

# Coherent Optical Transforms Data Center Interconnects

## Integrated photonics and new standards drive next-generation DCI

Demand for more and faster data continues to grow. Cloud-based services, video streaming, Internet of Things (IoT) devices, 5G connectivity, and more put a strain on communications networks. Network infrastructure, in particular data center interconnects (DCIs), must evolve and transform to support these demands. Today's DCIs need to offer higher bandwidth transfer rates and ensure energy efficiency.

While widely used in long-haul telecommunications networks, coherent optical technology has been cost prohibitive and impractical for use in shorter distances such as DCIs. Developments in integrated photonics technology and standards such as 400ZR will enable DCIs to reach a new speed class. Using coherent optical technology, DCIs can transport terabytes of information across a single fiber line and provide flexibility to address growing data demands.



### Three key trends highlighted in this paper:

- Coherent optical moves to DCI
- Integrated photonics enables terabit speeds
- 400ZR provides a cost-effective alternative

## Coherent Optical Moves to Data Center Interconnects

Distributed data centers need to communicate with each other to share data, balance workloads, provide backups, and scale data center capacity when needed. DCI connections are usually less than 80 km apart. The conventional means of data transfer through optical signaling using on-off keying (OOK) modulation was sufficient for speeds up to 100 gigabits per second (Gb/s). Today, many distributed data centers in a campus or metropolitan area need to significantly increase interconnection capacity. That drives demand for faster and more efficient DCI transport.

Coherent optical transmission technology offers the fastest and most efficient DCI transport. Traditionally, coherent optical technology was feasible only for long-distance telecommunications networks, where the cost per bit was acceptable given the distances. New developments in integrated photonics and the 400ZR standard make coherent optical an appealing solution for higher-speed DCIs.

### Coherent optics is faster and more efficient

Installing fiber lines is often cost prohibitive for network providers. Coherent optics enables higher rates of data transmission over the same fiber lines by using higher-order modulation, such as quadrature amplitude modulation (QAM). QAM modulates the amplitude and phase of light to transmit the signal. This results in a significant capacity increase of a fiber optic cable through the associated increase of spectral efficiency.

QAM is a two-dimensional format that modulates the phase and amplitude of the signal. This is achieved by combining two carriers that have the same optical frequency but are phase shifted by 90°. Those carriers are called in-phase (I) and quadrature (Q), and their amplitudes are modulated independently. The standard notation is 2<sup>n</sup>-QAM, with n-bits transmitted per symbol. For example, 16-QAM sends 4 bits per symbol, and 64-QAM sends 6 bits per symbol. Bitrate is determined using the following formula:

*Bitrate = symbol rate (symbols/sec) x coding (bits/symbol) x polarization (typically 2)*

Using 16-QAM, a transceiver with a 64 gigabaud (Gbaud) raw symbol rate (or 50 Gbaud without the overhead) could transmit 400 Gb/s on a single optical carrier.



**Higher-order modulation, such as QAM, enables:**

- Faster data transmission rates
- Higher levels of spectral efficiency

## Integrated Photonics Enables Terabit Speeds

Typically, photonics use discrete components, i.e. they are physically separate and interact using different coupling procedures to create a complete optical circuit. Integrated photonics streamlines this process with the use of photonic integrated circuits (PICs). PICs integrate multiple photonic functions in a single device, similar to an electronic integrated circuit, and use light instead of electricity to transmit signals. PICs provide numerous advantages over conventional circuits including higher bandwidth, expanded wavelength division multiplexing, smaller size, lower power consumption, and improved reliability.

### PICs and the end of Moore's Law

It is widely believed that Moore's Law — the observation that the number of transistors that can be placed on silicon chips in integrated circuits doubles every two years — is nearing its end. Traditional chip technology cannot continue to get much smaller or keep pace with the exponential increase in processing speeds data centers need to support emerging technologies such as 5G, IoT, and autonomous vehicles. PICs offer an alternative to the limitations of silicon chip technology.

PIC fabrication uses wafer-scale technology and lithography to create three-dimensional images of the circuit on substrate materials such as silicon, indium phosphide, silica, or lithium niobate. For example, in silicon photonics, photonic functions are implemented directly on silicon chips. Silicon photonics is an exciting technology that promises inexpensive, mass-produced optical components through photonics integration that leverage the high yield and throughput of mature CMOS process technology.

Facebook, Google, Microsoft, and other companies that provide hyperscale data centers plan to move to terabit speeds. They also need to find a way to reduce the power required to operate and cool data centers. This is especially true for data centers in a campus or metropolitan area. Integrated photonics technologies using PICs and optical modulation techniques, such as QAM, enable data centers to support terabit rates of data traffic at split-second switching speeds and reduce power consumption.





## 400ZR Provides a Cost-Effective Alternative

Traditionally, optical coherent technology was cost-effective only over great distances, such as those in long-haul transport networks. However, new standards such as 400ZR and 400GBASE-ZR enable coherent optical technology to move to data center interconnects. The Optical Internetworking Forum (OIF) is developing the 400ZR implementation agreement. It will enable 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 16-QAM at a symbol rate of about 60 Gbaud. To achieve this rate with maximum power consumption of 15 W and with space constraints in the target form factors, optical transceivers require dense electronic and photonic integration with tighter specifications and performance margins for all components. These small form factors need small component sizes and low electrical power consumption. These restrictions create challenges for digital signal processor (DSP) and component suppliers. Although not defined by the 400ZR specification, optical transceivers are designed to fit in a small client-side format such as octal small form factor pluggable (OSFP) or double density quad small form factor pluggable (DD-QSFP).

The Institute of Electrical and Electronics Engineers (IEEE) continues to develop a set of standards to define the physical and data link layers of wired Ethernet. The IEEE 802.3ct project will leverage the OIF 400ZR specification to create the 400GBASE-ZR standard for 400 Gb/s transmission on a single wavelength up to 80 km in a DWDM system. Both the OIF 400ZR and the IEEE 802.3ct standards will help reduce the cost and complexity of high-bandwidth data center interconnects and ensure interoperability among optical module manufacturers.



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## A Promising Future for Data Center Interconnects

Copper cabling and optical data transmission using OOK modulation for DCIs have been sufficient to date. However, traffic grows each year because of emerging technologies such as 5G and IoT. Data center interconnects therefore need to evolve to support faster data transmission rates and ensure energy efficiency between connected, distributed data centers.

Traditionally, coherent optical technology has been too expensive to use in data center interconnects, which are typically less than 80 km apart. New photonic integrated circuits and standards, such as 400ZR and IEEE 802.3ct, will enable physically separated data centers to cost effectively increase speeds to 400 Gb/s. These standards will ensure efficiency when sharing resources, balancing workloads, and scaling capacity. For component and device manufacturers, testing is a significant challenge. High-speed silicon that drives the optical transceivers lags the optics by about a year. Test equipment that can generate and analyze 16-QAM 64 Gbaud signals with optical impairments enables manufacturers to test their components and devices for terabit applications.

For information on how Keysight's solutions can help you address your optical and photonic test challenges, check out the following:

- Learn how coherent optical component test enables 1.2 Tb applications in this [case study](#)
- To accurately and efficiently test your transceivers so you can design the next generation of high-speed interconnects, visit [Optics and Photonics](#)

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