LESSON 25: DISPERSION MEASUREMENT AND TYPES OF DISPERSION

Objective:

To provide a detailed understanding of the concepts dispersion measurement and types of dispersion

Introduction

Once upon a time, the world assumed that fiber possessed infinite bandwidth and would meet mankind's communication needs into the foreseeable future. As the need arose to send information over longer and longer distances, the fiber optic community developed additional wavelength "windows" that allowed longer transmission. The 1550 nm region, with a loss of only 0.2 dB/km, seemed like the answer. Millions of kilometers of fiber were installed around the world creating a high-speed communication network. However, as the data rates increased and fiber lengths increased, limitations due to dispersion in the fiber became impossible to avoid.

Dispersion was initially a problem when the first optical fibers, multimode step-index fiber, were introduced. Multimode graded-index fiber improved the situation a bit, but it was single-mode fiber that eliminated severe multimode fiber related dispersion and left only chromatic dispersion and polarization mode dispersion to be dealt with by engineers.

Dispersion Measurement

Computing PMD is quite difficult unless specific measurements are made on the particular fiber span of interest. Because of this difficulty, and because PMD is generally a much smaller effect at any given data rate, we will not go into details of PMD computation. We will focus on computing the effects of chromatic dispersion.

Let's first consider non dispersion-shifted single-mode fiber, such as Corning SMF-28 CPC3 single-mode fiber. This fiber type makes up the largest percentage of the installed fiber base. Its zero-dispersion wavelength lies between 1301 nm and 1321 nm. At the zero-dispersion wavelength, the fiber bandwidth is very high. However, the fiber attenuation in this range is about 0.5 dB/km. This attenuation limits transmission distances to perhaps 60 km. It would be more desirable to operate in the 1550 nm band where attenuation is about 0.2 dB/km. This attenuation would allow transmission to about 150 km as long as dispersion does not limit performance.

Equation 1 can be used to compute the dispersion of Corning SMF-28 single-mode fiber.

$$D_\lambda = \frac{S_0}{4}\left(\lambda - \frac{\lambda_0^4}{\lambda^3}\right)$$

Where:
S_0 = 0.092 ps/(nm^2 • km)
λ_0 = 1311 nm (Corning specifies a range of 1302-1322 nm. This number is the average.)
D_λ = Dispersion (ps/nm/km)

Figure 4 shows the behavior of Equation 1 over the wavelength range from 1250 nm to 1650 nm. As expected, the dispersion goes to zero at a wavelength of 1311 nm. At the window of greatest interest, near 1550 nm, the dispersion is about 17 ps/nm/km. If a laser has a spectral width of 1 nm, then the dispersion will be 17 ps/km/nm.

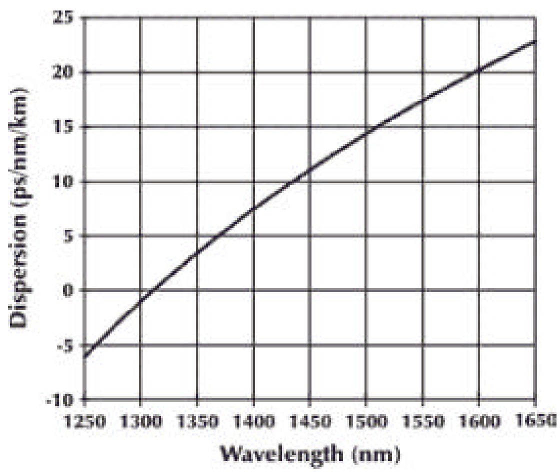

Figure 4 - SM Fiber Dispersion

Chromatic Dispersion

Chromatic dispersion represents the fact that different colors or wavelengths travel at different speeds, even within the same mode. Chromatic dispersion is the result of material dispersion, waveguide dispersion, or profile dispersion. Figure 1 below shows chromatic dispersion along with key component waveguide dispersion and material dispersion.

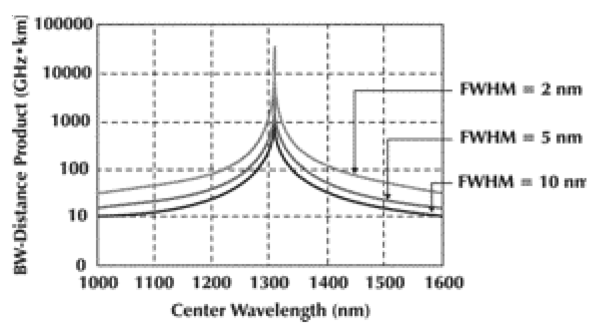

Figure 1 - Chromatic Dispersion

The Fig.1 shows chromatic dispersion going to zero at the wavelength near 1550 nm. This is characteristic of bandwidth dispersion-shifted fiber. Standard fiber, single-mode, and multimode has zero dispersion at a wavelength of 1310 nm.

Every laser has a range of optical wavelengths, and the speed of light in fused silica (fiber) varies with the wavelength of the light. Figure 2 illustrates the refractive index of fused silica as it changes with wavelength. Since a pulse of light from the laser usually contains several wavelengths, these wavelengths tend to get spread out in time after traveling some distance in the fiber. The refractive index of fiber decreases as wavelength increases, so longer wavelengths travel faster. The net result is that the received pulse is wider than the transmitted one, or more precisely, is a superposition of the variously delayed pulses at the different wavelengths.

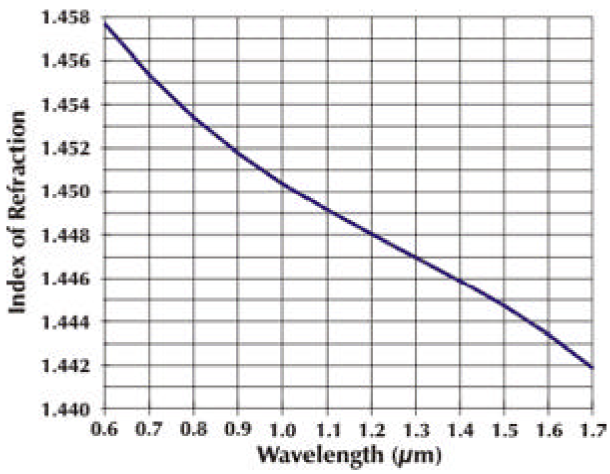

Figure 2 - Refractive Index of Fused Silica

A further complication is that lasers, when they are being turned on, have a tendency to shift slightly in wavelength, effectively adding some Frequency Modulation (FM) to the signal. This effect, called "chirp," causes the laser to have an even wider optical line width. The effect on transmission is most significant at 1550 nm using non-dispersion-shifted fiber because that fiber has the highest dispersion usually encountered in any real-world installation.

Polarization Mode Dispersion

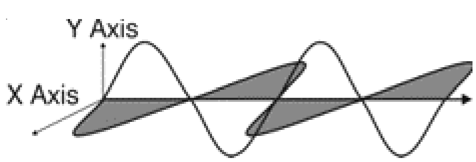

Figure 3 - Polarization Mode Dispersion

Polarization mode dispersion (PMD) is another complex optical effect that can occur in single-mode optical fibers. Single-mode fibers support two perpendicular polarizations of the original transmitted signal. If a were perfectly round and free from all stresses, both polarization modes would propagate at exactly the same speed, resulting in zero PMD. However, practical fibers are not perfect, thus, the two perpendicular polarizations may travel at different speeds and, consequently, arrive at the end of the fiber at different times.

Figure 3 illustrates this condition. The fiber is said to have a fast axis, and a slow axis. The difference in arrival times, normalized with length, is known as PMD ($ps/km^{0.5}$).

Excessive levels of PMD, combined with laser chirp and chromatic dispersion, can produce time-varying composite second order (CSO) distortion in amplitude modulated (AM) video systems. This results in a picture that may show a rolling or intermittent diagonal line across the television screen.

Like chromatic dispersion, PMD causes digital transmitted pulses to spread out as the polarization modes arrive at their destination at different times. For digital high bit rate transmission, this can lead to bit errors at the receiver or limit receiver sensitivity.

Notes