

Photonic Integration

In the world of microprocessors, we have seen tremendous increases in computational power with simultaneous decreases in cost and power consumption resulting from integration and standardized semiconductor manufacturing processes. The integration of optical components and functions into large scale photonic integrated circuits (PIC) and the use of semiconductor manufacturing processes for PICs has been pioneered by Infinera, and shows significant benefits when integrated into a DWDM system. Infinera's integration approach, first on the DTN at 100G and now on the DTN-X at 500G per pair of chips, enables significant power, space and cost savings for long haul DWDM applications.

Transforming the DWDM Market

In 2005, when Infinera released the DTN, a DWDM platform based on a 100G PIC operating with 10 channels of 10 Gb/s Intensity Modulation with Direct Detection (IM-DD), the effect was a radical transformation of the marketplace. Within just 18 months of the first customer shipments, the Infinera DTN had taken the #1 market position in the 10G North American

market, and gradually built upon this 10 Gb/s leadership over the subsequent eight years. In addition to the direct benefits of photonic integration listed above, the DTN was the world's first "Digital ROADM" platform. The smaller size and lower power consumption of a PIC-based solution provided the headroom for OTN switching to be integrated into every DTN, which transforms DWDM from an "analog," all-optical technology to a digital technology. Digital networks are easier to deploy and manage, and Infinera customers discovered they could use "time as a weapon" to deliver services faster, and to better compete and win against service providers who were still using conventional analog DWDM technology.

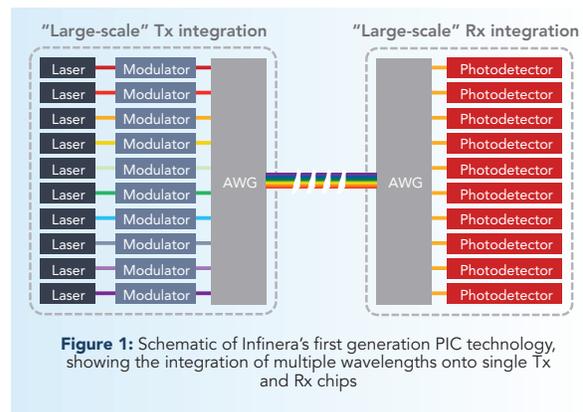


Figure 1: Schematic of Infinera's first generation PIC technology, showing the integration of multiple wavelengths onto single Tx and Rx chips

The Move to Coherent PIC Technology

As the 10G market matured, internet traffic continued to grow. Service providers demanded increases in fiber capacity by moving DWDM channels from 10 Gb/s to 40 Gb/s and more importantly 100Gb/s channels and beyond. The key to this evolution has been the move from IM-DD modulation to phase-based modulation with coherent detection (see "[Coherent DWDM Technologies](#)").

At 100 Gb/s per channel, coherent technology allows a tenfold increase in spectral efficiency, while delivering the same or even better optical reach compared to 10 Gb/s per channel IM-DD. But the price is a massive increase in the component complexity of both the transmit and receive optical circuits—100 Gb/s coherent has a 20x increase in component count over a 10Gb/s channel. Furthermore, many customers with large scale networks were asking to drive down operational and capital costs and requesting bandwidth deployable in larger increments of 500G, which further exacerbates the component count.

The answer to both of these problems was to develop large scale coherent PIC technology that could create a true coherent "super-channel" using just a pair of chips—one for transmit and one for receive (See: "[Super-Channels: DWDM Transmission at 100Gb/s and Beyond](#)"). As shown in Figure 2, a super-channel combines multiple, lower data rate carriers into a higher speed composite channel that is implemented on a single line card, and is treated as a single unit of operational capacity.

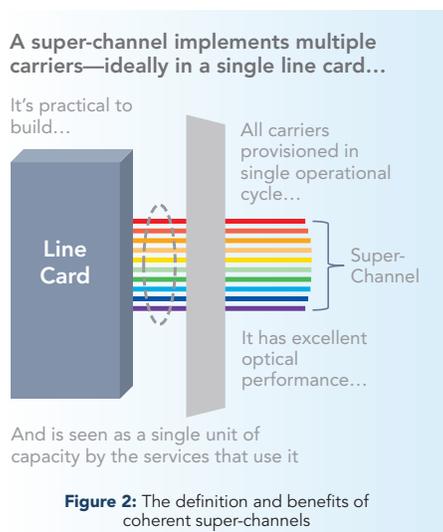


Figure 2: The definition and benefits of coherent super-channels

Infinera's DTN-X supports 500 Gb/s super-channels based on next generation coherent 500 Gb/s PICs, which integrate over 600 optical functions into just two optical chips. This PIC-based approach is combined with a high capacity electronic backplane that is already capable of supporting the next generation of terabit PIC line cards, and linking them together using a non-

The Right Material for the Job

Infinera's PIC technology optimizes the manufacturing process by choosing a single material—Indium Phosphide (InP)—with which it is possible to fabricate all of the necessary optical functions on a single semiconductor chip. This "monolithic" integration maximizes Infinera's ability to scale production, while at the same time delivering unprecedented component reliability. Note that, while other optically active materials are available (e.g. Silicon), none of these materials offers the same advantages as InP when applied to the long-haul DWDM market.

blocking OTN switching fabric. In other words, the DTN-X takes all of the network level benefits of the DTN and scales them to the terabit age.

Cashflow-Efficient Instant Bandwidth™

The reception for the DTN-X and its 500 Gb/s super-channels has been phenomenal. However there are service providers that would like to take advantage of PIC economics but that have lower levels of demand, and whose ideal unit of scaling might be anything from 200 Gb/s to 400 Gb/s. For those customers Infinera has developed a solution called Instant Bandwidth™. With this solution, a customer is able to deploy a full 500 Gb/s super-channel solution, and complete all of

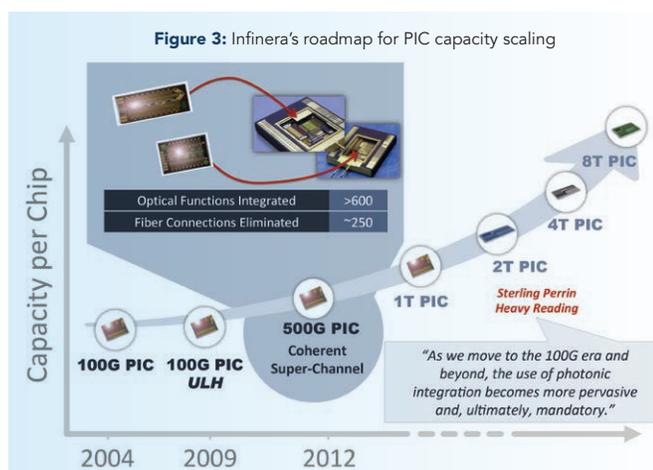
the wavelength planning, but only software-activate as much of this capacity as they need in the short term (in various units including 100 Gb/s). When they need more capacity, they simply request it via the Infinera DNA management system or via other convenient alternatives, and the new capacity is activated, and ready for revenue-generating services within a matter of minutes.

Instant Bandwidth offers permanent activation of line side capacity. Infinera's new Time-based Instant Bandwidth feature enables network operators to activate pre-deployed bandwidth in 25 Gb/s, 37.5 Gb/s, 50 Gb/s or 100 Gb/s increments for a short period of time. This bandwidth deactivates at the end of a customer-specified time period. Before this bandwidth is deactivated, network operators receive a notification in advance about its expiry, allowing them to plan their temporary capacity requirements ahead of time. Time-based Instant Bandwidth helps operators achieve high levels of flexibility to manage strategic as well as event driven short-term high capacity bandwidth needs. In addition, it can be used as a powerful tool to temporarily activate bandwidth over an alternate route for a short period of time to handle route failures.

Infinera's Instant Bandwidth and Time-based Instant Bandwidth capabilities take advantage of the vast pre-deployed optical network capacity enabled by Infinera's PIC technology to help operators build truly dynamic transport networks.

Continuously Scalable PIC Technology

Figure 3 shows Infinera's vision of how PIC technology will continue to scale exponentially, as measured by the data capacity per chip. Today's DTN-X has a backplane which supports 1 Tb/s per slot and already supports the next generation of terabit PIC, which Infinera demonstrated in early prototype form already. We see a continuous technology pathway that will allow PICs to scale to support 2 Tb/s, 4 Tb/s and even greater capacity per line card in the future. This ability to scale is the best chance that service providers have to keep pace with bandwidth demands that show no signs of slowing down.



Summary

Large-scale PIC technology has had a dramatic effect on the long-haul DWDM market. In addition to the expected advantages of component integration (smaller footprint, lower power consumption and higher reliability), PICs have enabled a digital approach to DWDM that enables service providers to use time as a weapon to compete more effectively. PIC technology also makes the deployment of capacity even more cashflow-efficient thanks to commercial innovations such as Instant Bandwidth. Finally, Infinera's unique PIC capabilities will continue to scale so that service providers can keep pace with the exponential growth in network demand.



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