Fiber Optic Passive Devices
By Larry Johnson

Since the early years of fiber optics, there has been a need to passively switch, tap, split, and multiplex optical signals. Today’s technology allows designers to expand on these original tasks by also providing the ability to direct, control, and filter optical signals for more creative and cost-effective system designs using innovative passive devices.

In fiber optics, the word “passive” refers to those devices do not require electrical-to-optical or optical-to-electrical conversion during its operation. Passive optical components include simple optical connectors, splices, and fixed optical attenuators, but also more complicated, electronically controlled, optical devices like switches and variable optical attenuators.

In the case of CATV networks, optical splitters allow for broadcasting of video signals to thousands of subscribers through the hybrid fiber coax systems. Splitters are also known as couplers, and have a number of characteristics that determine their function and application. These include the number of input and output ports, signal attenuation, the directionality of the light transmission, wavelength selectivity, single- or multimode operation, as well as the polarization sensitivity and the polarization-dependent loss of the device.

Planar optical couplers are used for FTTH 1:32 splits.

Courtesy Teem Photonics
In the early days, the only passive components available were simple optical splitters and attenuators, which used internal filters to change attenuation values. As optical technology matured, wavelength-specific components emerged, leading to advances such as wavelength division multiplexing, which vastly increased the data capacity of optical networks.

Wavelength division multiplexing, or WDM, combines a number of optical channels into a transmitting fiber, with each channel transmitted at a different wavelength. Early terrestrial systems operated over multimode fibers with dual WDM, at 850 and 1300 nanometers, using wide spectral width LEDs. Later, these systems migrated to single-mode fibers using laser sources operating at 1310 and 1550 nanometers.

WDM systems would not be possible without a range of wavelength dependent passive components and, as the technology grew, these products would lead to the communications explosion from long-haul oceanic and even fiber-to-the-home installations.

In the 1990s this expanded multiplexing capability came from a surge of new technologies, all influencing each other. Low loss single-mode fibers operating at 1550 nanometers with losses in the 0.2 dB per kilometer range, allowed for longer spans without regeneration of the optical signal.

Simultaneously, intense research and experimentation led to the development of the erbium doped fiber amplifier or EDFA, and incorporated passive optical couplers, isolators, filters, and WDMs.

The EDFA was unique in that it could optically amplify all wavelengths across an optical spectrum. As manufacturers began to produce lasers with tighter spectral widths, dense wavelength division multiplexing, known as DWDM, with optical spacings into the tenths of nanometers, became a reality. This required optical filters to demultiplex these wavelengths.

Another key requirement in DWDM systems was to prevent the optical drifting of the laser light sources. Wavelength lockers presented a solution to this problem. At the same time, optical isolators were being integrated into the optical sub-assemblies of high-speed systems and optical amplifiers due to the increased effects of reflections on laser and system performance.

Combined with new optical fibers, the EDFA and an explosive communications revolution, these technologies would drive optical multiplexing into point-to-point, long haul networks, and eventually into metropolitan area networks. These networks use DWDM in ring architectures, which require an optical solution to add and drop wavelengths at multiple points throughout the physical ring.

The fiber Bragg grating provided the ability to filter specific wavelengths, and when integrated with the optical circulator, would provide the add/drop function.
The fiber Bragg grating and optical circulator allow for optical add drop multiplexing.

Courtesy Proximion

Other passive products evolved for WDM, including the fiber optic interleaver. Unlike other demultiplexers, the interleaver uses light interference in a fiber structure to split a group of evenly spaced optical channels into sets of odd and even channels. These channel subsets have wider channel spacings and can be more easily processed by components not requiring such tight tolerances.

Another type of WDM, known as coarse wavelength division multiplexing or CWDM uses 20-nanometer channel spacings, allowing greater flexibility of components at a reduced cost.

Long-haul systems push the limits of technology and reliability, but providing fiber to the home has always been a goal of the fiber industry. In 1998, the International Telecommunications Union released the ITU-T G.983 “Broadband Optical Access System” standard based on the passive optical network to address a low-cost option of delivering bidirectional communications to the home and business over a single fiber.

The PON solution was actually quite simple, using the standard CATV architecture, low-cost active and passive components, along with established ATM and Ethernet protocols. Optical splitters would be located in the outside plant to allow a single light source to send signals to multiple homes and businesses.

The emergence of devices that integrated active components — such as lasers, photo diodes, WDMs, and filters — into packages called diplexers and triplexers allowed for the transmission of bidirectional voice, video, and data signals over two or three wavelengths between the service providers and the subscribers.

The ITU standard specified the optical wavelengths, attenuation, reflection, and dispersion values required using the ITU standardized G.652 single-mode fiber. By using standardized products originally developed for DWDM, the PON network design reduces the installation and operating costs by eliminating active components between the transmitting terminal and the subscriber.
Future versions of FTTx PON will incorporate other passive optical devices to expand the capabilities of the network. The use of optical switches at fiber distribution hubs in the outside plant allow for easy re-configuring of the network while the option of assigning each user their own wavelength through DWDM technology has already been demonstrated.

While PON continues to increase bandwidth capabilities for the home, this increase must also be supported in the local loop, metropolitan, and long haul networks. In these applications the use of optical switches, filters, gratings, along with re-configurable optical add-drop multiplexers, or ROADMs, will be optimized.

ROADMs will be used in the next phase of optical communications, incorporating new variations of optical switches. Simple 1:2 electronic optical switches have been around for decades, allowing easy switching between light sources operating at different wavelengths.

Optical switches improved with each newly developed state of the art technology. Terms like optical-electrical-optical or OEO, optical cross-connect or OXO, and optical-optical-optical or OOO, became common descriptions used to describe optical switches. The term “route redundancy” became the driving force behind optical switching evolution, along with the increased speed and efficiency of the networks, with re-configurations occurring in the milliseconds.

Key elements of the optical add/drop multiplexer or the OADM are the optical circulator and the fiber Bragg grating. These components allow switching of wavelengths by adding and dropping them though the optical ports with no fiber movement.

The development of the reconfigurable OADM, or ROADM, now incorporates MEMS technologies, resulting in equipment with a very small footprint. Power requirements for MEMS devices are also very small, reducing operating costs. Placing ROADMs in remote switching cabinets and into FTTx networks will provide the remote switching capability to supply customer wavelengths, network testing, protection, and route redundancy.

From a provider’s perspective, the addition of optical switches also allows the network to be re-configured from remote sites in response to the changing bandwidth needs of the individual network.

Optical switches can also be used to dynamically route a variety of data, audio, and video signals to different locations in applications such as video conferencing, intelligent transportation systems, and many others.

Earlier, we saw how the EDFA addressed the attenuation issue. But at high speeds and with alternate routing of a span, the problem of optical dispersion caused by the laser, the optical fiber, and differing physical lengths also needs to be addressed.
History has shown that when an optical problem surfaces, optical solutions are developed to resolve the problem. An example of this is four wave mixing in dispersion-shifted fiber. This problem was resolved by the development of non-zero dispersion-shifted fibers in the early 1990s, which led to the DWDM explosion.

A more recent example includes the optical dispersion compensator, which is designed to provide a solution to dispersion problems in high-speed and long distance installations.

Another important consideration in re-configurable networks is active dispersion management. When switching high-speed multiwavelength signals among fiber spans of different lengths, dispersion compensation must be tailored to the individual span. Optical switching systems can be used to switch in the correct amount of dispersion compensation as needed.

Passive components have created innovative opportunities for entirely new ways of handling multiwavelength optical signals. In the following chapters of this program we will look more closely at these critically important devices and how they have impacted and influenced optical communications.

This article is based on the introductory chapter of The Light Brigade’s *Fiber Optic Passive Devices* DVD (# W-6D-201), which is available from the Light Brigade at www.lightbrigade.com.

**About the Author**

Larry Johnson is Director and Founder of The Light Brigade and has been involved in fiber optics since 1977.