LUNA
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Optical Component DNA

Introduction to Chromatic Dispersion

Abstract: All forms of dispersion degrade a lightwave signal, reducing the data-carrying capacity through pulse-broadening. Chromatic dispersion results from a variation in propagation delay with wavelength, and is affected by fiber materials and dimensions.

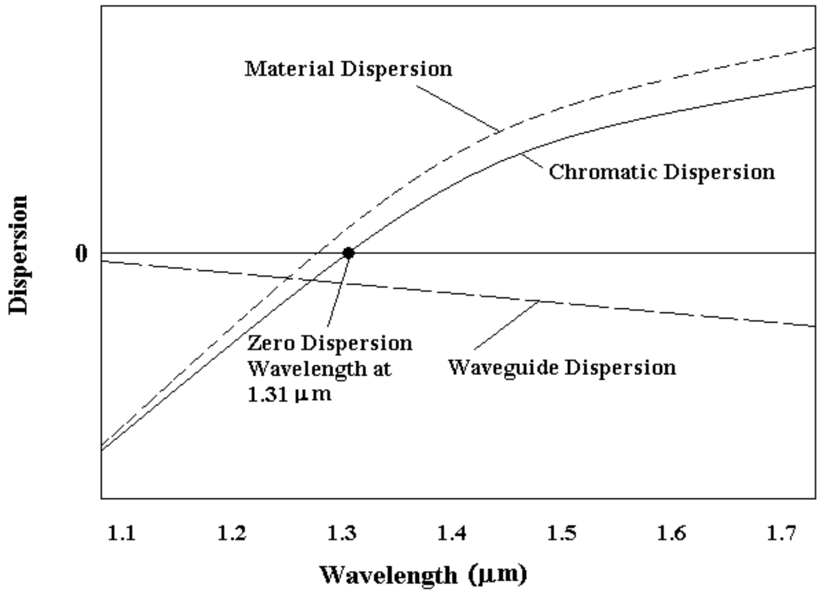
Chromatic dispersion is a broadening of the input signal as it travels down the length of the fiber. The concept to consider when talking about chromatic dispersion (CD) should be optical phase. It is important to mention optical phase before any explanations of CD or group delay because of their mathematical relationship. Group delay is defined as the first derivative of optical phase with respect to optical frequency. Chromatic dispersion is the second derivative of optical phase with respect to optical frequency. These quantities are represented as follows:

$$Group\ Delay = \frac{\partial \phi}{\partial \omega} \qquad\qquad Chromatic\ Dispersion = \frac{\partial^2 \phi}{\partial \omega^2}$$

$$where\ \phi = optical\ \ phase\ and\ \ \omega = optical\ \ frequency\ .$$

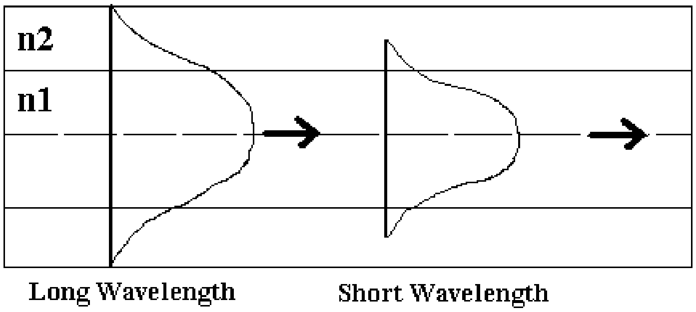
Chromatic dispersion consists of both material dispersion and waveguide dispersion as illustrated in Figure 1.

Figure 1: Dispersion in a standard single-mode optical fiber as a function of wavelength.



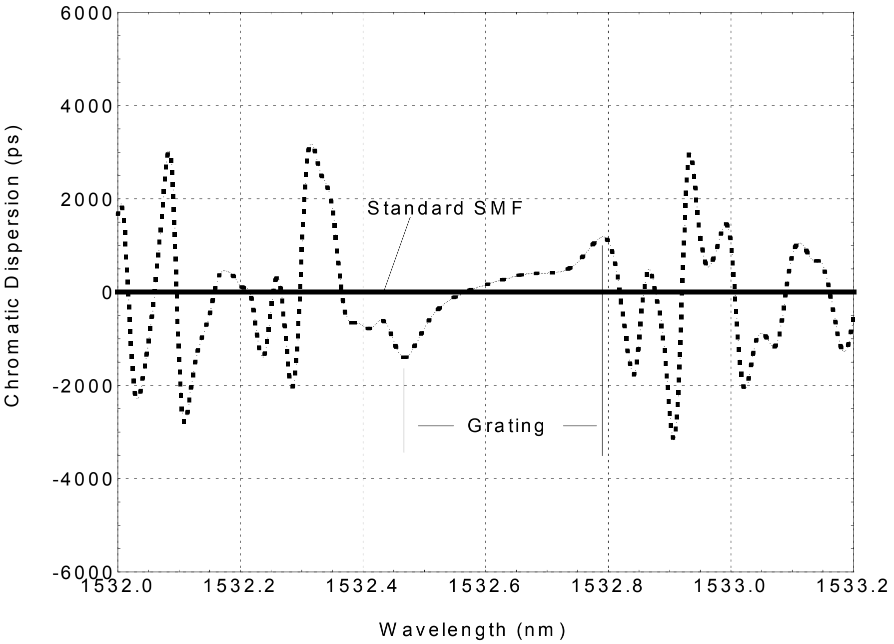
Both of these phenomena occur because all optical signals have a finite spectral width, and different spectral components will propagate at different speeds along the length of the fiber. One cause of this velocity difference is that the index of refraction of the fiber core is different for different wavelengths. This is called material dispersion and it is the dominant source of chromatic dispersion in single-mode fibers. Another cause of dispersion is that the cross-sectional distribution of light within the fiber also changes for different wavelengths. Shorter wavelengths are more completely confined to the fiber core, while a larger portion of the optical power at longer wavelengths propagates in the cladding. Since the index of the core is greater than the index of the cladding, this difference in spatial distribution causes a change in propagation velocity. This phenomenon, illustrated in Figure 2, is known as waveguide dispersion. Waveguide dispersion is relatively small compared to material dispersion.

Figure 2: Waveguide Dispersion - different wavelengths will experience different effective refractive indices.



Chromatic dispersion in a component is significantly different than chromatic dispersion in long length optical fiber. Chromatic dispersion remains constant over the bandwidth of a communications channel for long lengths of fiber. As seen in Figure 3, chromatic dispersion often varies over the bandwidth of the channel in optical components. As a result, chromatic dispersion is a poor predictor of component performance in a communications system.

Figure 3: Chromatic dispersion remains fairly constant in an optical fiber. However, chromatic dispersion varies with wavelength in a component.



Chromatic dispersion can cause bit errors in digital communications or distortion and a higher noise floor in analog communications, and, as shown in Figure 4, can pose a serious issue in high-bit-rate systems if it is not measured accurately and some form of dispersion compensation is not employed.

Figure 4: Pulse broadening due to chromatic dispersion