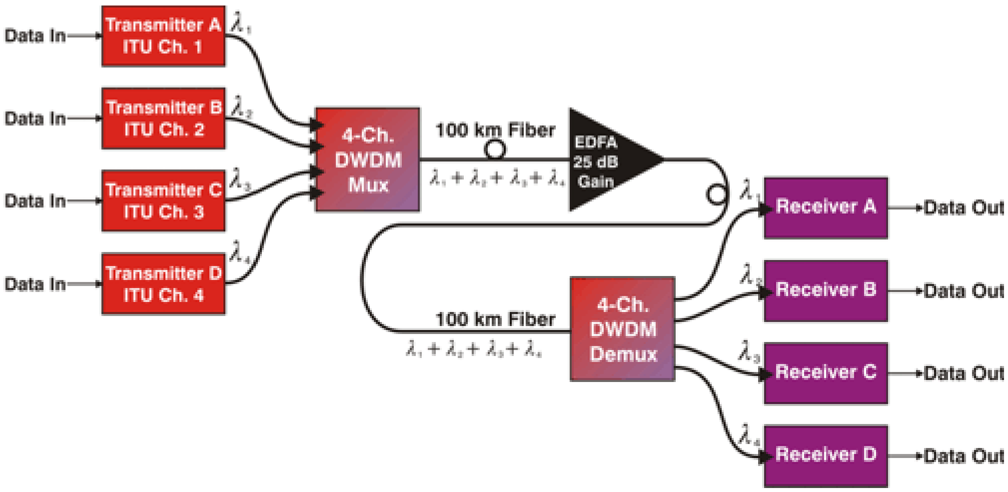
Dense Wavelength-division Multiplexing

Dense wavelength-division multiplexing (DWDM) revolutionized data transmission technology by increasing the capacity signal of embedded fiber. This increase means that the incoming optical signals are assigned to specific wavelengths within a designated frequency band, then multiplexed onto one fiber. This process allows for multiple video, audio, and data channels to be transmitted over one fiber while maintaining system performance and enhancing transport systems. This technology responds to the growing need for efficient and capable data transmission by working with different formats, such as SONET/SDH, while increasing bandwidth. The fiber optic amplifier component of the DWDM system provides a cost efficient method of taking in and amplifying optical signals without converting them into electrical signals. In addition, DWDM amplifies a broad range of wavelengths in the 1550 nm region. For example, with a DWDM system multiplexing 16 wavelengths on a single optical fiber, carriers can decrease the number of amplifiers by a factor of 16 at each regenerator site. Using fewer regenerators in long-distance networks results in fewer interruptions and enhanced efficiency.

DWDM System Considerations

Important components for a DWDM systems are transmitters, receivers, fiber amplifiers, DWDM multiplexers, and DWDMdemultiplexer. These components, along with conforming to ITU channel standards, allow a DWDM system to interface with other equipment and to implement optical solutions throughout the network.

Figure 1- DWDM System Application

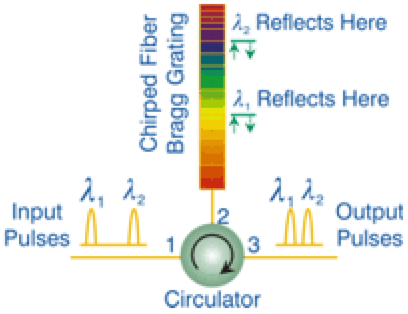


Multiplexers and Demultiplexers

The recent explosion of DWDM technology forced the fiber optic manufacturers to develop DWDM multiplexers and demultiplexers that can handle closely spaced optical wavelengths. These designs require narrow passbands, usually 0.4 nm wide, steep roll-off to reject adjacent channels, and stable operation over increased temperature.

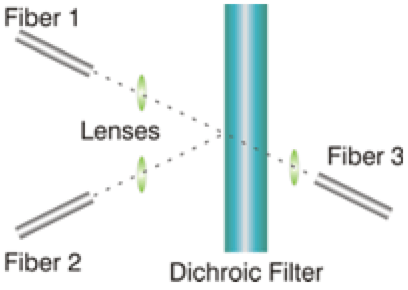
Recently, multiplexers have gained versatility, moving beyond the "wideband" wavelengths and into densely packed wavelengths that can be integrated into a multiple high frequency, 192 to 200 THz, transmission system. This type of system can maintain up to 16 channels, acting as a 16 fiber channel cable with each frequency channel operating to serve a STM-16/OC-48 carrier. Demultiplexers need to eliminatecrosstalk and channel interference. Couplers and dichroic filter, both passive devices, are the most favorable demultiplexers today. The first DWDM coupler design is based on fiber Bragg grating (FBG) filters illustrated in Figure 2. Bragg gratings are comprised of a length of optical fiber with the index of the core permanently modified periodically usually when exposed to an ultraviolet interference pattern. As a result, the fiber grating behaves as a wavelength dependent reflector and lends itself to precise wavelength separation.

Figure 2 - Bragg Grating



The second design is based on cascaded dichroic filters much like those used in the WDM system shown below in Figure 3. In a DWDM coupler, a second dichroic filter would be placed where the fiber 2 is located, and additional dichronic filters would be cascaded until all wavelengths have been combined or separated. At moderate cost, the dichronic filter method assures stability and excellent isolation between channels.

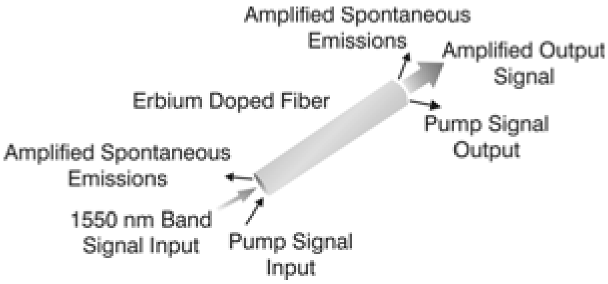
Figure 3 - Dichronic Filter



Fiber Amplifiers for DWDM

Because DWDM systems handle information optically rather than electrically, it is imperative that long-haul applications do not suffer the effects of dispersion and attenuation. Erbium-doped fiber amplifiers (EDFAs) counteract these problems. EDFAs are silica based optical fibers that are doped with erbium. This rare earth element has the appropriate energy levels in its atomic structure for amplifying light at 1550 nm. A 980 nm "pump" laser is used to inject energy into the doped fiber. When a weak signal at 1310 nm or 1550 nm enters the fiber, the light stimulates the rare earth atoms to release their stored energy as additional 1310 nm or 1550 nm light. This process continues as the signal passes down the fiber, continually growing stronger. Figure 4 illustrates an erbium-doped fiber.

Figure 4 - Erbium-doped Optical Fiber

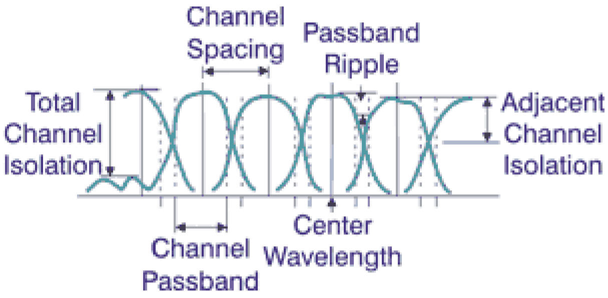


The photons amplify the incoming signal optically, boosting the wavelength, and avoiding almost all of the active components. The output power of the EDFA is large, and thus, fewer amplifiers may be needed in any given system design. The amplification process is independent of the data rate. Because of this benefit, upgrading a system means only changing the launch/receive terminals. As demands for wider bandwidth grow there is a call for more efficient and reliable optical amplifiers. The usable bandwidth of an EDFA is only about 30 nm (1530 nm-1560 nm), but the minimum attenuation is in the range of 1500 nm to 1600 nm. The dual-band fiber amplifier (DBFA) solves the usable bandwidth problem. It is broken down into two sub-band amplifiers. The DBFA is similar to the EDFA, but its bandwidth ranges from about 1528 nm to 1610 nm. The first range is similar to that of the EDFA and the second is known as extended band fiber amplifier (EBFA). Some features of the EBFA include flat gain, slow saturation, and low noise. The EBFA can achieve a flat gain over a range of 35 nm which is comparable to the EDFAs. EBFAs have the advantage of reaching a slower saturation keeping the output constant even though the input increases.

Channel Spacing

DWDM channel spacing governs system performance; 50 GHz and 100 GHz outline the standards of ITU channel spacing. Currently, 100 GHz is the most commonly used and reliable channel spacing. This spacing allows for several channel schemes without imposing limitations on available fiber amplifiers. However, channel spacing depends on the system's components. Channel spacing is the minimum frequency separation between two multiplexed signals. An inverse proportion of frequency versus wavelength of operation calls for different wavelengths to be introduced at each signal. The optical amplifiers bandwidth and receivers ability to identify two close wavelength, sets the channel spacing. Figure 5 illustrates the typical DWDM specifications.

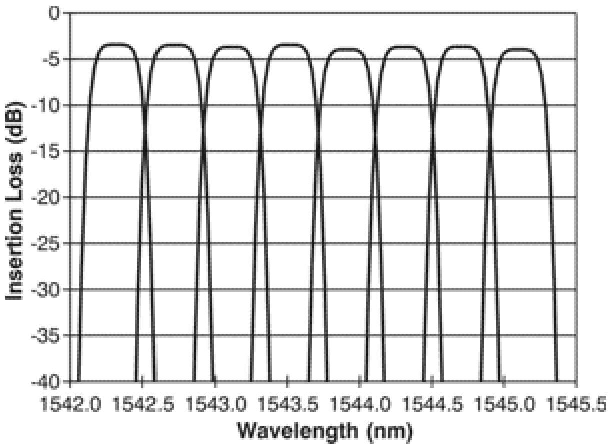
Figure 5 - Typical Optical Characteristics for DWDM Channels



Signal Direction

DWDM involved sending a large number of closely spaced optical signals over a single fiber. Standards developed by the ITU (International Telecommunications Union) define the exact optical wavelength used for DWDM applications. The center of the DWDM band lies at 193.1 THz with standard channel spacing of 200 GHz and 100 GHz. The closest "standard" spacing (100 GHz) allows transmission of 45 channels on one fiber. A 45 channel system spaced at 100 GHz would cover a optical span of 35 nm and require a costly wide bandwidth, gain-flattened EDFA. As system designers looked to pack more than the 45 channels at 100 GHz spacing, they started to use closer spaced optical channels. The channel spacing, in GHz, relates to the optical wavelength as follows: A spacing of 200 GHz corresponds to about 1.6 nm, 100 GHz corresponds to about 0.8 nm, and 50 GHz corresponds to about 0.4 nm channels spacing. Most commonly 50 GHz follows 100 GHz, although attempts at 75 GHz and 37.5 GHz show up in literature. While there is nothing magical about any of these numbers, it seems likely that 50 GHz will be the next logical step below 100 GHz. Using a channel spacing of 50 GHz (0.4 nm) allows 45 channels to occupy only 17.5 nm of optical bandwidth. This greatly simplifies the requirement for optical amplifiers in the system. Fiber increases in channels per fiber would likely lead to the use of 25 GHz spacing. Designing the optical demultiplexer to separate the signals at the receive end defines the greatest challenge in closely spaced optical channels. Because of subtle color differences in each of the optical channels, high performance DWDM optical demultiplexers must have three characteristics. First, it must be very stable over time and temperature. Second, it needs to have a relatively flat passband or region of frequencies. Third, it must reject adjacent optical channels so that they do not interfere. Several basic types of designs can be used in optical demultiplexers to separate the optical channels. Many of these designs have an increasingly difficult time separating the optical channels as the spacing becomes very close. Some, however, such as fiber Bragg gratings actually appear better suited for closer channel spacing. The need for close optic channel spacing is a trade-off between the performance required of the optical amplifiers used in the system and the number of channels to be transmitted per fiber. Figure 6 illustrates the transmission spectra of 0.4 nm spacing DWDM FBGs.

Figure 6 - 0.4 nm Channel Spacing DWDM Fiber Bragg Grating



Red and Blue Bands

The ITU approved DWDM band extends from 1528.77 nm to 1563.86 nm, and divides into the red band and the blue band. The red band encompasses the longer wavelengths of 1546.12 nm and higher. The blue band wavelengths fall below 1546.12 nm. This division has a practical value because useful gain region of the lowest cast EDFAs corresponds to the red band wavelengths. Thus, if a system only requires a limited number of DWDM wavelengths using the red band wavelength yields the lowest overall system cost.

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