# The path to 100G

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## Introduction

The past 5–10 years have seen a tremendous increase in Internet bandwidth requirements, driven by high-capacity business data services, increasingly powerful 3G/4G wireless smartphones and popular, video-intensive websites such as YouTube, Netflix and Hulu. This exponential increase in Internet traffic is stressing the capacity of carrier optical transport networks. In recent years, most metro and backbone optical transport networks have been built based on WDM architectures. Deploying WDM systems allowed carriers to tap enormous capacity by carrying multiple wavelengths over a single fiber. For carriers, this means a significant cost savings compared to the cost of deploying single-channel networks or overlaying multiple networks for each service offering. However, even 40-channel WDM systems operated at 10 Gbps per wavelength are quickly reaching capacity on heavily used routes. Carriers need a cost-effective solution for expanding capacity, while at the same time reducing the cost per bit transported. To meet immediate traffic growth, many vendors have developed 40 Gbps transponders and muxponders that can be used with existing deployed WDM networks, offering a 4× increase in network capacity. While 40G offers immediate benefits, ever-increasing data growth requires deployment of even higher-capacity WDM systems (e.g. 88 channels) with higher data rates (100 Gbps) utilized on each wavelength.

Unfortunately, as optical speeds increase, it becomes increasingly difficult to overcome optical impairments and still achieve acceptable performance. The industry is starting to solve these 100G transmission problems and develop key 100G optical components needed to implement and deploy 100G in real-world networks.

## Solving technology issues

Optical signals in a fiber are exposed to a number of destructive optical impairments including Chromatic Dispersion (CD) and Polarization Mode Dispersion (PMD). These impairments distort the integrity of the original optical signals; limiting the distance they can be transported. With speeds up to 10 Gbps, the industry has found methods to solve and compensate for these optical impairments. Unfortunately, the optical impairments get much worse and much more difficult to compensate for as speeds increase, as shown in Figure 1. Innovative techniques are required to transmit 100G over metro, regional and long-haul optical networks.

| Transmission Impairment Sensitivity | | | |
|---|---|---|---|
| | 10 Gbps | 40 Gbps | 100 Gbps |
| CD sensitivity | 1 | x 16 | x 100 |
| PMD sensitivity | 1 | x 4 | x 10 |
| ONSR requirement | 1 | + 6 dB | + 10 dB |
| Optical band-pass sensitivity | 1 | x 4 | x 10 |
| Sensitivity to fiber nonlinearity | 1 | x 4 | x 10 |

**Figure 1: Optical impairments at increased speeds**

### Modulation – pushing more bits at once

Given that optical performance impairments worsen with increasing speeds, one way to solve this problem is to send multiple bits of data down the fiber simultaneously, reducing the overall symbol rate. Encoding multiple bits of information into a symbol is known as "modulation."

Up to 10 Gbps, optical systems use simple on-off keying (OOK) to represent the digital 1s and 0s. A "1" is the laser light turned on, and a "0" is the laser light turned off, so one bit of information is transmitted with each optical symbol. This is a very simple and cost-effective modulation technique, and it has worked exceedingly well in optical networks up to 10 Gbps.

At higher data rates, more sophisticated modulation techniques are required to minimize the effects of optical impairments. At 100G, the industry has standardized on a modulation scheme known as DP-QPSK, as shown in Figure 2. A DP-QPSK modulator is relatively complex and costly to implement, but it allows four bits of data to be encoded and sent as one optical symbol. With the lower optical symbol rate, 25 Gbaud as opposed to 100 Gbps, optical impairments are somewhat easier to compensate.

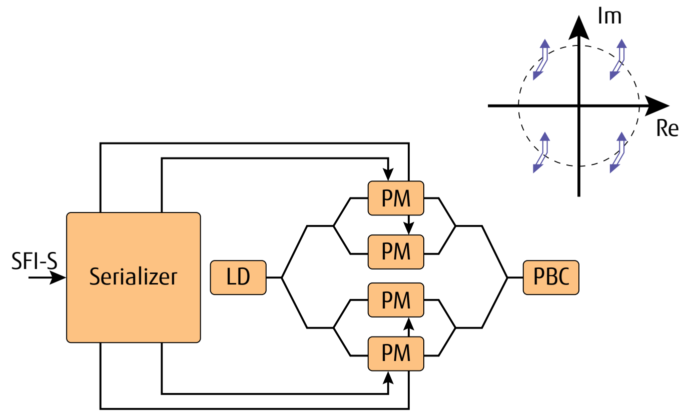


**Figure 2: 100G modulator based on DP-QPSK**

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## Coherent receivers – recovering the bits

Like 100G transmitters, 100G optical receivers are more complex due to the complex DP-QPSK modulation scheme. Up to 10 Gbps, a simple photodetector converted the incoming photons to digital "1" or "0" signals, a very simple and relatively low-cost approach. With the introduction of 100G DP-QPSK modulation, a much more complex optical receiver is required, as shown in Figure 3.

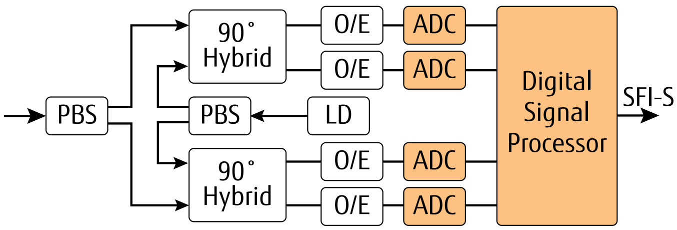


**Figure 3: 100G coherent receiver**

The additional complexity does have a few benefits. The high-speed ADCs and DSP allow optical impairments, such as CD and PMD, to be compensated electronically within the DSP, offering a larger range of compensation and finer control. The DSP enables a number of additional compensation and measurement techniques to be implemented that simply weren't possible with the optical-only photodetector receivers used at 10 Gbps and lower rates. For most vendors, these algorithms are the real secret sauce of their 100G optical units, and they differentiate the performance levels of these units compared to their competitors.

## 100G optical components

The designs for 100G DP-QPSK transmitters and 100G coherent receivers have been known for some time, as shown in Figure 4. However, it's taken the optical components industry until 2010 to develop and integrate these conceptual building blocks into actual optical components that can be used to implement 100G transponders.

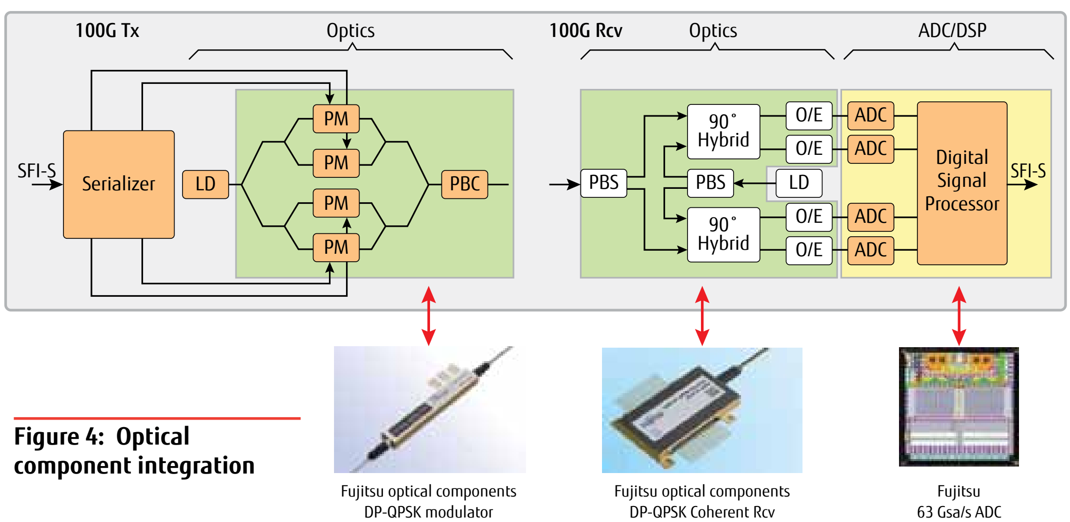


**Figure 4: Optical component integration**

The industry has gone one step further by defining a standard 100G transceiver module called an MSA module. The 100G MSA is an industry-wide standard that defines the physical size, pinouts, performance and power of the module. By standardizing on a common 100G transceiver, the industry should benefit from larger overall volumes, lower pricing and a wider choice of suppliers.The MSA module contains the optical components shown in Figure 5, including a DP-QPSK modulator, coherent receiver and ADC/DSP. These 100G MSA modules are expected to become generally available in mid-2011.

**Figure 5: MSA module**

## 100G applications

At a high level, the insatiable demand for high-speed data services, particularly Internet video services, is driving the need for higher network capacities. Within optical transport networks, this demand for additional bandwidth is resulting in a couple of primary 100G applications:

- Backbone capacity expansion
- Router Interconnect

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## Backbone capacity expansion

Wavelengths across an LH or ULH part of the network are at a premium, due to the expense of the long-haul wavelengths as well as the distances traveled. For example, adding overlay capacity along a Chicago-to-Atlanta route can be prohibitive due to the long distances and the number of OADM and ILA nodes required. Even worse is a situation in which a carrier is out of capacity and out of spare fibers along the route, since the only alternative is a very expensive project to dig, pull and construct new fiber along the entire route – easily a multimillion-dollar endeavor.

To ensure these wavelengths are fully utilized, most metro areas have aggregation platforms that combine lower-rate services into large, full 10G pipes for hand-off to the backbone network.

Due to the cost of the long-haul wavelengths, upgrading backbone networks will be one of the first applications for 100G muxponders and transponders. By adding 100G muxponders at the aggregation points, carriers can expand their backbone capacities by a factor of 10 without the cost of additional WDM overlay networks or fiber construction.

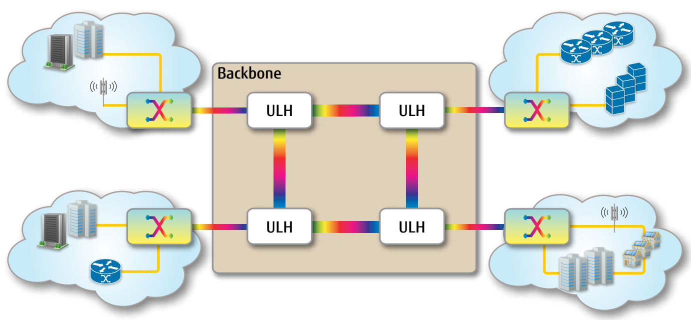


**Figure 6: 100G backbone capacity expansion**

## Router interconnect

The secondary 100G application is for router interconnection as shown in Figure 7. Today, many routers utilize multiple 10G connections across a network, as shown on the left side of the diagram. As the number of 10G router interconnections increases, router costs go up, router efficiency declines and operational complexity increases for the carrier. At a certain point, it makes more sense to switch to a single router port running at 100G. As 100G router interfaces become available, carriers will start to see more requests for 100G private-line service to interconnect these high-speed routers. The router interconnect application occurs across metro networks, regional networks and national backbone networks.

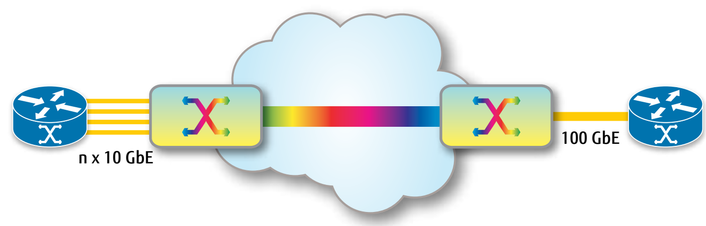


**Figure 7 – 100G router interconnect/private-line service**

## Summary

Carrier networks are facing tremendous increases in bandwidth transported, due to a combination of higher-speed business data services, mobile smart phones and Internet video traffic. At the same time, these networks are under immense pressure to lower their cost per bit transported. The solution is to carry more bits per wavelength by utilizing 100G, resulting in better network utilization, higher spectral efficiencies and lower overall operating costs. Higher optical speeds, beyond 10 Gbps, result in significant performance penalties due to optical impairments, such as chromatic dispersion and PMD. Advanced modulation techniques and coherent receivers overcome these optical impairments and limitations, allowing 100G transponders and muxponders to be deployed over existing networks. In 2010, the optical component industry responded with 100G integrated optical components, which enable the introduction of 100G transponders and muxponders in 2011. Initial 100G applications will likely be focused on increasing capacity across backbone networks and 100G router interconnections.

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| Acronym | Description |
| --- | --- |
| 3G | Third-generation wireless technology |
| 4G | Fourth-generation wireless technology |
| ADC | Analog-to-Digital Converter |
| CD | Chromatic Dispersion |
| DP-QPSK | Dual Polarization-Quadrature Phase Shift Keying |
| DSP | Digital Signal Processor |
| ILA | In Line Amplifier |
| LH/ULH | Long Haul/Ultra-Long Haul |
| MSA | Multisource Agreement |
| OADM | Optical Add/Drop Multiplexer |
| OOK | On-Off Keying |
| OSNR | Optical Signal-to-Noise Ratio |
| OTN | Optical Transport Network |
| PMD | Polarization Mode Dispersion |
| Packet ONP | Packet Optical Networking Platforms |
| ROADM | Reconfigurable Optical Add/Drop Multiplexer |
| WDM | Wavelength Division Multiplexing |



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