

400ZR Pluggable Module Test

For cost-effective and interoperable interconnect

Flexible and Cost-efficient Data Center Interconnect and Metro Networks

With 6G approaching, the spreading of AI in all domains, there are no clairvoyant abilities needed to foresee that the data center traffic won't stop increasing any time soon. Datacenter interconnect (DCI) networks become critical not only for backup/recovery purposes but also to connect computing resources spread over different locations. As the transmission reach of traditional direct detect PAM4 transmission is limited to 10km at 400 Gbps, an alternative to the expensive transport network is required to connect switches located in different data centers.

Coherent optical technology has been impractical for use in shorter distances such as DCIs for a long time mainly because of their prohibitive cost but also because their proprietary design prevents interoperability between different vendors' modules. However, standards such as 400ZR and 400GBASE-ZR, developed by the Optical Internetworking Forum (OIF), enable coherent optical technology to move to data center interconnects. IEEE prepares with 802.3cw an implementation agreement for coherent DCIs.

Using coherent technology, DCIs can transport terabytes of information across a single fiber line and provide flexibility to address growing data demands. This allows for efficient, cost-effective, and interoperable connectivity between data centers but also for metro networks.

Complex optical modulation enables transmission of a 400 gigabit Ethernet (GE) payload over data center interconnect links up to 80 km using dense wavelength division multiplexing (DWDM) and higher-order modulation. The 400ZR specification recommends dual polarization (DP) 16-QAM (quadrature amplitude modulation) at a symbol rate of about 60 Gbaud.

Coherent Technologies for the Datacenters

Lower power consumption with coherent transmission

The fact that complex optical modulation makes its move from long-haul networks to DCI distance largely owed to the latest CMOS (complementary metal-oxide semiconductors) node technology developments used for today's microchips. The power consumption of 7 nm CMOS digital signal processors (DSPs) that are used for 400ZR coherent technologies is already closer to the PAM4 equivalents (Figure 1) than it was the case for 200G. For 800G, the footprint of coherent and PAM4 transceivers is expected to be very similar.

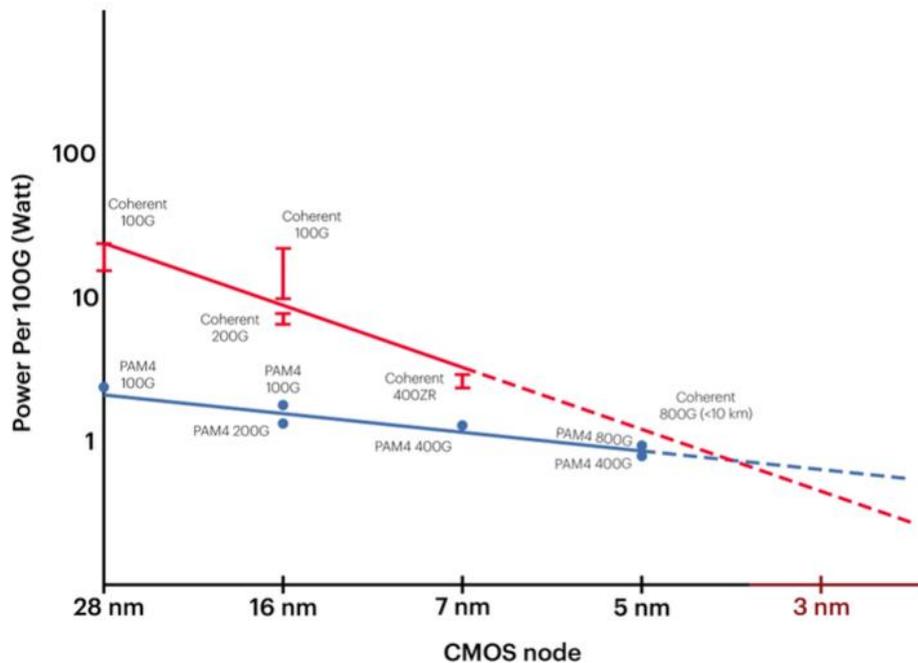


Figure 1. CMOS node power consumption of coherent and PAM4 direct devices become comparable for data rates reaching for 800 Gbps

With that development, coherent transceivers can compete with their direct detect counterparts and will move to shorter and shorter distances as the data rates increase as can be seen in Figure 2. For 400G, in the ZR distances (80 km), complex optical signaling is already the better alternative as direct detect systems have a reach here of only about 10 km; beyond they are facing serious signal quality issues that cannot be compensated for.

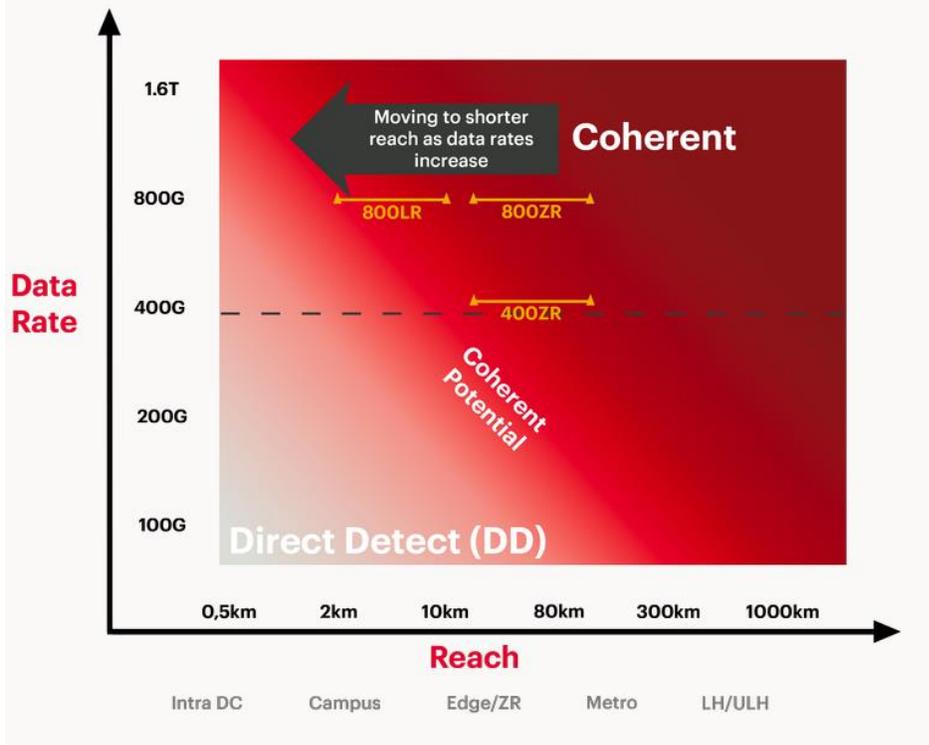


Figure 2. Coherent technologies get more and more attractive for shorter distances as the data rates increase.

But how about about technical challenges and cost?

Coherent technology always seems to be more complex and therefore more expensive, but it is not necessarily the case anymore.

The designs of coherent and intensity-modulated direct-detect (IM-DD) transceivers present many similarities (Figure 3), only the optical front end is significantly different. On the transmitter side, the coherent transceiver includes a coherent optical modulator that is, in fact, more complex than integrated amplitude modulators, but requires only one laser source (instead of at least four) to transmit a 400 Gbps or 800Gbps signal, bringing therefore potential power savings. On the receiver side, a 90-degree hybrid coherent balanced receiver design is more costly than a classical DD receiver but doesn't require an additional wavelength-division-multiplex (WDM) demultiplexer as the local oscillator acts as a tunable dense-wavelength-division-multiplex (DWDM) filter. In addition, coherent detection enables simple chromatic dispersion compensation, which tends to be more powerful and power-efficient than the one used for DD receivers for long distances.

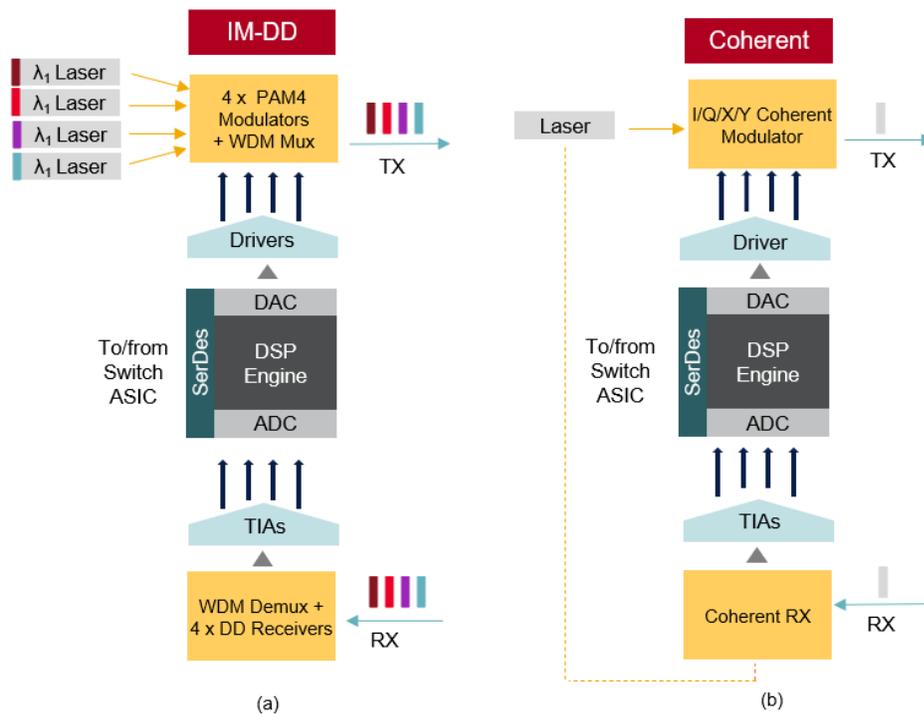


Figure 3. Obvious differences between IM-DD and coherent modules exist at the optical front end. Hidden complexity differences lie in the equalization that needs to be performed in the DSP engines with similar complexity and power consumption.

400ZR – the technology of choice for data center interconnect

For the above reasons, 400ZR has become the technology of choice for DCI, while coherent has become a strong candidate for intra-datacenter 800G links above 2 km.

The OIF developed the 400ZR networking implementation agreement (IA) for pluggable digital coherent optical (DCO) modules. The 400ZR standard enables the transmission of multiple 400 gigabit Ethernet (GE) payloads over DCI links up to 80 km using dense wavelength division multiplexing (DWDM) and higher-order modulation. The intent is to ensure an affordable and long-term implementation based on single-carrier 400G using dual-polarization 16-state quadrature amplitude modulation (16 QAM) at approximately 60 gigabaud (Gbaud). This is only possible using coherent detection and advanced digital signal processing (DSP). The 400ZR IA reduces cost and complexity of high-bandwidth data center interconnects and promotes interoperability among optical module manufacturers.

On the host-side, 400ZR uses the 400GAUI-8 interface. The 400ZR IA details the full data path from this interface to the coherent optical signal on the line side. This also includes the full definition of a concatenated forward-error correction (FEC) scheme, which consists of a hard-decision (HD) outer FEC and a soft-decision (SD) inner FEC.

There is a strong interest by data center operators to use the 400ZR coherent interface to link distributed data centers, which are up to 80 km apart. While the IA does not target a specific form factor, the specifications are written such that the use of QSPFDD, OSFP, or COBO modules are possible. This allows to directly connect to data center switches just like client-side optics and will remove the need for costly and bulky transport networking equipment inside the data centers. Also, the telecommunications industry wants to use 400ZR for residential backhaul traffic of 200 Gb/s streams using 64 Gbaud signaling and quadrature phase shift keying (QPSK).

Pitfalls of validating 400ZR Transceivers Designs

To achieve data rates of 400 Gbps and higher with a constrained power consumption of 20 W and with space constraints in the target form factors (QSFP-DD and OSFP), optical transceivers require dense electronic and photonic integration with tighter specifications and performance margins for all components. The need for Interoperability is a further big concern for physical chip suppliers as well as module vendors. A large variety of tests must be done to guarantee module performance and interoperability (Figure 4).

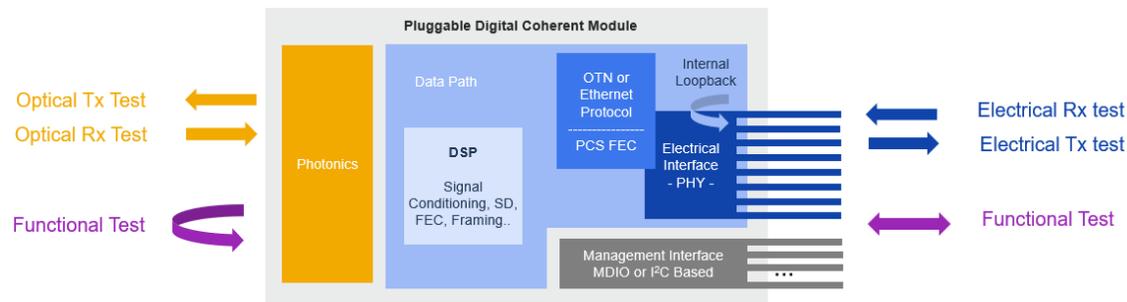


Figure 4. 400ZR coherent pluggable test needs

On the **optical transmitter test** side alone, you need to account for measurements of:

- EVM (error vector magnitude)
- Carrier frequency offset,
- I/Q skews, polarization skew
- Power delta between X and Y polarization
- Gain Imbalances between I- and Q-signals
- Quadrature errors
- IQ-offset
- phase & frequency response
- In-band and out-band OSNR (optical signal-to-noise ratio)
- Relative intensity noise (RIN).

The **optical receiver tests** include:

- I/Q skews, polarization skew
- IQ-angles
- Gain Imbalances
- Power delta between X and Y polarization
- Phase & frequency response
- Sensitivity measurements (pre-FEC vs. power)
- OSNR margin (pre-FEC vs. OSNR)
- FEC margin ([White Paper: Forward Error Correction Challenges in 400G Device Test](#))

Functional tests that you need to consider for both TX and RX are:

- Physical layer stressing (clock offset, amplitude, RF jitter)
- BER (bit error ratio, FLR (frame loss ratio), error burst and packet loss measurements
- Common Management Interface Specification (CMIS (5.0)) and diagnostic monitoring
- Multivendor interoperability test

Keysight supports you in testing all these with a comprehensive test solution bundle.

S1205A 400ZR Pluggable Modules Test Bundle

Keysight offers the industry-only 400ZR test solution that covers all coherent pluggable measurement needs described above in:

- Optical transmitter test
- Optical receiver test
- Functional test

The solution is tailored for 400ZR modules validation and can be simplified for fully automated production testing.



Figure 5. S1205A solution

M8290A optical modulation analyzer and high-speed digitizer test solution

Options	Description	Comments
M8292A-C92	92GSa/s coherent optical receiver C-band	
M8292A-800	External local oscillator optical input and output	Optional
M8292A-BU2	M9505A 5-slot AXIe chassis with USB option and M9537A AXIe embedded PC controller	
M8292A-C05	Pre-installation of M8290A software on M9537A AXIe embedded PC controller	
N4391B-C20	N4391EM0C-1FP optical modulation analysis software, node locked perpetual license, essential	
89601200C	Basic vector signal analysis and hardware connectivity	
89601AYAC	Digital demodulation analysis	
N4391EM0C-1FP	Optical modulation analysis and device test, node-locked perpetual license, essential	
N7752C	Variable optical attenuator with optical PM (2 channels)	Optional
N7752C-022	Angled connectors	Optional
N7742FI	Connector interface FC, 2x	Optional

Outlook to 800G Coherent for the Data Center

Standardization activities of next-generation 800G coherent links are underway and suggest doubling the symbol rate to 120 Gbd and targeting intra-DC links of up to 10 km (OIF 800LR, IEEE 800GBASE or IEEE 802.3dj) and inter-DC links of up to 80 km (OIF 800ZR).

Keysight already offers the tools for designing and validating these technologies. For instance, combining the G800GE-02 and N4391B optical modulation analyzer enables you to test 400G and 800G coherent pluggable modules and components in C-band (800ZR) and O-band (800LR).

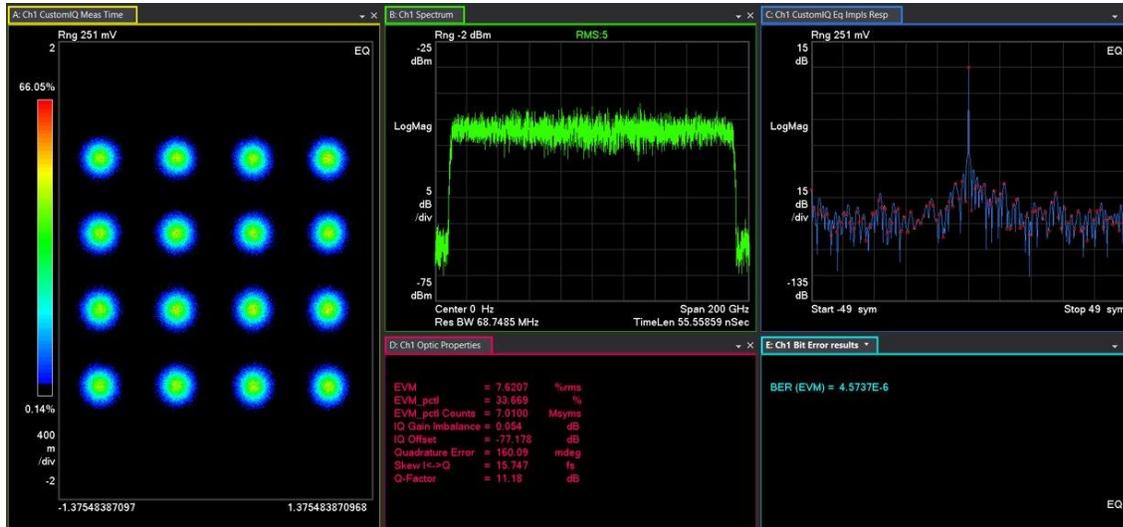
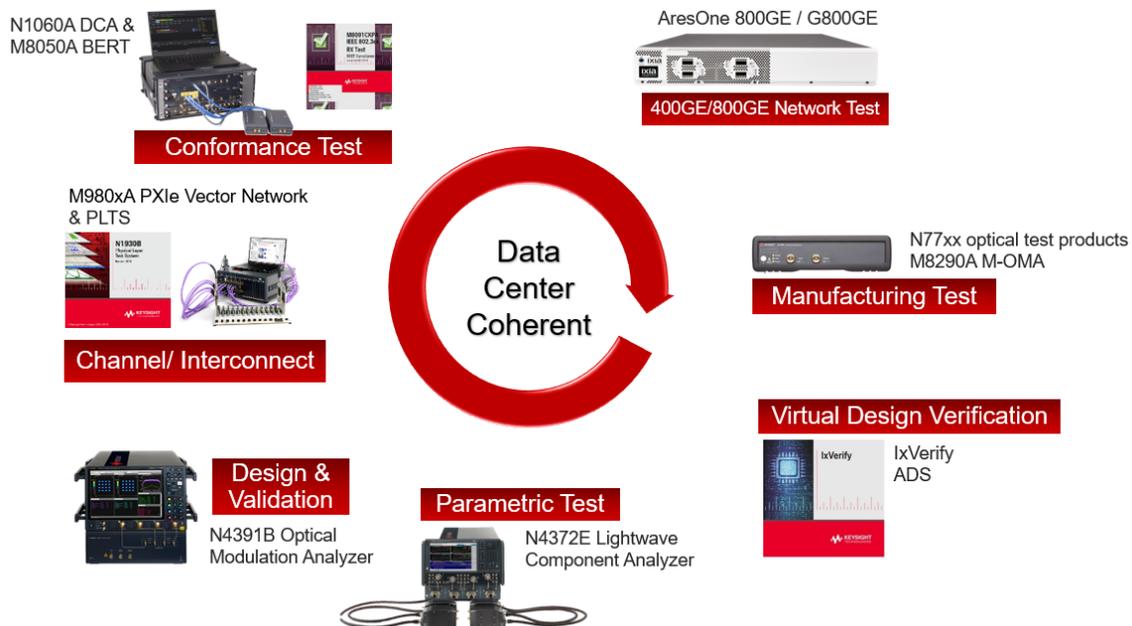


Figure 7. 16QAM at 180 Gbaud signal (1.44 Tb/s) captured and analyzed using Keysight N4391B

800G Coherent test solutions



For More Information

To learn about Keysight solutions for coherent transmission please visit

[Coherent Transmission Test Instruments](#)

For more insights on performance and compliance test solutions for 100G and 400G datacom optical transceiver modules please visit

[Optical Transceiver Test Solutions](#)



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