Understanding Fiber Optics

ofs
A Furukawa Company

Polarization Mode Dispersion

Polarization Mode Dispersion (PMD) is a serious problem that can limit distances and data rates in a single-mode optical fiber system. PMD is a time varying quantity that degrades system bandwidth and is costly to mitigate. It affects network reliability and is becoming more evident as network speeds increase.

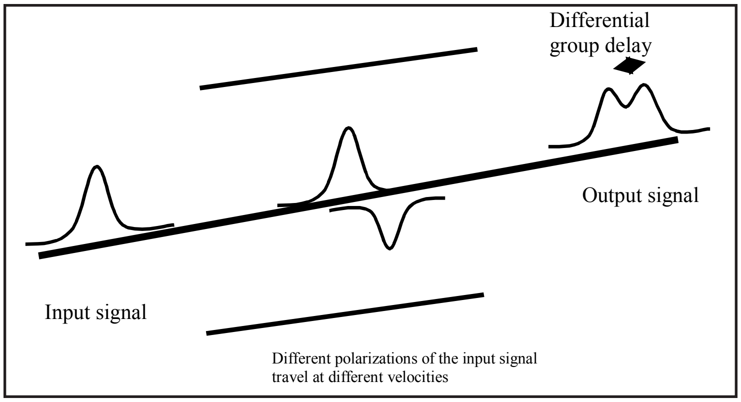
The impact of PMD was first noticed in CATV transmissions due to the sensitive nature of the analog signal. But as networks migrate to higher speeds, the effect becomes more apparent, to the point where it is now affecting some short haul (metro) transmissions. And as bit rates continue to increase, the impact on the reliability, reach, and bandwidth of single-mode fiber optic systems will be more pronounced. Further complicating matters, PMD is a random, statistically based phenomenon and is often measured improperly.

What is PMD?

When light travels down a single-mode fiber toward the receiver, the "single mode" is actually made up of two modes associated with the principle states of polarization in the fiber. In a perfect fiber these two modes travel at the same speed, but in real fibers asymmetries and imperfections can cause the modes to have different propagation speeds. This effect, known as birefringence, is proportional to the difference in the refractive indexes of the two principle states. As this polarization evolves along the length of a single-mode fiber, it can spread the pulse enough to make it overlap with other pulses or change its own shape until it is undetectable at the receiver.

The amount of pulse spreading caused by the difference in speeds of the principal modes is called differential group delay (DGD), measured in picoseconds (10^{-12} seconds). Small variations along the optical fiber can affect DGD, and may even cause the light to switch randomly between the two polarization states as it propagates down the fiber. Consequently, DGD can vary with time and wavelength.

The PMD coefficient is a length-normalized statistical average of the DGD values that can be used by system designers to help ensure the reliability of the system.



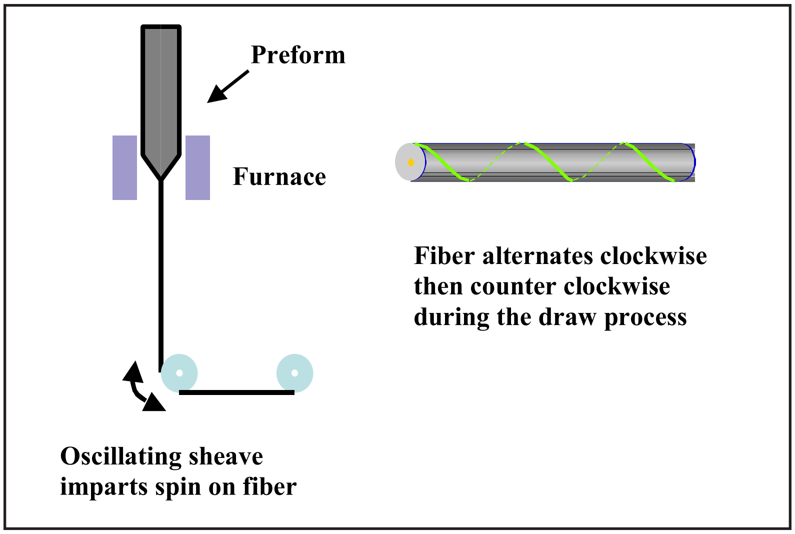
In addition to fiber geometry, PMD also is created by external forces such as bends, twists, and stress. The external causes can be timedependent, especially when the fiber is cabled and deployed in a network. Here, the fiber is subjected to time-varying stresses due to temperature changes, cable configuration and/or mechanical vibrations (like trucks or trains passing nearby), making compensation difficult.

Manufacturing Fiber to Reduce PMD

Many of the causes of fiber PMD result from the manufacturing process. Traditional single-mode fiber with perfectly symmetric cores drawn with no non-uniformities is expected to have very low PMD. However, even with these precautions these fibers are highly susceptible to external sources of stress, an effect only noticed as network speeds increased. This has led to the development of "built-in" methods to control birefringence, and thus PMD.

A patented OFS technology creates a "spin" within the fiber during the draw process. This built-in spin reduces birefringence by mixing the light between the two polarizations, which enables the fiber to exhibit ultra low PMD. In this process, an oscillating sheave imparts spin to the fiber at the base of the draw tower. The spin then propagates upward to the neck-down region where the molten glass is spun first one way and then the other. As the glass cools, the spin is "locked in" to the fiber. The angle of the spin and the rate of oscillation can be varied to impart different end-use characteristics.

Process control during fiber production can also help to reduce the possibility of high fiber PMD. Careful production techniques are required to minimize assymetries in the core rod, cladding and coating of the optical fiber.



Minimizing defects such as bubbles in the preform and airlines in the fiber is vital to the process. And, although the spinning process is designed to impart spin within the fiber, all external stresses must be minimized.

Difficult to Measure

PMD is difficult to measure and meaningfully specify because of two key challenges: first, PMD is extremely sensitive to the measurement conditions; second, the property when measured in fiber form can differ from that in the installed cable. Further difficulty arises from the statistical nature of PMD. Of particular interest to the network installer is the differential group delay of an installed group of linked, or "concatenated" fiber sections rather than an individual fiber.

Polarization Mode Dispersion (PMD)

The goal of the fiber supplier is to develop a measurement methodology that will determine what PMD will be observed in the cabled fiber once it is installed. Simply measuring the PMD "on spool" as it comes off the production line is not a good indicator of PMD in installed fiber. With non-spun fiber, "on spool" PMD values tend to be low due to randomization caused by the spooled fiber itself. Taken off the spool, these fibers exhibit higher PMD when measured on a flat surface under no tension. Conversely, spun fibers, which often show similar on-spool PMD values to non-spun fibers, actually register lower PMD when measured on a flat surface under no tension.

If measuring "on spool" is not a reliable indicator of network performance, what is? The International Telecommunications Union (ITU) recommends measuring a 30 cm diameter coil of fiber at less than 15 grams of tension. But even this bending diameter can elevate the PMD in the best fibers. Additionally, due to the statistical nature of PMD, many wavelengths need to be measured before one can assess the PMD.

Link design value (LDV) is a useful design parameter for estimating the worst-case contribution of the fiber toward the overall system PMD of a link. LDV, also referred to as PMDQ, is used to evaluate the impact of fiber-related PMD where cabled fibers are deployed in concatenated sections. The LDV is the expected worst case PMD of the end-to-end link made up of randomly chosen cable sections spliced together and deployed. IEC standards indicate that LDV should have a maximum cumulative distribution Q of nominally 0.001 to 0.0001. This implies that 0.1% to 0.01% of all spans (made up of concatenated sections) would be above this level of PMD.

The cabling process can elevate PMD by putting stresses on the fiber. Thus, the PMD measured by the fiber supplier should be considered a best-case scenario. Cable designs must be qualified to determine their impact on PMD. Measuring cable reels can give a good indication of how the fiber will behave in the field, but it is best accomplished by measuring PMD on installed cables and comparing the results to fiber data. When all these factors are taken into consideration, one can truly see the importance of specifying single-mode fiber that uses proper PMD mitigating technology.

It's important to look beyond the current standards when specifying PMD requirements. Why? Because in designing a fiber link, both the transmission speed and the transmission distance must be considered. The tightest PMD specification published by ITU recommends a PMDQ < 0.2 ps/sqrt (km). While this specification may be sufficient for 2.5 and 10 Gb/s transmission rates, it is not sufficient for many systems as data rates progress towards 40 Gb/s or higher. In many cases, the transceivers contribute to the system PMD as well, making high-speed transmission even more challenging. For best results, be sure to select an optical fiber with a PMD Link Design Value of less than 0.06 ps/sqrt (km).

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