**How to Speak "Fiber Geek"**
**Article 3 – Dispersion and Other Non-Linear Effects**

**Welcome back, Fiber Geeks!**

As a quick refresher, article 1 in this series highlighted some bandwidth demand drivers and introductory standards information while also examining how the demand for additional bandwidth is driving the need for wavelengths across the optical spectrum. In addition, article 2 focused on attenuation and other critical optical parameters.

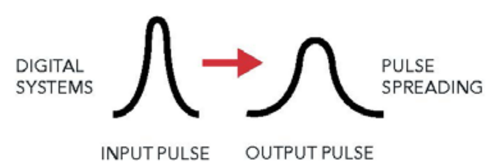
Now, in this third article in the series, we will focus on parameters affecting available bandwidth in fibers, dispersion mechanisms of different types and non-linear effects.

Dispersion describes the process of how an input signal broadens out as it travels down the fiber. There are several types of dispersions that we will cover. We'll also take a cursory look at other important non-linear effects that can reduce the amount of bandwidth that is ultimately available over a fiber.

## Dispersion

Much, but not all, of the traffic traveling through fiber networks takes the form of a laser pulse, where the laser is pulsed on and off, effectively forming a digital square wave comprised of "1"s and "0"s.

The effect of dispersion on a pulse is that the dispersion causes the pulse to spread out over time, effectively rounding the edges, and making it harder for the detector to determine whether a "1" or a "0" is being transmitted. When this happens, the effective bandwidth of the link is reduced.



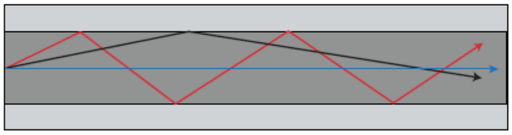

Dispersion causes a pulse to spread out over time, potentially reducing the bandwidth of a link.

The three main types of dispersion mechanisms are modal dispersion, chromatic dispersion and polarization mode dispersion. Because these mechanisms affect different fiber networks in different ways, we'll discuss each in some depth.

## Modal Dispersion

In general, the "How to Speak Fiber Geek" series has focused on single-mode fibers since they comprise the vast majority of fiber kilometers deployed around the world. In contrast to multimode fibers, single-mode fibers are used for all high-capacity, long-distance networks due to their low attenuation and high bandwidth. A main limiting factor of multimode fibers is modal dispersion.

Multimode fibers carry multiple modes of light at the same time. While a mode of light can be thought of as a ray of light, a typical multimode fiber can have up to 17 modes of light traveling at once. These modes all traverse slightly different paths through the fiber, with some path lengths longer than others. Modes that take a straighter path will arrive sooner, and modes that bounce along the outer edges of the core of the fiber take a longer path and arrive later. The effect on the end pulse is called modal dispersion, since it is due to the different modes in the fiber. Multimode fibers are designed to reduce the amount of modal dispersion with precise control of the index of refraction profile, through the amount of dopants used in the core. However, it isn't possible to completely eliminate modal dispersion in multimode fibers.



Modal dispersion in multimode fiber- different modes take different paths through the fiber.

Single-mode fibers carry one mode of light and have no modal dispersion.

By definition, single-mode fibers carry a single mode of light. This means there is no modal dispersion in single-mode fibers, a fact which enables these fibers to have higher bandwidth than multimode fibers. Although single-mode fibers lack modal dispersion, they have a very important, peripherally-related specification which is the cutoff wavelength. The cutoff wavelength is the wavelength below which the fiber can carry more than one mode, and ceases to be single-mode. The cutoff wavelength is specified below the wavelength range where the fibers are expected to operate. For fibers meeting ITU Recommendation G.652 (the most common fibers in the world today), the cutoff wavelength is 1260 nm.

**Chromatic Dispersion**

Chromatic dispersion describes a combination of two separate types of dispersion, namely material dispersion and waveguide dispersion. Light travels at different speeds at different wavelengths, and all laser pulses are transmitted over a wavelength range. Light also travels at different speeds through different materials. These varying speeds cause pulses to either spread out or compress as they travel down the fiber. Fiber designers can use these two points to customize the index of refraction profile to produce fibers for different applications. Chromatic dispersion isn't always a bad thing. In fact, it can be used as a tool to help optimize network performance.

For example, the first lasers used for fiber transmission operated at 1310 nm, and many networks still use that wavelength. Fiber designers therefore developed the first single-mode fibers to have minimum or zero dispersion at this wavelength. In fact, G.652 fibers are still designed this way. In these fibers, dispersion is higher in the 1550 nm window.

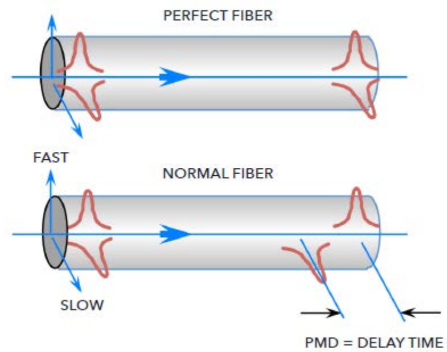
As we discussed in Article 2, loss is lower in the 1550 nm window. For this reason, fiber designers have developed several types of fibers to operate with lower dispersion in this wavelength band.

Today's networks often operate with multiple wavelengths running over them. In these networks, non-linear effects that result from the multiple wavelengths can affect network operation. We'll give a brief overview of some of these non-linear effects in this article. Chromatic dispersion is often used as a tool to help optimize these types of networks.

By changing the index of refraction profile to either speed up or slow down light at certain wavelengths, fiber designers can effectively compensate for chromatic dispersion in a network. Dispersion compensating fiber is used for this purpose. Also, for 100 Gbps+ long-distance networks with coherent optics, some chromatic dispersion compensation can take place in the signal processing in the electronics. However, there are limits to the amount of compensation that occurs in the electronics.

**Polarization Mode Dispersion (PMD)**

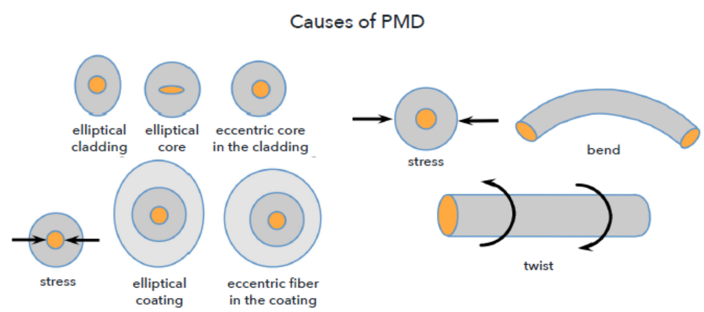
Light is an electromagnetic wave, and is comprised of two polarizations that travel down the fiber at the same time. In a perfectly round fiber deployed with perfectly balanced external stresses, these polarizations would reach the end of the fiber at the same time. Of course, our world isn't perfect. Even small amounts of glass ovality/non-concentricity or non-concentric stresses in the cable can cause one of the polarizations to travel faster than the other, spreading out in time as they travel along the fiber. This phenomenon is called polarization mode dispersion (PMD).




Polarization mode dispersion - delay in the two polarizations traveling down a fiber.

For networks < 2.5 Gbps, even for distances longer than 1000 km, PMD is not typically an issue. However, as speeds increase, it becomes a more important parameter. Operators with networks > 10 Gbps need to pay attention to PMD.

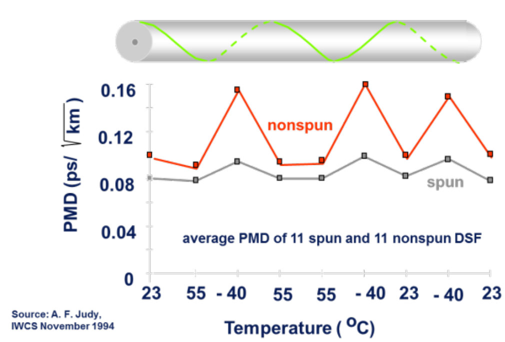
PMD is an interesting parameter, since it can be affected by the fiber manufacturing process, cabling, installation and the operating environment of the cable.




PMD is affected by fiber manufacturing, cabling and installation and operating conditions.

Cabling and installation affect PMD, and even things like vibration from trains moving down tracks or wind-induced aerial cable vibrations can affect PMD. However, the impacts of these interactions are typically smaller than the inherent PMD caused by the glass manufacturing process.

There are ways to mitigate PMD. One very effective method is to make the glass fiber as geometrically round and consistent as possible. OFS uses a special technique to accomplish this. Using a patented process called fiber "spinning"; half-twists are translated through the fiber during the draw process, reducing the non-concentricities and ovalities in the glass that are the major contributors to increased PMD.




Spinning fiber is an effective way to mitigate PMD.

Finally, there are methods to compensate for PMD in already-operational networks, but they are less common in networks operating at < 100 Gbps. Networks using coherent optics with > 100 Gbps transmission speeds use digital signal processing techniques to electronically compensate for both PMD and Chromatic Dispersion.

**Non-Linear Effects**

There are a host of other factors that network, equipment and fiber designers have needed to take into account as network capabilities have grown over the years. These often result as we collectively add more and more wavelengths of traffic at greater speeds and higher power levels.

It is not the intent of this article to review each of these in depth, but to touch on them so the reader can have a passing familiarity. The highest profile of these is four-wave mixing, which led to the development of non-zero dispersion-shifted fibers (NZDF). However, other non-linear effects include self-phase modulation, cross-phase modulation, Raman and Brillouin scattering and others. As mentioned earlier, chromatic dispersion can be used to offset the effects of four-wave mixing. For those non-linear effects related to higher power levels, increasing the effective area where the light travels down the fiber can help to reduce the impact of these other non-linear effects.

Dispersions and non-linear effects are the least understood in the general fiber user population, mainly because the guidelines used to match up today’s fibers and electronics typically work so that the end user doesn’t need to have a detailed background to bring up a system.

However, fiber geekdom is a journey, not a destination, and there’s always more to learn. OFS has multiple decades of experience with fiber optic networks. Please contact your local OFS representative if you would like additional information regarding any of the items in this article.