

# Chromatic Dispersion

## AEN 19, Revision 4

The two fiber parameters that have the greatest effect in limiting digital transmission over optical waveguides are attenuation and pulse spreading. In single-mode fibers, pulse spreading is caused by chromatic dispersion. Attenuation attracted most of the attention in the early years of single-mode fiber because it was generally the limiting factor in determining maximum repeaterless span lengths. As the required information carrying capacity of optical systems was increased (higher bit rates), the maximum allowable system pulse spreading decreased. This fact, in conjunction with lower fiber attenuation, eventually resulted in systems that were dispersion limited instead of attenuation limited.

Dispersion causes a light pulse to spread in time as it travels through a fiber. This spreading increases the potential for interference between sequential pulses. Pulses launched close together (high bit rates) that spread too much (high dispersion) result in bit errors.

Dispersion for a single-mode fiber is more precisely referred to as chromatic dispersion and consists of material dispersion and waveguide dispersion. Chromatic dispersion is determined by the fiber's material composition, structure and design, and by the light source's operating wavelength and spectral width. Chromatic dispersion is measured in units of ps/(nm•km): picoseconds ( $10^{-12}$  seconds) of light pulse spread per nanometer ( $10^{-9}$  meters) of laser spectral width and per kilometer of fiber length ( $10^3$  meters).

Material dispersion is caused by molecular and light energy interactions. It occurs in every medium except a perfect vacuum. The amount of material dispersion varies with the composition of the glass and is a function of the wavelength of the light source. Material dispersion occurs because the speed of light in a medium is a function of wavelength. No transmitter produces a pure light source of only one wavelength. Instead, sources produce a range of wavelengths around a center wavelength. Light at these wavelengths travels at slightly different speeds, resulting in pulse spreading that increases with distance.

Waveguide dispersion is a function of the structure of the refractive index profile of the fiber and varies as the percentage of light in the core and cladding changes. These percentages are a function of the operating wavelength.

Altering the glass composition changes material dispersion only slightly, but its effect can be significantly changed by using a better light source. Significant changes in waveguide dispersion can be achieved by altering the internal structure (index profile) of the fiber. Standard single-mode fiber is made up of a core with a high index of refraction and a cladding with a lower index. This simple step index profile yields a zero dispersion wavelength (where the material and waveguide components of dispersion cancel) near 1310 nm. By changing the internal structure of the fiber (variations in refractive index and core geometry) designers can shift the zero dispersion point.

Corning Incorporated has designed a segmented core fiber, which has larger waveguide dispersion than the standard single-mode fiber. This shifts the zero dispersion wavelength to just below the 1550 nm operating window. This fiber, known as non-zero dispersion-shifted fiber, has a small amount of dispersion in the 1550 nm operating window. This fiber type is widely used for transmitting multiple high-speed data channels across a single fiber in the 1550 nm range.

### EXAMPLE

Given:

Source Center Wavelength Range	1285 nm - 1330 nm
Source Spectral Width (SSW)	4 nm (FWHM)
Maximum Fiber Dispersion	3.3 ps/(nm•km) (1285 nm - 1330 nm)
System Data Rate	565 MBit/sec
Allowable System Pulse Broadening	550 ps
System Length	40 km

Determine Maximum Dispersion For A Given Length:

$$\begin{aligned} \text{Dispersion} &= (\text{Fiber Dispersion}) \times (\text{Spectral Width}) \times (\text{System Length}) \\ D &= (3.3 \text{ ps}/(\text{nm}\cdot\text{km}))(4 \text{ nm})(40 \text{ km}) \\ D &= 528 \text{ ps} \end{aligned}$$

This is less than the maximum pulse broadening allowed by the end equipment manufacturer (550 ps).

Determine Maximum Allowable Length Due To Dispersion:

$$\begin{aligned} \text{Length} &= (\text{Maximum Allowable Pulse Broadening}) / \{(\text{Fiber Dispersion})(\text{Spectral Width})\} \\ L &= (550 \text{ ps}) / \{(3.3 \text{ ps}/(\text{nm}\cdot\text{km}))(4 \text{ nm})\} \\ L &= 41.7 \text{ km} \end{aligned}$$