Recent Trends in 100G Module and Subsystem Development for Long Haul DWDM Applications

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Abstract
We review recent trends and progress in the area of 100G module and subsystem development for long haul DWDM applications and explore how the 100G market will likely differ from that experienced at 40G.

Introduction
100G long haul DWDM transmission has been an area of intense research and development over the past several years, with commercial system availability generally expected within the next couple years. In an effort to predict the requirements for these new 100G DWDM interfaces we briefly review the evolution of the 40G market, identifying probable similarities as well as areas that will likely differ for the 100G market.

Commercial 40G deployments to date have been driven by the need for connecting 40G router interfaces across the WAN. Core routers prefer the highest possible data rate for interconnect due to the efficiencies gained relative to inverse multiplexing and link bundling [1]. The emergence of these 40G core router interfaces necessitated 40G transport over the WAN. For first generation 40G transport systems, the network infrastructure was determined by the state of the art transport products of the day. These were primarily 10G optimized systems. There existed a need, therefore, for the 40G channels to flexibly operate over these existing 10G optimized systems. This put the following restrictions on these 40G channels: (1) Channel spacing and optical filter compatibility, (2) Launch power compatibility, (3) Chromatic dispersion (CD) compatibility (±800ps/nm for core links), (4) Polarization Mode Dispersion (PMD) tolerance (10ps mean Differential Group Delay, or <DGD>), (5) Negligible impact on existing (10G) channels, as they are carrying revenue generating traffic, (6) Reach (1,500km marks the point of diminishing returns in regards to reducing O-E-O regeneration costs in North American core networks). Further complicating these 40G upgrades, transport networks were evolving from point to point links to reconfigurable mesh based networks, facilitated through deployment of Reconfigurable Optical Add Drop Multiplexer (ROADM) nodes. The net effect was the need for 40G solutions that could tolerate the limited optical bandwidth available for the channel.

In an attempt to meet the evolving 40G market requirements with available component technology, many modulation formats were offered with varying success. The more popular introductions to the market included Non-Return-to-Zero (NRZ), Carrier-Suppressed Return-to-Zero (CSRZ), Phase Shaped Binary Transmission (PSBT), Differential (Binary) Phase-Shift Keying (DPSK), Differential Quaternary Phase-Shift Keying (DQPSK), and coherent Polarization-Multiplexed Quaternary Phase-Shift Keying (PM-QPSK). This presented significant challenges to component suppliers, as each format had its own component requirements. Adding to the market fragmentation were varying requirements for the high speed electrical interfaces. These included co-planar, V-connector (coaxial), and GPPO (coaxial) interfaces in both single-ended and differential variants. This highly fragmented component market resulted in general supply chain weakness. In contrast, the 100G market is expected to experience significantly less fragmentation due to the limited number of modulation formats capable of addressing the market requirements outlined above. Reduction in the number of modulation formats being pursued by systems companies results in less fragmentation seen by component suppliers addressing the market. Focusing of the market on a limited number of modulation formats provides confidence in the entire supply chain and paves the way for implementation

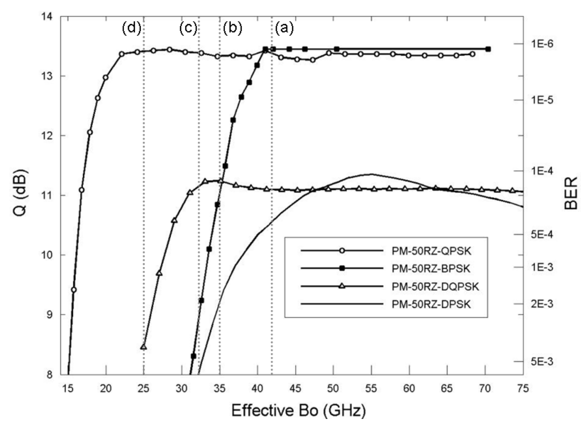

Fig. 1. Simulated Q (left axis) and BER (right axis) versus effective optical bandwidth (B_0) for coherent and direct-detection polarization multiplexed binary and quaternary phase shift keying formats. All modulation formats have a line rate of 110 Gbps. The OSNR is 17 dB (reported in 0.1 nm resolution bandwidth). Direct-detection formats are indicated by a "D" (e.g. PM-50RZ-DQPSK). Also indicated are typical effective optical bandwidths for (a) one pair, (b) 2 pairs, (c) 3 pairs, and (d) 8 pairs of 50GHz optical filters.

agreements (IAs) and multi-source agreements (MSAs), further reducing market fragmentation.

Moving from 40G to 100G

If one applies the same requirements and adoption scenarios to 100G that made 40G a commercial success, the challenges to the systems designers grow significantly and modulation format options become limited. One candidate, coherent PM-QPSK, has been attracting considerable attention for 100G long haul optical interfaces for its OSNR performance (>2dB improvement over direct detection formats), spectral efficiency, and tolerance to inter-symbol interference (see, for example, [2]). The later two are illustrated by its tolerance to narrow optical filtering compared to direct detection formats, as shown in Figure 1 for the conditions detailed in [3].

As it is doubtful the market will embrace new transmission technologies that do not improve the total capacity of transmission links, it is taken as a

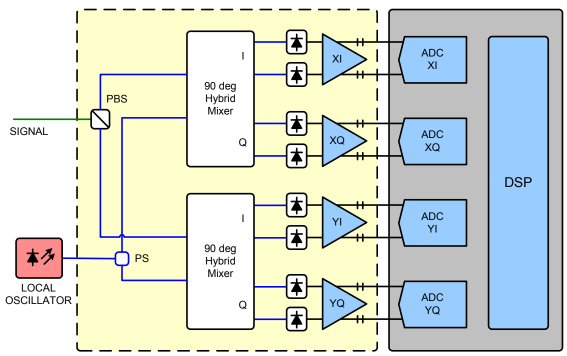

Fig. 2: Schematic for a typical coherent PM-QPSK reciever utilizing two optical 90º hybrids and balanced photo-receivers. PBS and PS stand for polarization beam splitter and polarization maintaining splitter, respectively. The dashed outline indicates functionality being specified in the OIF's 100G DWDM Integrated Photonics project (project OIF-0044).

requirement that 100G channels operate on a 50GHz grid, which is the de facto standard for long haul DWDM systems. This improves spectral efficiency to 2bps/Hz, but can result in effective optical bandwidths as low as 25GHz for the 100G channel over the link. As evidenced in Figure 1, PM-QPSK is clearly able to meet this requirement.

PM-QPSK is also capable of compensating for large amounts of CD and PMD, the amount dictated by the number of taps in the digital filter (see, for example, [4]). It is also noted that PM-QPSK is able to meet the market requirements for other parts of the network as well, notably those of metro networks, due to its excellent filtering, CD, and DGD tolerances.

While able to meet the objectives via its increased symbol interval and powerful digital signal processing, PM-QPSK has a considerably more complex optical architecture than previous generations of transmission products. This is exemplified in Figure 2 for a typical PM-QPSK receiver. The challenge is not in the optical and photonic technology itself, as the key pieces already exist (e.g. addressing the existing 40G market). The challenge is instead to reduce the size and cost of using the required technology. Improvements in cost can be realized not only by reduction in total component cost, but also from improved manufacturability of the modules and systems utilizing these components. Integration of these optical functions is viewed by the authors as a key requirement for ensuring market viability. This view is shared by many in the industry, as evidenced by the large support of efforts in industry forums such as the Optical Internetworking Forum (OIF), where component and module suppliers are involved in defining key aspects of practical implementations [5]. These efforts target IAs and MSAs based on agreement by a critical mass of suppliers and customers of the technology. For photonics component customers, this provides a secure supply chain fostering competition based on performance, size, cost, etc. instead of being dictated by availability of proprietary interfaces. For component suppliers, it opens the door for their product (and future iterations of their product) to be used across a much larger customer base than can be achieved with proprietary interfaces.

Summary

The 40G DWDM system, module, and component markets experienced significant fragmentation in their attempt to broadly address market requirements. However, this is not expected at 100G. In order to meet the market requirements at 100G, system designers are moving beyond direct-detection formats and are utilizing the power of coherent detection and digital signal processing for mitigation of channel distortions. Coherent modulation formats, such as PM-QPSK, are able to broadly meet 100G market requirements. Due to the increased complexity of the optical architecture in coherent designs, integration of optical functions is viewed as a key enabler for large scale manufacturability of this new generation of transmission products. Industry forums, such as the OIF, are actively working towards implementation agreements to minimize market fragmentation in the 100G module and component market.

References

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