

# Optical add/drop multiplexing architecture for metro area networks

Louay Eldada

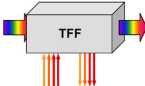
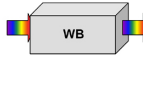
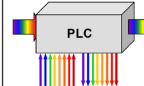
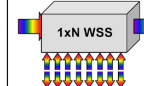
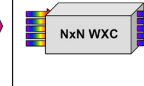
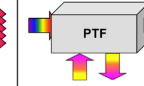
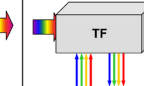
*Increased demand for bandwidth has fueled significant innovation in the routing of optical signals.*

Routers are the traffic cops of communication networks. Manufacture of routers based on various optoelectronic technologies has enabled commercial deployment of several types of optical add/drop multiplexers (OADMs) for intelligent handling of telecommunications signals. Each among the assorted subsystems has unique functionality, architecture, attributes, and underlying engineering for use in specific parts of the network. Subsystems consist of core optical modules (see Figure 1) and peripherals that complete functionality. In addition to the original fixed version (FOADM), there are blocker or broadband (BOADM), reconfigurable (ROADM), and tunable (TOADM) alternatives.

Early FOADMs, with preassigned channels at static nodes, were typically built with thin-film filters (TFFs), and allowed adding and dropping of individual or multiple wavelength channels from a dense wavelength multiplexer/demultiplexer (DWDM) multichannel stream. Some models currently available are configurable (COADMs) in that the manufacturer can factory-customize the number of channels, filter specifications, and power equalization. For dense channel

plans with 50GHz channel spacing, the FOADM typically includes an optical frequency interleaver. FOADMs or COADMs that feature power equalization include set-screw-adjustable variable optical attenuators. Most configurations boast low loss and are temperature-insensitive.

BOADMs were the first commercially available OADMs with remote channel reconfiguration capability. They employ wavelength blocker (WB) modules or variable multiplexer/demultiplexer (VMux/Demux) modules. These perform essentially the same task, serving as dynamic channel equalizers where maximum attenuation provides a shutoff (or on/off) function. A BOADM subsystem typically has ‘broadcast and select’ architecture (see Figure 2). The WB generally uses free-space optics, and switching actuation is achieved with microelectromechanical systems (MEMS), liquid crystal devices (LCDs), or liquid crystal on silicon (LCoS).<sup>1</sup> A WB-based BOADM is used principally in long-haul (LH) networks and typically has 80 channels with channel spacing of 50GHz. The VMux/Demux is usually fabricated in a planar lightwave circuit (PLC) platform. The associated BOADM is used mainly in metropolitan area networks, and generally has 32 or 40 channels with a channel spacing of 100GHz. Its ports are often colored (i.e., wavelength channels are ‘hard-wired’ to specific ports). Although ports can be made colorless through the use of tunable filters at the drop

FOADM	BOADM	ROADM			TOADM	
Thin Film Filter (TFF) Based OADM	Wavelength Blocker Based OADM	Planar Lightwave Circuit (PLC) ROADM	Wavelength Selective Switch (WSS)	Wavelength Crossconnect (WXC)	Passband Tunable TOADM	Wavelength Tunable TOADM
						
<ul style="list-style-type: none"> <li>• 2 multi-<math>\lambda</math>, ports (1 In, 1 Out) + 2N single-<math>\lambda</math>, ports (N Add, N Drop)</li> <li>• Pre-defined channels / bands dropped / added at a static node</li> </ul>	<ul style="list-style-type: none"> <li>• 2 multi-<math>\lambda</math>, ports (1 In, 1 Out)</li> <li>• Blocks or attenuates <math>\lambda</math>'s</li> <li>• No built-in Add or Drop or power monitoring</li> <li>• Used in 'Broadcast &amp; Select' architecture</li> </ul>	<ul style="list-style-type: none"> <li>• 2 multi-<math>\lambda</math>, ports (1 In, 1 Out) + 2N single-<math>\lambda</math>, ports (N Add, N Drop)</li> <li>• One 1x2 switch per <math>\lambda</math></li> <li>• Switches <math>\lambda</math>'s from In / Add to Out / Drop</li> <li>• Built-in power monitors</li> </ul>	<ul style="list-style-type: none"> <li>• N+1 multi-<math>\lambda</math>, ports (1 In, 1 Out, N-1 Add or Drop or mesh or expansion)</li> <li>• Switches <math>\lambda</math>'s from In / Mesh In / Add to Out / Mesh Out / Drop</li> <li>• No built-in power monitors</li> </ul>	<ul style="list-style-type: none"> <li>• 2N multi-<math>\lambda</math>, ports (N-1 In or Mesh In or expansion, 1 Add, N-1 Out or Mesh Out or expansion, 1 Drop)</li> <li>• Switches <math>\lambda</math>'s from In / Mesh In / Add to Out / Mesh Out / Drop</li> </ul>	<ul style="list-style-type: none"> <li>• 4 multi-<math>\lambda</math>, ports (1 In, 1 Out, 1 Add, 1 Drop)</li> <li>• Add / Drop ports: add / drop up to N adjacent <math>\lambda</math>'s in pre-defined band</li> </ul>	<ul style="list-style-type: none"> <li>• 2 multi-<math>\lambda</math>, ports (1 In, 1 Out), 2N single-<math>\lambda</math>, ports (N Add, N Drop)</li> <li>• Add/Drop ports: add / drop any <math>\lambda</math>, on any port</li> </ul>

*Figure 1. Functionalities of fixed, blocker, reconfigurable, and tunable add/drop multiplexer modules.*

*Continued on next page*

ports and tunable lasers at the add ports, such an approach is costly.

Different reconfigurable solutions are available, depending on the degree of the node or the number of fibers crossing at a node.<sup>1</sup> The PLC ROADM is a degree-2 solution that integrates add and drop ports and power monitoring (see Figure 3). The polymer-based 40-channel unit by DuPont supports 24 nodes at 10Gbps and 8 nodes at 40Gbps for non-return-to-zero on-off keying (NRZ-OOK) modulated signals. It can support 48 nodes at 10Gbps and 16 nodes at 40Gbps with optical differential phase-shift keying (DPSK) or duobinary modulation formats. A key property of the polymer-based ROADM is power consumption which, at 10W,<sup>2</sup> is lower by a factor of 4 to 6 compared with silica-based PLC ROADMs.<sup>3</sup>

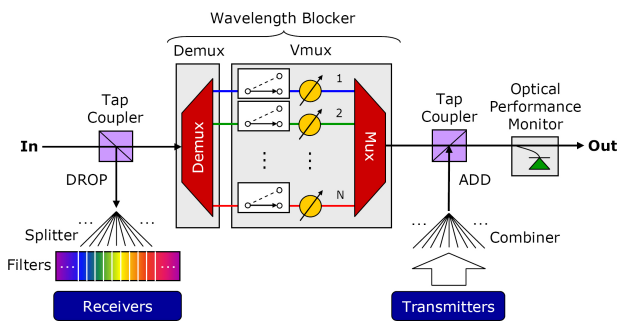


Figure 2. Architecture of a BOADM subsystem. Demux: Demultiplexer. Mux: Multiplexer.

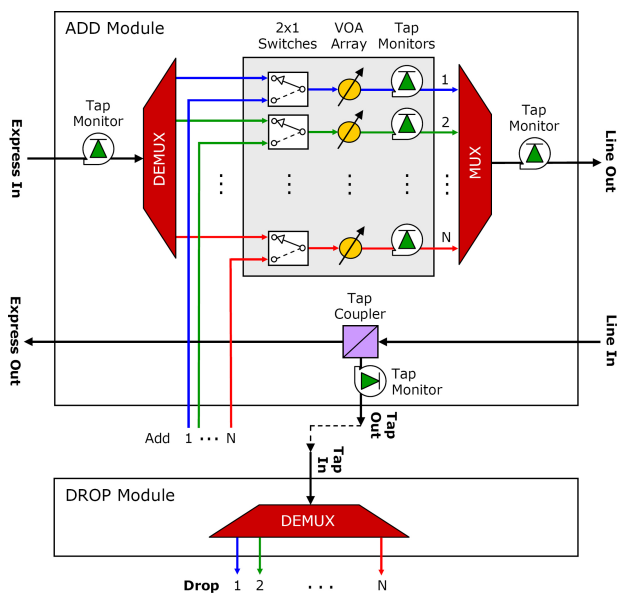


Figure 3. Functional schematic of a PLC ROADM. VOA: Variable optical attenuator.

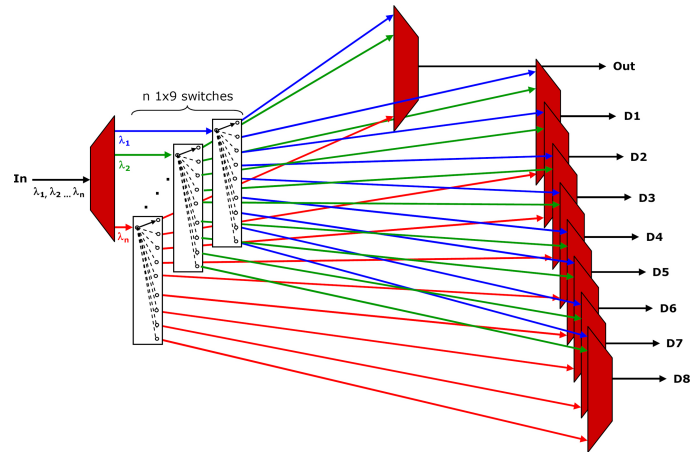


Figure 4. Functional diagram of an  $n$ -channel  $1 \times 9$  WSS ROADM providing one input port, one output port, and eight add/drop/mesh/expansion ports.

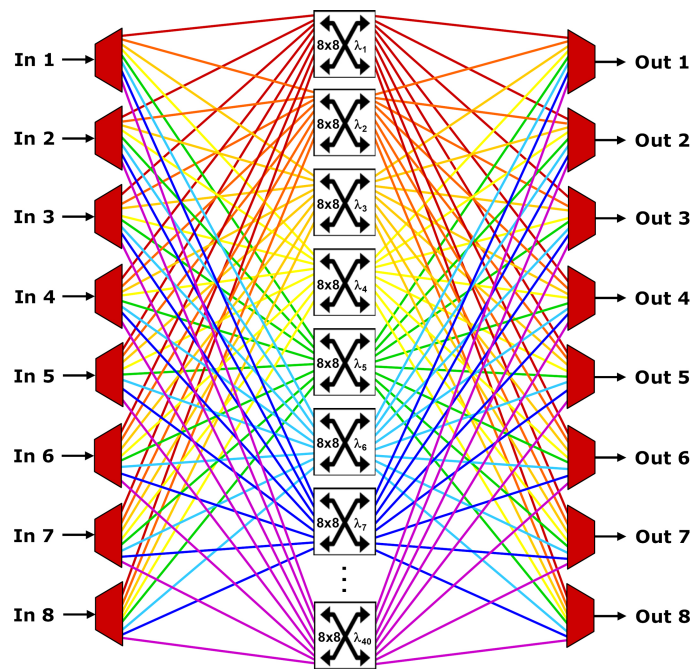
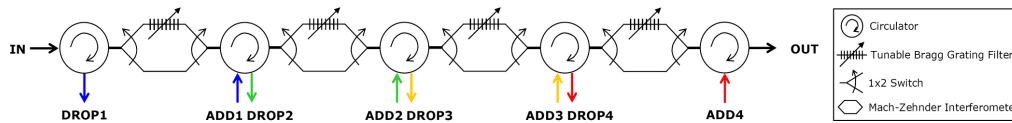


Figure 5. Architecture of a WXC ROADM for a degree-7 node with 40 channels per fiber.

This unique advantage, accruing to DuPont’s polymer-based devices, is widely recognized within the industry.<sup>4</sup> A  $1 \times N$  wavelength selective switch (WSS) ROADM module has one input port, one output port, and  $N-1$  add/drop/mesh/expansion ports. A degree  $N-1$  node requires  $N-1$   $1 \times N$  WSS

Continued on next page



**Figure 6.** Functional schematic of a four-channel add/drop optical add/drop multiplexers (TOADM) based on tunable Bragg grating filters.

modules to support mesh connectivity alone, and  $3(N-1)$   $1 \times N$  WSS modules to support mesh connectivity and colorless add/drop ports, although the latter is prohibitively expensive today.<sup>5</sup> Figure 4 schematically shows the functionality of a  $1 \times 9$  WSS module. A degree-8 node requires eight  $1 \times 9$  WSS modules to support mesh connectivity alone, and twenty-four  $1 \times 9$  WSS modules for colorless add/drop ports. Most WSS implementations use free-space optics, where a single bulk diffraction grating is shared for all the demultiplexing and multiplexing functions, and switching is achieved with MEMS, LCD, or LCoS.<sup>1</sup>

Wavelength cross-connect (WXC) ROADMs provide complete  $N \times N$  connectivity for mesh networks. PLC-based solutions have recently addressed the cost issue.<sup>6</sup> For a degree  $N-1$  node and  $n$  wavelengths per fiber, a WXC needs  $N$  Demuxes,  $N$  Muxes, and  $n N \times N$  switches. Figure 5 shows a 40-channel WXC for a degree-7 node, where one of the eight inputs is used for the local add and another for the local drop. The WXC subsystem includes eight 40-channel Mux/Demux pairs and forty  $8 \times 8$  switches. Each  $8 \times 8$  switch operates on a single wavelength and switches it from any input fiber to any output fiber, thus providing truly colorless ports.

Tunable optical filters can be used to produce simple types of remotely reconfigurable OADMs. Tunable filters can select and add/drop a channel or band without the need for demultiplexing and multiplexing, adding a measure of simplicity. Some TOADMs use passband-tunable filters in which tuning broadens or narrows the width of the band and the added/dropped channels are adjacent. A preferred approach uses a wavelength-tunable filter that maintains the passband shape during tuning. Different channels are selected with the range typically covering the full band of operation (e.g., C-band or L-band).<sup>7</sup> Figure 6 shows a four-channel TOADM that uses four wavelength-tunable filters to add/drop any four channels on any of the add/drop ports. The four filters are built-in Mach-Zehnder interferometers that allow switching to a bypass path during tuning to ensure hitless behavior, and the two switches operate in synchronized fashion to maintain transmission during the transition. The TOADM also includes two 3-port circulators and three 4-port circulators to route the added and dropped signals. The add/drop ports are single-channel colorless ports and this type of TOADM is ordinarily used in metro edge networks,

which are cost-sensitive and need to add or drop at each node one, two, four, or eight channels.

In general, each type of OADM has its optimal place in the network. The FOADM is best for static networks, while the WB BOADM plays a role in long-haul networks. The VMux/Demux BOADM can be used as a low-cost metro ROADM. The PLC ROADM is most appropriate for degree-2 nodes, and the WSS ROADM, for degree-3 and degree-4 nodes. The WXC ROADM is best for nodes of degree 5 and higher, and the TOADM for edge networks.

#### Author Information

##### Louay Eldada

DuPont Photonics Technologies  
Wilmington, MA

Louay Eldada is the CTO and vice president of engineering for DuPont Photonics Technologies. He holds a PhD in optical networking components from Columbia University. He started his career at Honeywell, where he founded the Telecom Photonics business unit and managed its product development arm. He held the same position when this business was acquired by Corning. He later founded Telephotonics and served as its CTO and vice chairman until its acquisition by DuPont.

#### References

1. L. Eldada, "Roadm architectures and technologies for agile optical networks," *Proc. SPIE* **6476**, 2007.
2. L. Eldada *et al.*, "40-channel ultra-low-power compact plc-based roadm subsystem," *Proc. OFC/NFOEC*, 2006.
3. L. Eldada, "Photonic integrated circuits," *Encyclopedia of Optical Engineering*, Marcel Dekker, New York, 2003.
4. D. J. Dougherty, "Advances in planar lightwave circuits," *Proc. OFC/NFOEC*, 2005.
5. B. Basch *et al.*, "Dwdm system architecture and design trade-offs," *Proc. OFC/NFOEC*, 2006.
6. L. Eldada *et al.*, "Intelligent optical cross-connect subsystem on a chip," *Proc. OFC/NFOEC*, 2005.
7. L. Eldada, "Organic photonics," *Microphotonics: Hardware for the Information Age*, MIT, Cambridge, 2005.