Coherent transceivers

An overview of the technology and its benefits

app note

EXFO

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What is a coherent transceiver?

Until recently, most transceivers were based on direct detection technology. Direct detection looks only at the optical amplitude of the incoming signal. This is one of the simplest and common modulation techniques. Non-return to zero (NRZ), also called PAM2 and PAM4 (pulsed amplitude modulation, 4-levels) are primary examples of direct detect modulation. Because of the simplicity of the technique, its more susceptible to noise. So, the direct detect transceivers are designed for short-haul links and client interfaces. This type of optical transceiver can be found in core switching of service providers, premises equipment, personal computers, enterprises and data centers.

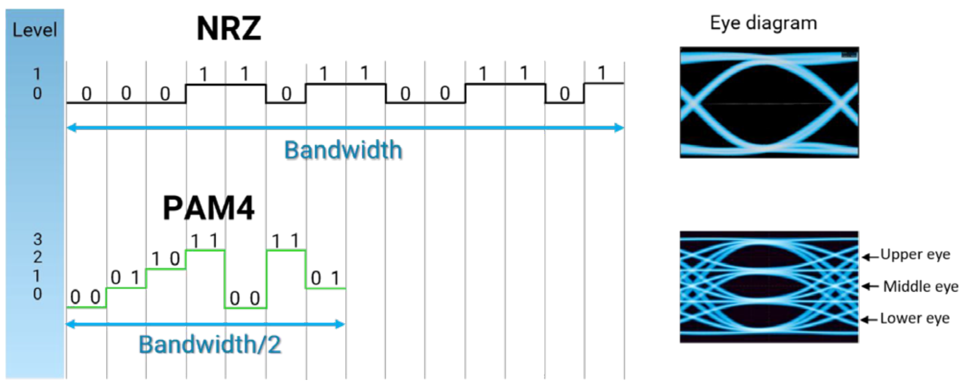

Figure 1. NRZ and PAM4 binary levels and associated eye diagrams.

For longhaul communications, where reliability and signal integrity are paramount, PAM4 alone is often insufficient to overcome the challenges of maintaining high performance over extended distances. The system can struggle with issues such as noise, distortion, and fiber impairments, which can significantly degrade signal quality over long links. However, with advanced modulation techniques like phase shift keying (PSK) and polarization multiplexing, coherent transceivers can mitigate fiber impairments and help maintain signal integrity.

A coherent transceiver is an advanced optical communication module that transmits and receives data using coherent detection techniques. It combines high-speed lasers and sophisticated digital signal processing to modulate and demodulate signals, allowing for enhanced data transmission over long distances with high spectral efficiency. Coherent transceivers are particularly effective in mitigating signal degradation due to factors like dispersion and nonlinearity, making them ideal for modern optical networks.

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The designation of coherent transceivers at 100 Gbit/s is 100ZR, 400 Gbit/s is 400ZR and for 800 Gbit/s is 800ZR. It is available in form factors like **quad small form-factor pluggable double density (QSFP-DD)** and **octal small form-factor pluggable (OSFP)**, making it suitable for use in high-speed network switches and routers. The reach between two ZR transceivers is 80 km. The ZR+ is an extension of the 400ZR standard and is designed for **longer distances** than the standard 80 km range, extending up to **hundreds of kilometers**.

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ZR coherent transceivers support a **broader range of modulation formats**, such as **quadrature phase shift keying (QPSK)** and **higher-order quadrature amplitude modulation (QAM)**, allowing for adjustments based on link requirements like reach and spectral efficiency.

Figure 2. Example of a coherent transceiver model 400ZR QSFP-DD.

How do coherent transceivers work?

The key components of coherent transceivers (figure 3) include tunable lasers, modulators, and polarization management. A tunable laser serves as the source of light in the transmitter, and it generates a stable laser beam at a precise wavelength. This wavelength can be adjusted across a range, making the laser "tunable" and allowing the device to adapt to different DWDM channels within the optical network.

Once the laser generates the light, it is passed through a modulator. The modulator is responsible for encoding data onto the light beam. It modifies the light's phase and amplitude based on the input data, allowing the transceiver to use complex modulation formats such as quadrature phase shift keying (QPSK) or quadrature amplitude modulation (QAM). These formats enable the transmission of multiple bits per symbol, significantly increasing data throughput.

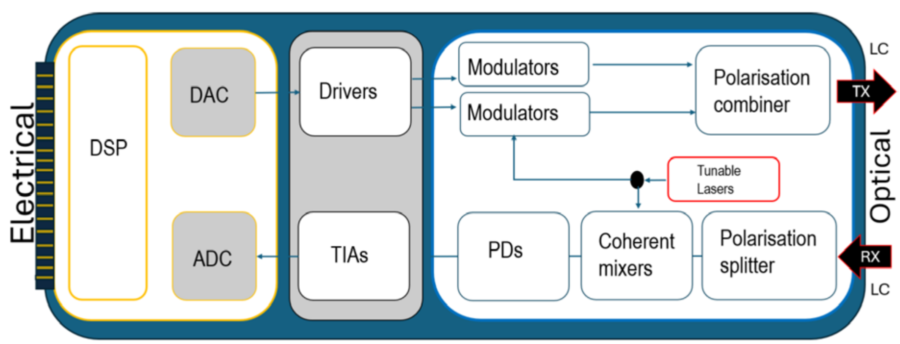

Figure 3. Functional diagram of a coherent transceiver.

In addition to modulation, polarization plays a critical role in coherent transmission. Light is polarized, meaning that its electric field oscillates in a particular direction. The polarization multiplexing is used to double the transmission capacity by encoding separate data streams on two orthogonal polarizations (vertical and horizontal). Figure 4 below shows a 16 QAM coherent signal constellation.

ZR transceivers can transmit up to 800 Gbit/s — enough to support approximately 100,000 simultaneous HD (1080p) video streams.

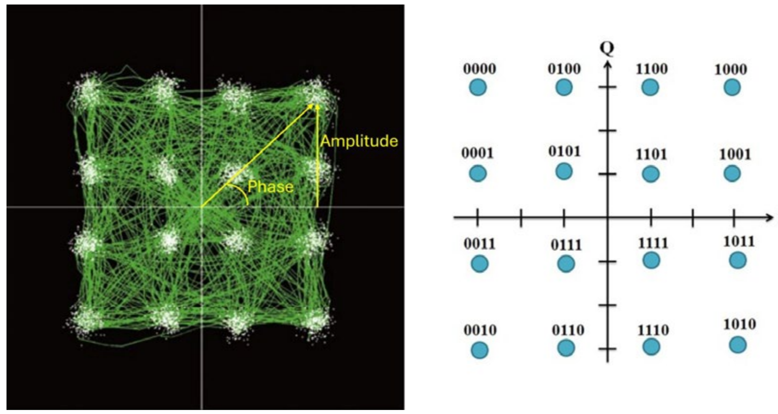

Figure 4. 16 QAM constellation measurement and corresponding binary values.

The coherent receiver must be able to distinguish and separate these polarization states to accurately recover the transmitted data. When the optical signal reaches the receiver, the transceiver uses a local oscillator laser, the same tunable laser used for the transmitter, to perform coherent detection. It combines the incoming signal with the local oscillator's light in a process called interference. This process enables the receiver to extract both the amplitude and phase information of the received signal, which is then processed by a digital signal processor (DSP). The DSP plays a crucial role in accurately reconstructing the transmitted data by compensating for signal impairments and optimizing signal quality.

Through this combination of a tunable laser, advanced modulation techniques, and polarization management, a coherent transceiver allows for highly efficient and robust data transmission. It provides improved sensitivity and enables higher data rates, over longer distance, making it ideal for modern, high-capacity optical networks.

What are the key benefits of coherent transceivers?

1. **High bandwidth:** ZR transceivers can transmit up to 800 Gbit/s — enough to support approximately **100,000 simultaneous HD (1080p) video streams**.
2. The signal from the ZR transceiver can be used directly in a DWDM system, as it is a line-side module tuned to a specific channel (see figure 5). This represents a significant difference compared to client-type transceivers.

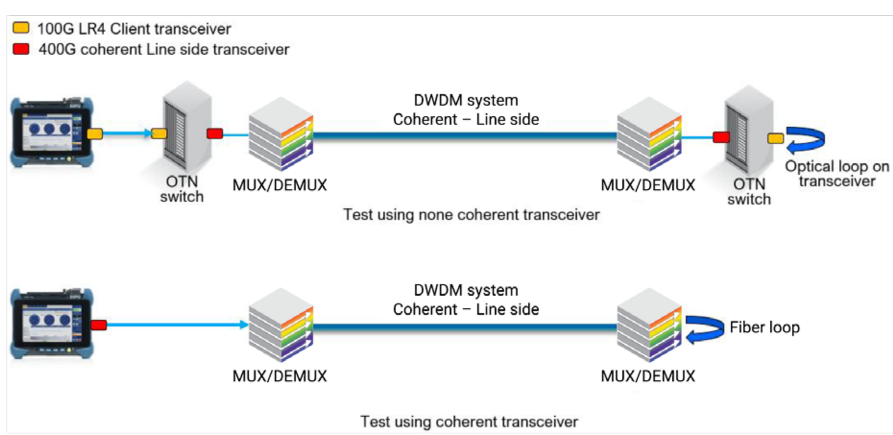

Figure 5. Testing over DWDM systems with a coherent transceiver.

3. The use of **phase and amplitude modulation** enables coherent transceivers to better handle **signal impairments** such as **chromatic dispersion (CD)** and **polarization mode dispersion (PMD)**. This allows coherent transceivers to transmit data over distances of hundreds of kilometers without requiring frequent **optical amplifiers** or **regenerators**, making them ideal for longhaul **data center interconnection** and **submarine cable systems**.
4. Standards like **400ZR** and **800ZR** have brought a level of **interoperability** to coherent transceivers, allowing network operators to mix and match transceivers from different vendors without compatibility issues. This is called an **open line system (OLS)**.
5. By reducing the use of amplification, and transport equipment, ZR coherent transceivers offer a **cost-effective solution for network expansion**. Service providers can deploy these transceivers to extend their network reach without incurring the high costs associated with additional amplification equipment.

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The 400ZR standard is designed to support high-speed, point-to-point (P2P) optical transmission over distances of up to 80 km without the need for optical amplification.

What types of coherent transceivers are available?

The Optical Internetworking Forum (OIF) is responsible for defining the specifications of ZR coherent transceivers by facilitating collaboration among industry stakeholders, including manufacturers and service providers, to establish standardized technical requirements for optical interfaces, data rates, protocols, and modulation formats. Through rigorous standardization, the OIF ensures interoperability by conducting tests that validate compatibility and interoperability among different vendors' products, with EXFO participating in the process. This collaborative effort keeps the ZR specifications relevant to market demands, fostering the adoption of high-performance transceivers across various applications, such as data centers and telecommunications. Additionally, the OIF is committed to continuous improvement, regularly updating the specifications to reflect technological advancements and emerging industry needs.

The 400ZR standard is designed to support high-speed, point-to-point (P2P) optical transmission over distances of up to 80 km without the need for optical amplification, making it ideal for data center interconnects (DCI) and metro networks. This reach in unamplified P2P scenarios is limited by factors such as signal loss, CD and PMD, which can cause signal degradation over longer distances. However, with the use of optical amplifiers like erbium-doped fiber amplifiers (EDFAs), the reach of 400ZR can be extended beyond 80 km to approximately hundreds of kilometers, depending on the quality of the amplifiers and the network configuration. Despite this, PMD becomes a significant limiting factor over longer distances, requiring advanced digital signal processing (DSP) techniques to mitigate its effects and maintain signal integrity. As such, while 400ZR can achieve longer reach with amplification, its efficiency and performance are best suited for medium-long range applications. The table below shows types of ZR and related specifications. The 800GBASE-ZR transceivers are still in the early stages of adoption, with their specifications yet to be fully standardized.

For more information

FTBx-88480 Series — dual-port 1G-400G, 800G-ready testers
www.EXFO.com/en/products/field-network-testing/transport-testing-sonet-sdh-otn/ftbx-88480

Type	Form factor	Line rate	Client rate	Reach with amplification	Modulation format	Max Tx power	Max power cons
400GBASE-ZR	QSFP-DD OSFP	400G	4×100GbE 1×400GbE	500 km	DP-16QAM	−9 dBm	18.5 W
400GBASE-ZR+	QSFP-DD OSFP	100G 200G 300G 400G	1-4×100GbE	1000 km	DP-QPSK DP-8QAM DP-16QAM	0 dBm	22.5 W
800GBASE-ZR*	QSFP-DD OSFP	800G	4-8×100GbE	800 km	DP-16QAM	1 dBm	20.0 W
800GBASE-ZR+*	QSFP-DD OSFP	400G 600G 800G	1-8×100GbE	1200 km	DP-16QAM	1 dBm	25.0 W

*QSFP-DD 800G ZR is planned to be available.

How can EXFO's solutions help?

EXFO provides comprehensive testing solutions that are particularly well-suited for the deployment of coherent transceivers, such as those based on 400ZR and 800ZR standards. Coherent optical transceivers are complex devices that require precise validation of their performance and compatibility with network infrastructure. EXFO's solutions help ensure that these transceivers function optimally across various conditions, reducing deployment risks and improving overall network reliability.

EXFO's optical test equipment includes bit error rate testers such as the FTBx-88480, FTBx-88800, and optical spectrum analyzers such as the FTBx-5255, which are crucial for characterizing the performance of coherent transceivers.

The FTBx-88800 Series and FTBx-88480 Series can verify the performance of transceivers at high data rates (e.g., 800G and 400G respectively), allowing operators to assess the error-free transmission capabilities and ensure that forward error correction (FEC) works correctly. This is especially important for coherent transceivers, which use complex modulation formats like QPSK and 16-QAM.

EXFO also offers advanced OSAs that can precisely measure the optical signal-to-noise ratio (OSNR), wavelength stability, and power levels, which are critical for evaluating the quality of coherent signals, particularly in dense wavelength-division multiplexing (DWDM) environments.

In addition, EXFO's automation capabilities streamline testing processes, allowing network operators to accelerate the deployment of coherent optics by automating complex test sequences and remote monitoring. This ensures faster turn-up of services and reduces the time spent troubleshooting, providing a robust and reliable framework for deploying advanced coherent transceiver technology in real-world networks. Overall, EXFO's solutions help operators validate the performance, compatibility, and long-term reliability of coherent transceivers, ensuring a smooth deployment process and optimal network performance.

Conclusion

Mastering coherent transceivers is critical for operators deploying and maintaining high-speed networks. With EXFO's high-speed test solutions and support, operators can effectively address the challenges of 100G, 400G, 800G and beyond, ensuring that their networks remain efficient, reliable, and prepared for future demands.