

Three Key Trends in Data Center Interconnects

REACH 400G SPEEDS AND BEYOND

INTRODUCTION

Integrated Photonics and New Standards Drive Next-Generation Data Center Interconnects

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 traditionally been cost prohibitive and impractical for use in shorter distances such as DCIs. Developments in integrated photonics technology and new 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.

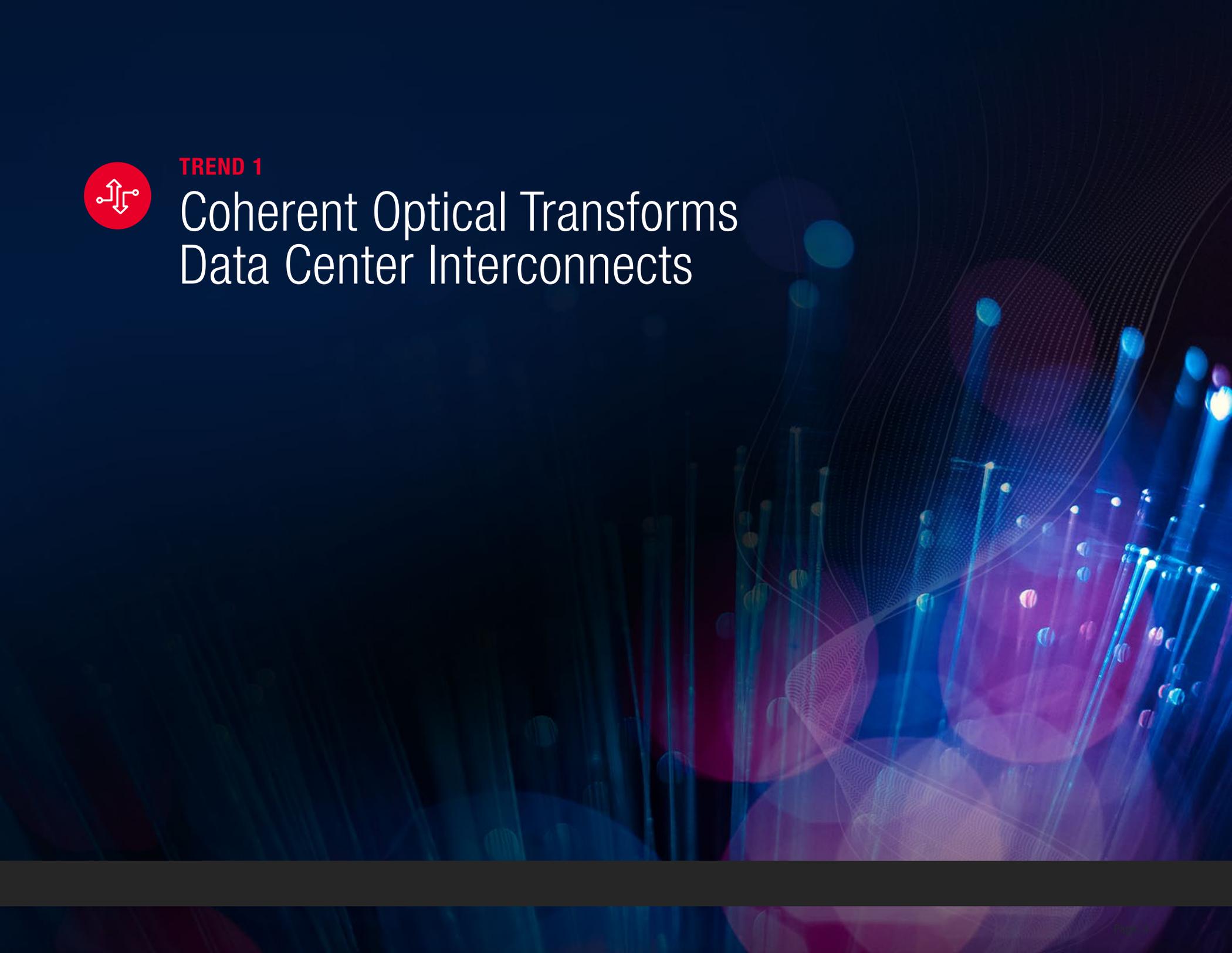
Contents





TREND 1

Coherent Optical Transforms Data Center Interconnects



TREND 1

Coherent Optics Enable Faster and More Efficient Data Transmission

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.

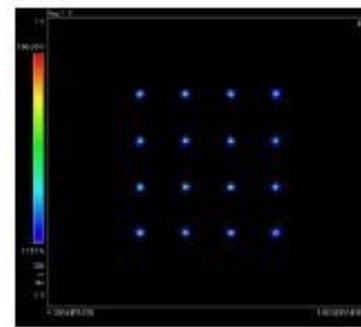
Coherent Optics Increase Spectral Efficiency

Coherent optics enable higher rates of data transmission over the same fiber lines 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 significant fiber optic cable capacity increases thanks to increased spectral efficiency.

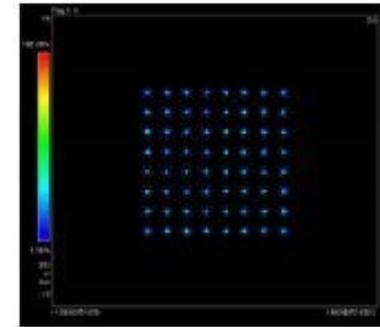
Optical component and device manufacturers face new test challenges. Test equipment that generates and analyzes 16-QAM signals at 60 gigabaud (Gbaud) with optical impairments enables manufacturers to test their components and devices for 400G applications. Multi-terabit-per-second dense wavelength division multiplexing (DWDM) networks are needed to support 400G applications. Optimizing designs for next-generation DCI requires accurate testing of new 400 Gb/s optical coherent components and transceivers.

Coherent optical communications enable capacity gains through three key variables:

- Higher-order modulation
- Higher symbol rate
- Better spectral efficiency



16-QAM
4 bits/symbol



64-QAM
6 bits/symbol

Figure 1. Constellation points of QAM-schemes distributed in a square lattice



TREND 2

New Standards Drive Next-Generation DCI

TREND 2

New Standards Employ Coherent Optical Technology for DCIs

Distributed data centers need to communicate with each other to share data, balance workloads, provide backups, and scale capacity when needed. In a campus or metropolitan area, distributed data centers need to increase interconnection capacity significantly.

Using coherent optical transmission technology, DCIs can transport terabytes of information across a single fiber line, significantly reduce power consumption, and provide flexibility to address growing data demands. The Optical Internetworking Forum (OIF) and the Institute of Electrical and Electronics Engineers (IEEE) continue to work on new standards, such as 400ZR, 100GBASE-ZR, and 400GBASE-ZR, that will enable 100G and 400G DCI speeds to reach up to 80 km.

What is 400ZR?

The OIF is developing the 400ZR networking implementation agreement (IA) for pluggable digital coherent optical (DCO) modules. The 400ZR standard will enable the transmission of multiple 400 gigabit Ethernet (GE) payloads over DCI links up to 80 km using 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 QAM at approximately 60 Gbaud. This is only possible using coherent detection and advanced digital signal processing (DSP). The 400ZR IA will reduce the cost and complexity of high-bandwidth data center interconnects and promote 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.

What is 400GBASE-ZR and 100GBASE-ZR?

In 2018, the IEEE approved the 802.3ct project. IEEE 802.3ct will leverage the OIF's 400ZR IA to create the 400GBASE-ZR standard for 400 Gb/s transmission on a single wavelength up to 80 km in a DWDM system. A DWDM system involves multiplexing data signals from different transceivers using a single optical fiber.

For 100GBASE-ZR, the IEEE leverages the International Telecommunication Network's (ITU's) work for a 100 Gb/s transmission standard that uses a dual-polarization differential quadrature phase shift keying (DP-DQPSK) modulation scheme, as well as CableLabs full duplex coherent optics specification.

What is 400ZR Plus and 400ZR Minus

Beyond the interoperable 400G mode, 400ZR transceivers will support additional modes to increase the range of addressable applications. Those modes are referred to as 400ZR+ and 400ZR-. The plus means that the module consumes more power than the 15W required by the IA (and some of pluggable form factors), enabling the modules to use more powerful signal processing techniques to span distances of several hundreds of kilometers. On the other hand, the minus refers to the modules supporting lower speed modes, like 300G, 200G, and 100G, which provide valuable flexibility to network operators.

Industry Benefits of 400ZR

Although 400ZR technology is in its infancy, it is expected to significantly impact a number of industries once rolled out:

Hyperscale data centers/cloud service providers

A large part of the demand for high-speed data center networking comes from hyperscale data centers owned by companies such as Google, Amazon, Microsoft, and Facebook, as well as Baidu, Tencent, and Alibaba. These massive data centers need to increase connection speeds to accommodate the exponential growth in cloud services, IoT devices, streaming video, and more. Developments in DCI and networking technology help cloud and hyperscale data centers adapt to the ever-increasing network need for more bandwidth.

Distributed campuses and metropolitan areas

For many organizations, building a hyperscale data center is not feasible. This is especially true for distributed campuses and metropolitan areas, where managing multiple data centers is the new norm because of space constraints and disaster recovery requirements. Distributed data centers need to communicate with each other to share data, balance workloads, provide backups, and scale data center capacity when needed. 400ZR technology will enable high bandwidth interconnects essential to connect distributed data centers.

Telecommunications providers

Like data centers, telecommunications companies grapple with the explosive growth in networking traffic, as consumers demand higher connectivity at home, in the office, and 5G mobile. Applications such as streaming video, online video games, videoconferencing, and online backup services will benefit from 400 Gb/s speeds enabled by 400ZR.

The 400ZR standard will allow telecommunications companies to backhaul residential traffic. When operating at 200 Gb/s, using 64 Gbaud signaling and QPSK modulation, 400ZR increases the reach of high-loss spans. For 5G networks, 400ZR offers mobile backhaul by aggregating multiple 25 Gb/s streams.



Testing 400G Coherent Optical Components and Transceivers

Arbitrary waveform generator and optical modulation analyzer

In telecommunications and data communications, it is important to optimize coherent optical transmitters for reach, spectral efficiency, and power consumption. Performing common measurements, such as error vector magnitude (EVM), IQ offset, IQ imbalance, quadrature error, and skews, is complex in coherent optical signal analysis. To thoroughly test an optical transmitter, it is necessary to stimulate it with complex waveforms using different modulation formats and data sources. It is also important to de-skew and pre-distort input signals to account for any linear impairments in the test setup and measure the true performance of the optical transmitter. A flexible and scalable test solution, comprised of an arbitrary waveform generator (AWG) and an optical modulation analyzer (OMA), ensures fast and accurate testing of optical transceivers.

Testing 400G coherent optical transceivers and its sub-components requires test equipment capable of clean signal generation and analysis. The test equipment also requires a measurement bandwidth of at least 40 GHz. Both the stimulus and analysis side need many different modulation schemes and pulse shapes on four synchronized channels for dual-polarization in-phase and quadrature (IQ) signals. This is provided by instruments based on high-speed digital-to-analog converters (DAC) and analog-to-digital converters (ADC). Software tools that provide a comprehensive set of general-purpose algorithms, including interfaces to work with self-developed specialized algorithms, increase test efficiency.

Coherent optics device test

Optoelectrical components used in coherent optical transmission systems have unique test challenges. For example, to test dual-polarization IQ modulators and intradyne coherent receivers, it is necessary to measure the electrical-to-optical (E/O) and optical-to-electrical (O/E) conversion efficiency, respectively. Characterizing coherent optical devices requires measurements such as bandwidth, gain, imbalances, group delay, and skew. These measurements are complex and time-consuming. Selecting the right test equipment saves valuable time and reduces costs for the development and qualification of coherent optical devices.

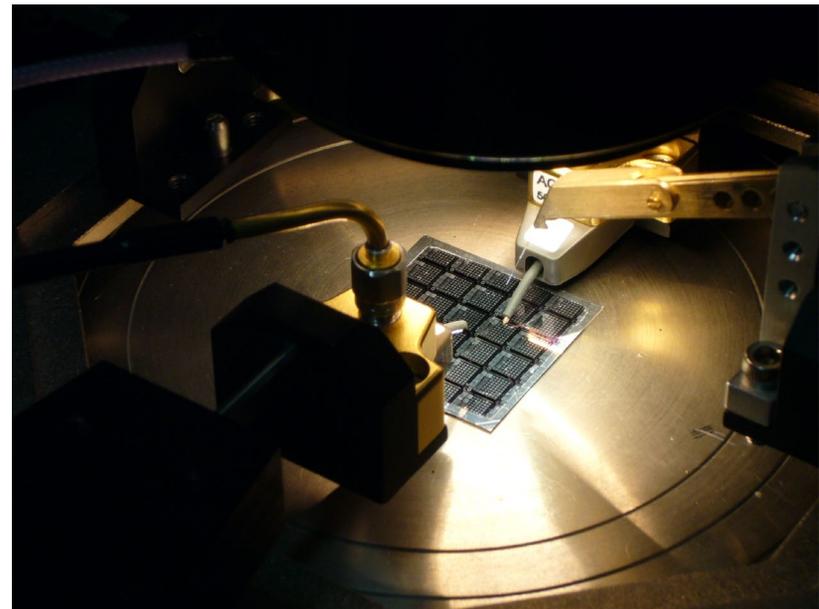


Figure 2. Optical coherent device test



TREND 3

Integrated Photonics Enable Terabit Speeds

TREND 3

Integrated Photonics Revolutionize Data Center Interconnects

Integrated photonics is highly beneficial in a range of distances, from short range chip-to-chip to local area networks (LANs) and wide area networks (WANs) with ranges beyond 100 km. For telecommunications, integrated photonics technology increases the amount of data transmitted over the same fiber lines without the need to expand fiber cabling. For data center interconnects at distances typically less than 80 km, integrated photonics promises higher capacity and more efficient data transfer.

Integrated photonics technology continues to evolve. It is not yet ready to replace entire electrical-based systems because of insufficient standards and the inability to easily integrate into data center architectures. Instead, hybrid photonic and electrical systems will coexist for data center interconnects and long haul fiber transmissions. To overcome the limitations of PICs, progress in these and other optical components depends on new foundries, commercial modeling tools, and photonic test capabilities.

PIC fabrication involves wafer-scale technology and lithography to create three dimensional images of the circuit on substrate materials such as silicon, silica, or lithium niobate. For example, in silicon photonics, photonic functions are implemented directly on silicon chips, enabling inexpensive, mass-produced optical components through photonics integration.

Silicon Photonics Increase Capacity and Save Energy

Communication networks and data centers need to manage higher volumes of traffic and provide faster response times than ever before. Consumers and businesses add billions of devices to the internet each year. Our insatiable hunger for real-time data and analytics means 100G simply will not be able to keep up. Data center operators need to evolve the speed of their networks from 100G to 400G. Similarly, data centers within a campus or metropolitan area need to significantly increase connection capacity between each other to deliver faster and more efficient DCI transport.

Silicon photonics technology delivers significantly higher and more efficient bandwidth transmission within and between data centers. Silicon photonics technology involves creating photonic devices with new optical components on a silicon substrate. Optical-based systems use light to transmit data much faster and more efficiently over fiber optics lines compared to systems that transmit data with electrical signals. Multilevel pulse amplitude modulation (PAM4), advanced optical modulation formats like QAM and orthogonal frequency-division multiplexing (OFDM), and coherent detection techniques improve spectral efficiency.

Moore's Law and Photonic Integrated Circuits

Moore's Law states that the number of transistors placed onto silicon chips within integrated circuits doubles about every two years. For many years, Moore's Law held true. However, transistor size is now approaching the size of an atom, and the laws of physics hinder further size reductions. The latest circuit technology, which produces nanometer-sized transistors, is highly complex and expensive. Traditional silicon chip technology struggles to keep pace with increasing processing speeds needed by data centers and high-performance computing technology.

PICs integrate multiple photonic functions in a single device in a very compact way, like an electronic integrated circuit, using light instead of electricity to transmit signals. PICs provide numerous advantages over conventional circuits including higher bandwidth, expanded wavelength division multiplexing, increased multiple switching, smaller size, lower power consumption, and improved reliability. PICs are optical engines that move the optical interfaces closer to the digital processors avoiding long energy consuming PCB board traces.

Hybrid Photonics Technology

Since photonic technology is still in development, full photonic systems with PICs have not yet completely replaced the large, complex infrastructures found in electronic systems. Instead, a hybrid approach that includes a high-level integration of electronics and optics provides new functionalities and benefits. There are now silicon chips that include optical transmitters and receivers that work in conjunction with electrical circuits.

Hybrid photonics are now in widespread use in data centers and long-haul communication networks. These systems use specialized PICs to convert photonic data into electrical signals for processing, as data networks are primarily electrical systems. New developments in photonic switching components allow switching to occur at the speed of light, which is thousands of times faster than conventional switching technology.

Within the next five to ten years, photonic technology will progress to the point when photonic systems and components can replace entire electronic systems. However, current limitations require supplementing and replacing specific components in electrical systems, including the integration of both PICs and integrated circuits (ICs), switches, and more into electrical systems.



SUMMARY

The Future of Data Center Interconnects

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 today.

FOR MORE INFORMATION

To find out how Keysight solutions can help you address your optical and photonic test challenges, check the following links:

- 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 solutions](#)

