Enabling Technologies for Scalable ROADMs (invited)

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Abstract: Continued ROADM capacity scaling will require WSS devices in quad and octal configurations, with higher port counts, that operate across wider bands (C and L). Introduction of hybrid fiber/wavelength switching architectures for multi-rail will follow.

1. Introduction

Since their introduction into commercial use more than twenty years ago, ROADMs (Reconfigurable Optical Add/Drop Modules) have evolved to become critical elements in all long haul and metro DWDM networks to provide scalability and network flexibility. The key element in the ROADM is the wavelength selective switch (WSS), which in combination with node optical amplification and channel monitoring, allows wavelengths to be selectively switched and controlled through the node and to local transceiver termination. Through this history, ROADMs have gone through many generations of improvement, moving from simple wavelength blockers controlling through traffic for 2-degree nodes, to the introduction of LCOS-based flexible spectrum WSS [1] to allow flexible add-drop switching to achieve true end-to-end network provisioning and route reassignment.

2. Extended band WSS and WSS arrays

As the unrelenting pace of traffic growth continues, now fuelled by cloud and emerging ML/AI applications, ROADMs will need to continue to evolve to accommodate and enable ongoing network scalability. As transmission technologies approach Shannon's limit, networks will increasingly saturate the C-band and will require additional spectrum. In support of this emerging requirement, WSSs are being developed which can switch across a broader spectrum, initially integrated C and L band in a single device and potentially beyond into the O, S, E and U bands. While this spectral expansion of operation of the WSS can be readily achieved by reducing the wavelength dispersion of the grating within the WSS, maintaining high resolution passband shaping within the WSS is challenging and further innovations in WSS design are required to expand the spectrum without compromising performance or reintroducing cost.

But the evolution beyond C and L to wide band transmission will be hampered by the lack of cost-effective optical amplification in the S, O, E and U bands. Significant research efforts are being made in new doped-fiber strategies (e.g. Bismuth), new pump lasers and alternative amplifier designs but it is likely that this work will not yield cost-effective field-ready products before C and L band saturation is reached in significant parts of the network and as a result, multi-rail (i.e. parallel fiber pairs) deployments are expected to become the norm. WSSs will need to not only support integrated C and L bands but will need to evolve beyond current twin configurations to quad and potentially octal to maintain cost effective scalability. This can be done with WSS designs which project multiple switched spectra onto a single LCOS as shown in Figure 1.

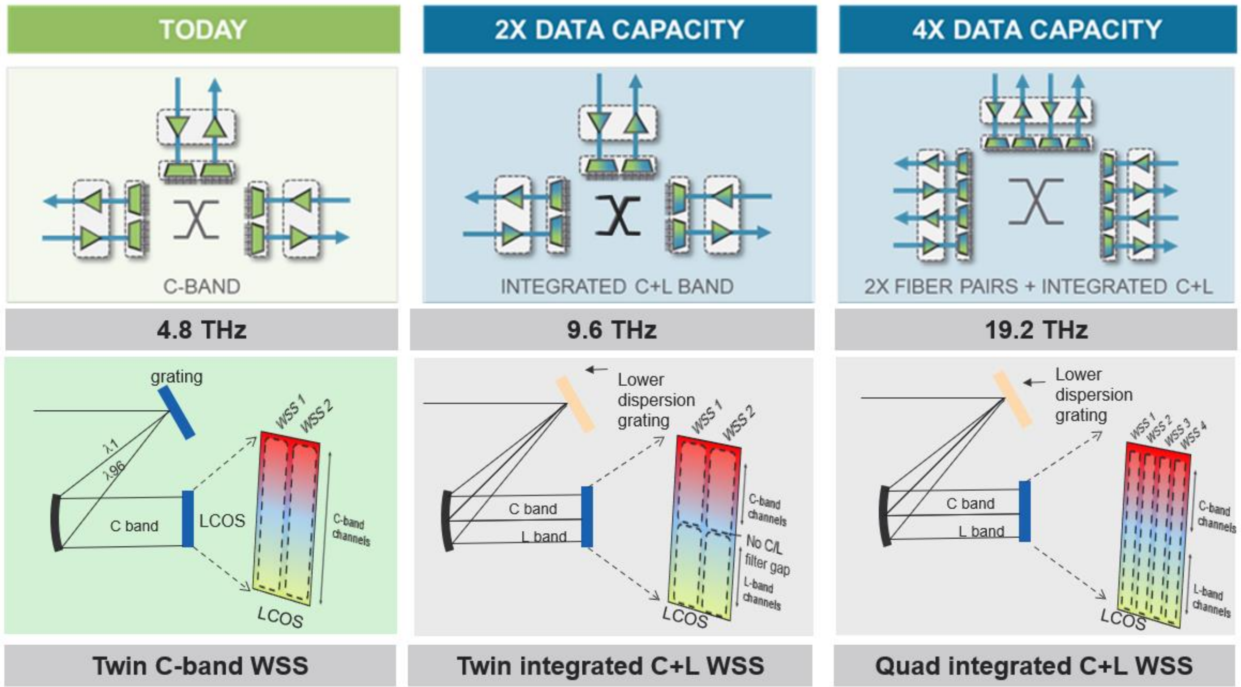

Fig. 1. ROADM node evolution showing C-band ROADM, integrated C+L ROADM and multi-rail integrated C+L ROADM. The associated WSS device evolution shows basic operation of C-band twin device, integrated C+L twin device and integrated C+L quad device.

3. High port count WSS, MxN WSS and hybrid fiber/wavelength ROADMs

Support of multi-rail configurations will effectively drive up the degree count of ROADM nodes resulting in the requirement for higher port count line WSSs beyond today's 32-port devices toward 64 or 80 ports and potentially beyond. These additional ports are required for the additional internal interconnection of ROADM nodes required for multi-rail configurations, but also to connect add/drop MxN WSSs. Colorless-directionless (CD) or colorless-directionless-contentionless (CDC) ROADM support will require new MxN WSS developments. Low insertion loss MxN WSS designs for CD and CDC ROADMs have been developed [2,3] and will need to be extended within the node from the twin 8x25 WSSs which are commercially available today to 16x25 and higher (Figure 2). Higher port counts are also valuable for flexible spectrum mux/demux configurations in IPoDWDM where transceivers directly connect to the WSS.

As end-to-end channel capacities increase, the Shannon limit constraint means that the channel spectral widths will increase proportionally. Current 400Gbps over 150GHz channels will give way to 800Gbps over 300GHz and even wider channels as channel capacities grow to multiple Tbps. This will inevitably lead to a point when wavelength granularity switching will become unnecessary for express traffic through the node and switching a full fiber will become more cost-effective. But even in that scenario, wavelength granularity control will be needed for traffic aggregation and for periodic traffic grooming. Hybrid fiber-wavelength switch architectures are currently being explored [4] and their adoption will be enabled by new fiber switch and hybrid fiber-wavelength switch devices. These devices are likely to continue to exploit the advanced MEMS and LCOS technologies that are currently employed in today's ROADMs. And it should be noted that WSS are not only used for traffic routing but for periodic channel equalization to counteract accumulated spectral non-flatness due to attenuation ripple in the fiber and gain variation within the optical amplifiers. Fiber-wavelength ROADM node architecture must anticipate the continued need for spectral flattening and associated device technologies must be developed.

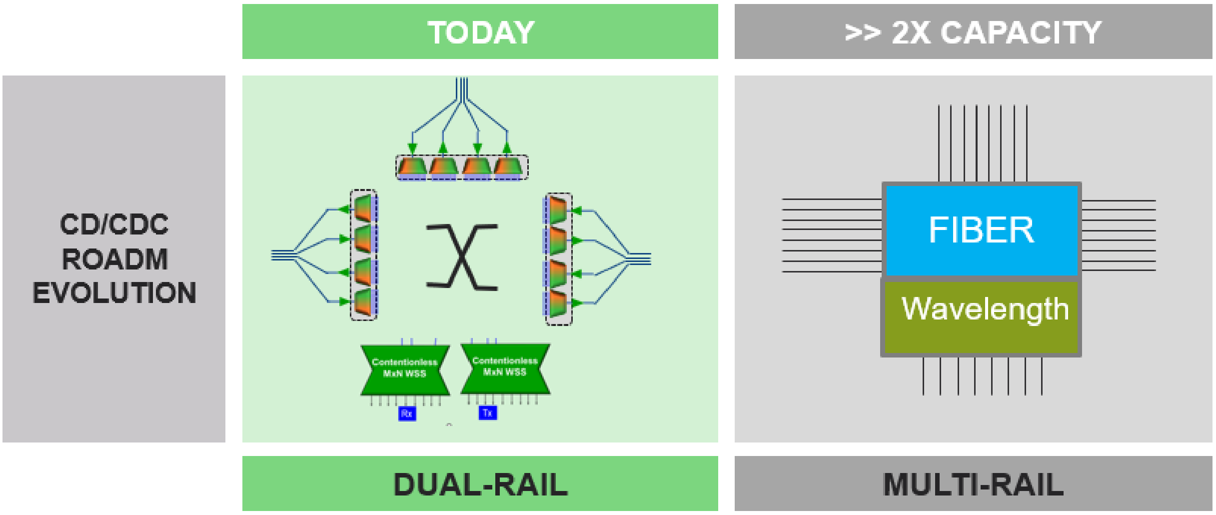

Fig. 2. CD/CDC ROADM evolution from dual rail wavelength switch to multi-rail hybrid fiber/wavelength switch.

4. Other enabling technologies

Finally, the requirements for increasingly complex WSS devices operating over wider spectrums with higher port counts and with multiple integrated devices will fundamentally challenge the high volume manufacturability of these devices. Development of technologies for manufacturing automation will be required in the areas of test, calibration and optical alignment. Incremental advancements of current approaches may not be sufficient.

In addition to the ROADM technology requirements described, there are many more pathways for technology innovation to be considered. Fundamentally new technologies for ROADM switching such as silicon photonics remain a tantalizing if distant possibility. Accommodating evolution to multi-core and perhaps hollow-core fiber needs to be anticipated. Pressure to decrease power consumption to meet sustainability goals and new ROADM deployment modes such as outside plant or subsea will also drive new trajectories of WSS innovation.

5. References

[3] S. Frisken et al., “Flexible and grid-less wavelength selective switch using LCOS technology,” in Optical Fiber Communication Conference, OSA Technical Digest (Optical Society of America, 2011), paper OTuM3

[2] M. Matthews et al., “Demonstration of a Novel Twin 10x10 WSS for Application in a flexible Colorless and Directionless ROADM” in Asia Communications and Photonics Conference 2013, OSA Technical Digest (online) (Optica Publishing Group, 2013), paper AF4E.1.

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[4] P. Winzer, “Spatial multiplexing in fiber optics: the 10x scaling of metro/core capacities”, Bell Labs Tech. J., **19**, 22-30, (2014)