length
MTP12-FF-S1M	12-ribbon patch cable	MTP 12 fiber	SMF	1 m
MTP12-FF-S3M	12-ribbon patch cable	MTP 12 fiber	SMF	3 m
MTP12-FF-S5M	12-ribbon patch cable	MTP 12 fiber	SMF	5 m

NOTE: The terms MPO and multifiber termination push-on (MTP) describe the same connector type.

3

CHAPTER

Install or Remove 400G Optical Transceivers and Fiber-Optic Cables

IN THIS CHAPTER

Install an QSFP-DD Transceiver

SUMMARY

Use the information in this topic to install QSFP-DD optical transceivers and fiber-optic cables. Juniper Networks transceivers are hot-removable and hot-insertable field-replaceable units (FRUs). You can remove and replace them without powering off your device or disrupting device functions. To understand how to install or remove a transceiver and fiber-optic cables of your device, read the following sections.

Before you install a transceiver in a device, ensure that you have taken the necessary precautions for safe handling of lasers (see Laser and LED Safety Guidelines and Warnings).

NOTE: We recommend that you use only optical transceivers and optical connectors purchased from Juniper Networks with your Juniper Networks device.

CAUTION: The Juniper Networks Technical Assistance Center (JTAC) provides complete support for Juniper-supplied optical modules and cables. However, JTAC does not provide support for third-party optical modules and cables that are not qualified or supplied by Juniper Networks. If you face a problem running a Juniper device that uses third-party optical modules or cables, JTAC may help you diagnose host-related issues if the observed issue is not, in the opinion of JTAC, related to the use of the third-party optical modules or cables. Your JTAC engineer will likely request that you check the third-party optical module or cable and, if required, replace it with an equivalent Juniper-qualified component.

Use of third-party optical modules with high-power consumption (for example, coherent ZR or ZR+) can potentially cause thermal damage to or reduce the lifespan of the host equipment. Any damage to the host equipment due to the use of third-party optical modules or cables is the users' responsibility. Juniper Networks will accept no liability for any damage caused due to such use.

To install an QSFP-DD transceiver:

1. Wrap and fasten one end of the ESD wrist strap around your bare wrist, and connect the other end of the strap to a site ESD point or to the ESD point on the device.
2. Remove the transceiver from its bag.

CAUTION: To avoid electrostatic discharge (ESD) damage to the transceiver, do not touch the connector pins at the end of the transceiver.

3. Check to see whether the transceiver is covered by a rubber safety cap. If it is not, cover the transceiver with a rubber safety cap.

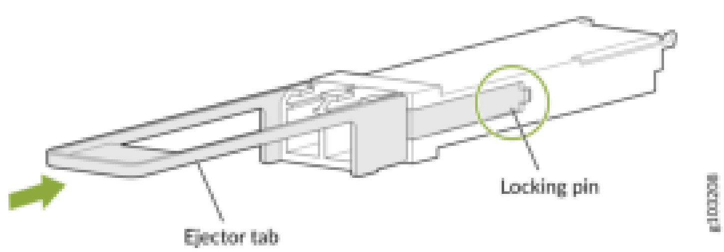
LASER WARNING: Do not leave a fiber-optic transceiver uncovered except when inserting or removing a cable. The rubber safety cap keeps the port clean and prevents accidental exposure to laser light.

4. If the port in which you want to install the transceiver is covered with a dust cover, remove the dust cover and save it in case you need to cover the port later. If you are hot-swapping a transceiver, wait for at least 10 seconds after removing the transceiver from the port before installing a new transceiver.

NOTE: Make sure to use a dust cap to cover ports that are unused.

5. Orient the transceiver over the port so that the transceiver connector faces the appropriate direction.
6. Slide the transceiver into the slot until the locking pins lock in place. If there is resistance, remove the transceiver and flip it so that the connector faces the other direction.

Figure 16: Install an QSFP-DD Transceiver



7. Remove the rubber safety cap from the transceiver when you are ready to connect the cable to the transceiver.

LASER WARNING: Do not look directly into a fiber-optic transceiver or into the ends of fiber-optic cables. Fiber-optic transceivers and fiber-optic cables connected to transceivers emit laser light that can damage your eyes.

NOTE: After you insert a transceiver or after you change the media-type configuration, wait for 6 seconds for the interface to display operational commands.

Remove an QSFP-DD Transceiver

SUMMARY

Use the information in this topic to remove QSFP-DD optical transceivers and fiber-optic cables. Juniper Networks transceivers are hot-removable and hot-insertable field-replaceable units (FRUs). You can remove and replace them without powering off your device or disrupting device functions. To understand how to install or remove a transceiver and fiber-optic cables of your device, read the following sections.

Before you remove a transceiver from a device, take the necessary precautions for safe handling of lasers (see Laser and LED Safety Guidelines and Warnings).

CAUTION: The Juniper Networks Technical Assistance Center (JTAC) provides complete support for Juniper-supplied optical modules and cables. However, JTAC does not provide support for third-party optical modules and cables that are not qualified or supplied by Juniper Networks. If you face a problem running a Juniper device that uses third-party optical modules or cables, JTAC may help you diagnose host-related issues if the observed issue is not, in the opinion of JTAC, related to the use of the third-party optical modules or cables. Your JTAC engineer will likely request that you check the third-party optical module or cable and, if required, replace it with an equivalent Juniper-qualified component.

Use of third-party optical modules with high-power consumption (for example, coherent ZR or ZR+) can potentially cause thermal damage to or reduce the lifespan of the host equipment. Any damage to the host equipment due to the use of third-party optical modules or cables is the users' responsibility. Juniper Networks will accept no liability for any damage caused due to such use.

Ensure that you have the following parts and tools available:

- An antistatic bag or an antistatic mat

- Rubber safety caps to cover the transceiver and fiber-optic cable connector
- A dust cover to cover the port or a replacement transceiver

To remove an QSFP-DD transceiver:

1. Place the antistatic bag or antistatic mat on a flat, stable surface.
2. Wrap and fasten one end of the ESD wrist strap around your bare wrist, and connect the other end of the strap to a site ESD point or to the ESD point on the device.
3. Label the cable connected to the transceiver so that you can reconnect it correctly.
4. Remove the cable connected to the transceiver (see Disconnect a Fiber-Optic Cable). Cover the transceiver and the end of each fiber-optic cable connector with a rubber safety cap immediately after disconnecting the fiber-optic cables.

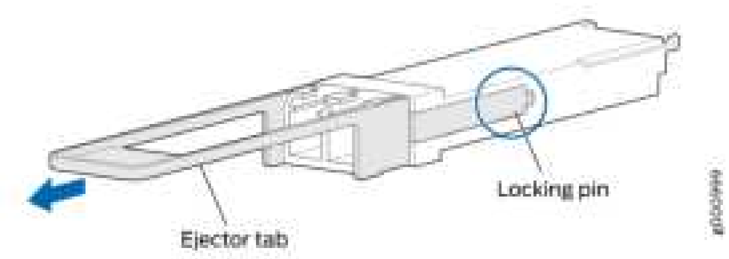
   LASER WARNING: Do not look directly into a fiber-optic transceiver or into the ends of fiber-optic cables. Fiber-optic transceivers and fiber-optic cables connected to transceivers emit laser light that can damage your eyes.

   LASER WARNING: Do not leave a fiber-optic transceiver uncovered except when inserting or removing a cable. The rubber safety cap keeps the port clean and protects your eyes from accidental exposure to laser light.

   CAUTION: Do not bend fiber-optic cables beyond their minimum bend radius. An arc smaller than a few inches in diameter can damage the cables and cause problems that are difficult to diagnose.

5. If there is a cable management system, arrange the cable in the cable management system to prevent it from dislodging or developing stress points. Secure the cable so that it does not support its own weight as it hangs to the floor. Place excess cable out of the way in a neatly coiled loop in the cable management system. Placing fasteners on the loop helps to maintain its shape.
6. Pull the transceiver's ejector tab straight back. The locking pins on the transceiver release automatically.
7. Gently slide the transceiver straight out of the port and place the transceiver on the antistatic mat or in the electrostatic bag.

Figure 17: Remove an QSFP-DD Transceiver



> **CAUTION**: To avoid ESD damage to the transceiver, do not touch the connector pins at the end of the transceiver.

> **NOTE**: After you remove a transceiver or after you change the media-type configuration, wait for 6 seconds for the interface to display operational commands.

8. Insert a dust cover in the empty port.

Maintain Fiber-Optic Cables

IN THIS SECTION

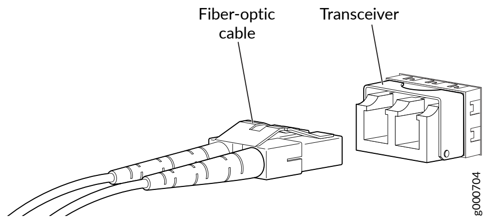
Connect a Fiber-Optic Cable

Before you connect a fiber-optic cable to an optical transceiver installed in a device, take the necessary precautions for safe handling of lasers (see Laser and LED Safety Guidelines and Warnings).

To connect a fiber-optic cable to an optical transceiver installed in a device:

> **LASER WARNING**: Do not look directly into a fiber-optic transceiver or into the ends of fiber-optic cables. Fiber-optic transceivers and fiber-optic cables connected to transceivers emit laser light that can damage your eyes.

1. If the fiber-optic cable connector is covered with a rubber safety cap, remove the cap. Save the cap.
2. Remove the rubber safety cap from the optical transceiver. Save the cap.
3. Insert the cable connector into the optical transceiver.



4. Secure the cables so that they do not support their own weight. Place excess cable out of the way in a neatly coiled loop. Placing fasteners on a loop helps cables maintain their shape.

> **CAUTION**: Do not bend fiber-optic cables beyond their minimum bend radius. An arc smaller than a few inches in diameter can damage the cables and cause problems that are difficult to diagnose.
>
> Do not let fiber-optic cables hang free from the connector. Do not allow fastened loops of cables to dangle, which stresses the cables at the fastening point.

Disconnect a Fiber-Optic Cable

Before you disconnect a fiber-optic cable from an optical transceiver, ensure that you have taken the necessary precautions for safe handling of lasers. See Laser and LED Safety Guidelines and Warnings.

Ensure that you have the following parts and tools available:

- A rubber safety cap to cover the transceiver
- A rubber safety cap to cover the fiber-optic cable connector

Juniper Networks devices have optical transceivers to which you can connect fiber-optic cables.

To disconnect a fiber-optic cable from an optical transceiver installed in the device:

1. Disable the port in which the transceiver is installed by issuing the following command:

```
[edit interfaces]
user@device# set interface-name disable
```

> **LASER WARNING**: Do not look directly into a fiber-optic transceiver or into the ends of fiber-optic cables. Fiber-optic transceivers and fiber-optic cables connected to transceivers emit laser light that can damage your eyes.

2. Carefully unplug the fiber-optic cable connector from the transceiver.
3. Cover the transceiver with a rubber safety cap.

> **LASER WARNING**: Do not leave a fiber-optic transceiver uncovered except when inserting or removing a cable. The rubber safety cap keeps the port clean and protects your eyes from accidental exposure to laser light.

4. Cover the fiber-optic cable connector with the rubber safety cap.

How to Handle Fiber-Optic Cables

Fiber-optic cables connect to optical transceivers that are installed in Juniper Networks devices.

Follow these guidelines when handling fiber-optic cables:

- When you unplug a fiber-optic cable from a transceiver, place rubber safety caps over the transceiver and on the end of the cable.
- Anchor fiber-optic cables to prevent stress on the connectors. When attaching a fiber-optic cable to a transceiver, be sure to secure the fiber-optic cable so that it does not support its own weight as it hangs to the floor. Never let a fiber-optic cable hang free from the connector.
- Avoid bending the fiber-optic cables beyond their minimum bend radius. Bending fiber-optic cables into arcs smaller than a few inches in diameter can damage the cables and cause problems that are difficult to diagnose.
- Frequent plugging and unplugging of fiber-optic cables in and out of optical instruments can damage the instruments, which are expensive to repair. To prevent damage from overuse, attach a short fiber extension to the optical equipment. The short fiber extension absorbs wear and tear due to frequent plugging and unplugging. Replacing the short fiber extension is easier and cost efficient compared with replacing the instruments.

- Keep fiber-optic cable connections clean. Microdeposits of oil and dust in the canal of the transceiver or cable connector can cause loss of light, reduction in signal power, and possibly intermittent problems with the optical connection.
    - To clean the transceiver canal, use an appropriate fiber-cleaning device such as RIFOCS Fiber Optic Adaptor Cleaning Wands (part number 946). Follow the instructions in the cleaning kit you use.
    - After cleaning the transceiver, make sure that the connector tip of the fiber-optic cable is clean. Use only an approved alcohol-free fiber-optic cable cleaning kit such as the Opptex Cletop-S® Fiber Cleaner. Follow the instructions in the cleaning kit you use.

4

CHAPTER

400G Optical Transceivers FAQs

IN THIS CHAPTER

Frequently Asked Questions

IN THIS SECTION

Why should I use 400G transceivers?

- Increased capacity—400G transceivers offer twice the capacity of 200G transceivers, allowing for faster data transmission.
- Higher port density—One 400G transceiver can replace two 200G transceivers, providing a higher port density and easier aggregation.
- Scalability—400G transceivers are compatible with upcoming network devices and can support constantly evolving deployment scenarios.

Which 400G transceivers does Juniper offer?

See Hardware Compatibility Tool for a list of all the 400G transceivers offered by Juniper, along with their detailed specifications.

Which 400G transceivers does my device support?

See Hardware Compatibility Tool for a list of the supported transceivers for your device.

Can I use a third-party transceiver with my device?

We recommend that you use only optical transceivers and optical connectors purchased from Juniper Networks with your Juniper Networks device.

> **CAUTION**: The Juniper Networks Technical Assistance Center (JTAC) provides complete support for Juniper-supplied optical modules and cables. However, JTAC does not provide support for third-party optical modules and cables that are not qualified or supplied by Juniper Networks. If you face a problem running a Juniper device that uses third-party optical modules or cables, JTAC may help you diagnose host-related issues if the observed issue is not, in the opinion of JTAC, related to the use of the third-party optical modules or cables. Your JTAC engineer will likely request that you check the third-party optical module or cable and, if required, replace it with an equivalent Juniper-qualified component.

Use of third-party optical modules with high-power consumption (for example, coherent ZR or ZR+) can potentially cause thermal damage to or reduce the lifespan of the host equipment. Any damage to the host equipment due to the use of third-party optical modules or cables is the users' responsibility. Juniper Networks will accept no liability for any damage caused due to such use.

What form factors do 400G transceivers support?

Juniper supports QSFP-DD transceivers. We currently do not support OSFP transceivers.

See "Quad Small Form Factor Pluggable Double Density (QSFP-DD)" on page 22 for details on the QSFP-DD form factor.

What speeds do 400G transceivers support?

400G transceivers can support a range of speeds, depending upon their type. They can support:

- A single port of 400 Gbps
- Two ports of 200 Gbps
- Four ports of 100 Gbps
- Eight ports of 50 Gbps

What are the different types of 400G transceivers?

400G transceivers can be classified based on their electrical and optical interface configurations.

- Electrical Interfaces
  - 4-Lane Electrical Interface (400GAUI-4)
  - 8-Lane Electrical Interface (400GAUI-8)
- Optical interfaces
  - Single-Lane Optical Interface

- 4-Lane Optical Interface
- 8-Lane Optical Interface

See "400G Optical Transceiver Flavors" on page 3 for details.

What standards do 400G transceivers follow?

400G transceivers and modules adhere to the IEEE 802.3-2022 standards. See No Link Title for a complete list of standards.

Tunable DWDM optics support the OpenZR and OpenZR+ multi-source agreement (MSA) standards defined by Optical Internetworking Forum (OIF), in addition to the IEEE standards.

How are 400G transceivers different from 800G transceivers?

See Table 1 on page 5 for a detailed comparison of 400G and 800G transceivers.

What does the name of the optic mean?

Optics and transceivers follow a naming convention where the product name contains the form factor, data rates, and lane distribution of the optic. See "Juniper Optical Product Numbers" on page 10 for a detailed example.

What is the optical lane distribution on 400G transceivers?

400G optics generally use 4 parallel lanes, each of which support 100 Gbps. Multiplexing occurs over multiple fibers, parallel optics, or optical or wavelength multiplexing techniques.

What modulation techniques do 400G transceivers support?

400G optics use Pulse Amplitude Modulation 4-level (PAM4) and Non-return to Zero (NRZ) or PAM2 modulation.

PAM4 combines two bits into a single symbol with four amplitude levels, enabling you to transmit twice as much data. It has a higher required signal-to-noise ratio which requires shorter transmission distances. It requires Forward Error Correction (FEC) to handle the loss of signal integrity. FEC is enabled by default on Juniper's transceivers.

NRZ is a binary modulation format with two distinct amplitude levels within a data channel. NRZ is currently not supported on Juniper Networks optics.

See "Modulation Methods" on page 7 for more details.

What is Digital Signal Processing (DSP)?

Digital Signal Processing techniques are used to enhance the signal integrity on optical connections and to extend the reach of optical transceivers. DSP involves components such as Serializer/Deserializer (SerDes), Feed-forward Equalization (FFE), and Decision Feedback Equalization (DFE).

What is Clock Data Recovery (CDR)?

Clock Data Recovery is the process of extracting timing information from a data signal. The receiver uses the timing information embeddded in the data signal to determine the frequency of the transmitter's clock. The receiver then uses this information to re-time the signal to ensure accurate data retrieval and transmission. CDR helps to reduce jitter and improve signal integrity and reach.

What are the components of a 400G transceiver architecture?

400G (x8) optics are composed of the following:

- 400G Host Platform
- 8x50 Gbps Electrical Interface
- PAM4 Digital Signal Processor/Clock Data Recovery (DSP/CDR)
- Drivers (8)
- Modulators (8)
- 4x100G Optical Interfaces
- Transimpedance Amplifiers (TIA) (8)

- Photo-Detectors (8)

See "400G (X8) Transceiver Architecture" on page 11 for a detailed explanation of each component.

What is Dense Wavelength Division Multiplexing (DWDM)?

Dense Wavelength Division Multiplexing (DWDM) uses multiple light wavelengths or channels to increase the amount of data that can be transmitted over a single optical fiber.

What are tunable DWDM transceivers?

Tunable DWDM optical transceivers use advanced modulation and equalization techniques to encode more data onto light waves and overcome transmission impairments. Tunable DWDM optics use both amplitude and phase modulation for data encoding.

Juniper's tunable DWDM optics use two types of DWDM connections:

- Unamplified link (limited optical power)
- Amplified link (limited optical signal-to-noise ratio and chromatic dispersion)

See "Tunable DWDM Optics" on page 14 for more details on tunable DWDM optics.

What are ZR, ZR-M, and ZR-M-HP optics?

ZR or OIF 400ZR optics are primarily used for single-span applications due to their limited chromatic dispersion range. ZR optics use the concatenated forward error correction (CFEC) technique.

ZR-M or Open ZR+ optics are mainly used for single-span applications as they have high chromatic dispersion mitigation capabilities. They have a longer reach than ZR optics. ZR+ optics use the open forward error correction (OFEC) technique.

ZR-M-HP optics are the same as ZR-M but with higher transmission (Tx) or output power.

What are breakout capability and breakout cables?

Breakout capability is the ability to split a high-speed link into multiple smaller, lower-speed links. This is also called channelization. Breakout capability is crucial for optimizing the use of available bandwidth and physical infrastructure in various networking scenarios.

You can configure port speeds at the chassis level or the interface level. You can channelize an individual port, a block of ports, or a quad of ports.

Breakout cables have a single transceiver at one end and multiple transceivers at the other end. You can use breakout cables to physically split a single high-speed port to multiple lower-speed ports.

For more details, see "Breakout Capability" on page 30.

How does my device support breakout/channelization?

See Port Checker for details on channelization support for your device.

What are single-mode and multi-mode fibers?

Single-mode fibers (SMF) are designed to trasmit only one mode of an optical signal at a time. They have a core diameter of 9 microns. They have low attenuation and can support higher data rates and longer transmission distances.

Multi-mode fibers (MMF) can transmit multiple optical signals at the same time. They have a core diameter of 62.5 microns. They are easier to handle and manufacture as compared to SMF. They have higher attenuation and are used to transmit data over shorter distances.

What are the different types of cables used in 400G transceivers?

400G transceivers use direct attach cables (DAC) and active optical cables (AOC). See "Cable Types and Length" on page 26 for details.

For a list of AOC and DAC cables supported by Juniper, see Hardware Compatibility Tool.

What are the different types of connectors used in 400G transceivers?

400G optical cables use MPO-12/APC, MPO-16/APC, duplex LC/PC, and MPO-12/BiDi/UPC connectors. See "Connector Types" on page 23 for more details.

What is the power requirement for 400G optics?

400G QSFP-DD transceivers require between 7 to 12 W of power.

Tunable DWDM optics (ZR/ZR+) require between 18 to 23 W of power.

Can I plug an OSFP module into a QSFP-DD port?

No. OSFP and QSFP-DD refer to optics with different physical form factors.

Juniper currently does not support OSFP transceivers.

Can there be an OSFP connector on one end of an 400G link and a QSFP-DD connector on the other?

Yes. OSFP and QSFP-DD connectors can interoperate with each other on the same link, provided the Ethernet media type is the same.

Can I plug a 100G QSFP28 module into a QSFP-DD port?

Yes. The QSFP-DD ports are backward compatible with the QSFP56, QSFP28, and QSFP+ ports.

You must configure the QSFP-DD port for a data rate of 100G (or 40G) instead of 400G.