Technology Note

Polarization of Light in Fiber Causes Signal Dispersion

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The capabilities of fiber-optic communication networks depend greatly on the performance of optical fibers and cables. Transmission range and rate are the two main optical link parameters that system designers seek to maximize. Range is mainly a function of transmitter output power, receiver sensibility, and loss in the fiber. Rate is mainly limited by transmitter and receiver frequency response as well as dispersion (chromatic, intermodal, or polarization mode) in the fiber. While chromatic and intermodal dispersions can be corrected and fairly well controlled, it is difficult to compensate for a stochastic phenomenon such as polarization mode dispersion (PMD). In spite of these difficulties, it is essential to deal with PMD since it adversely affects signal transmission rates of fiber-optic networks.

Definition

PMD is due to the difference in speed of the polarization modes of a light wave travelling in an optical fiber. This difference in speed results from birefringence, a phenomenon whereby the effective index of refraction differs from one input polarization state to another.

Birefringence is caused by small defects in the manufacturing process, bends, and other mechanical stresses that may affect the circular fiber geometry. The magnitude of this effect at any given point in standard telecom fiber is usually quite small, and its orientation (the axes of the birefringence) normally varies along the length.

The polarization state of a light pulse can always be decomposed into orthogonal polarization modes. Any small segment of birefringent fiber will decompose the incident light into polarization modes corresponding to the axes of birefringence[1] (assuming this light is not already polarized along one of the principal axes). As a consequence, a propagation delay will result as the pulse passes through this segment. This decomposition of the pulse into two pulses (corresponding to each polarization mode) is in fact the general effect when the birefringent axes remain invariant along the full length of the fiber, as is the case with so-called HiBi or polarization maintaining fiber (see Figure 1).

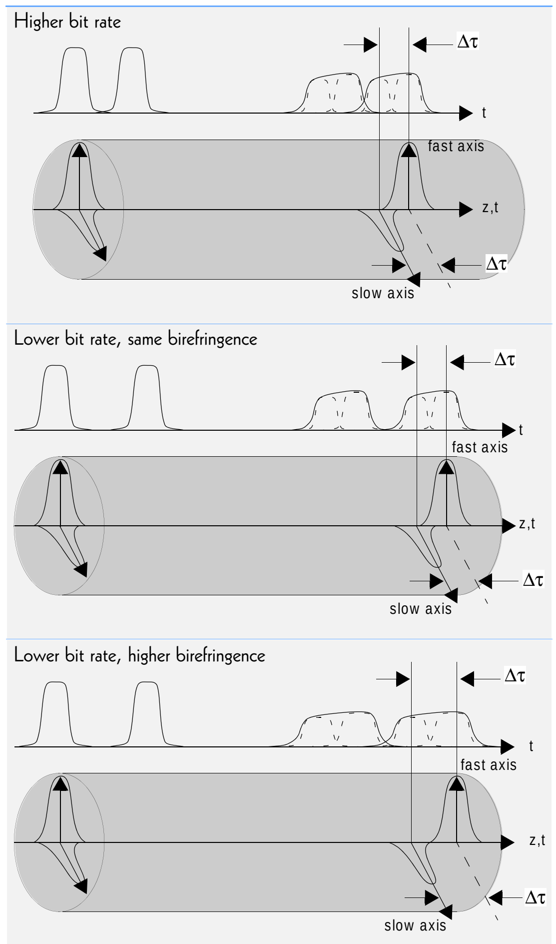

Figure 1. *Effects of birefrengence on the DGD (Δτ) and on the pulse passing through a fiber*

1.There is frequent confusion between the terms "axes of birefringence" and "input (and output) principal states of polarization (PSP)". The former refers to a local orientation of the fast and slow axes in the fiber, based upon the physical geometry of the fiber. The latter refers to the two (generally orthogonal) states of polarization of a (monochromatic) input light pulse which pass through a birefringent medium, including a concatenation of randomly-oriented birefringent elements, without spreading. The two corresponding states of polarization of such a pulse as it exits the medium are referred to as the "output PSPs", which are, in general, different from those of the input PSPs. For a constant birefringence medium (e.g. high birefringence fiber), the axes of birefringence and the PSPs are the same, but for a complicated medium having local birefringence which changes along its length (e.g. concatenated high birefringence fibers), the input and output PSPs in general do not correspond to the axes of birefringence (anywhere along the fiber).

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However, in the case of standard telecommunication fiber, the orientation of the birefringent axis varies. There is then a cumulative effect of many, randomly-oriented birefringent segments, leading to a mixing (and partial depolarization) of the polarization states. As a consequence, instead of being split into two distinct output pulses, the output pulse is broadened in time (see Figure 1). The magnitude of this broadening is sensitive to environmental perturbations, and hence is a stochastic phenomenon that can only be determined from a series of statistically averaged measurements.

Units and Measurements

The units in which PMD is expressed depend on the mode coupling in the system under test. Generally speaking, mode coupling is the exchange of energy among modes. In the context of polarization of light, it is the level of energy exchange between the two PSPs.

PMD delay is usually expressed in picoseconds (ps = 10^{-12} seconds), which for a cable or fiber can be given as a coefficient over a known fiber or cable length (in km). If the mode coupling is weak (or negligible), PMD is expressed in ps for discrete components, and in terms of a PMD coefficient in ps/km for HiBi fiber (polarization maintaining fiber). In the case of strong (or random) mode coupling, this coefficient is expressed in ps/km$^{1/2}$.

For a polarization-maintaining fiber, a short length of singlemode fiber, an isolator, or a coupler, mode coupling is weak (or negligible) and PMD delay is usually small, typically 0.5 ps or less (except for isolators, some of which exhibit PMD values over 0.5 ps). For long cable lengths (such as in the field), mode coupling is usually strong (or random).

Applications

PMD measurement applications can be divided into four levels.

1. Fiber manufacturing process
2. Cable manufacturing
3. Cable installation evaluation
4. Existing network upgrade evaluation

The first two levels take place at the plant and concern the fiber manufacturer. PMD in singlemode fiber is caused by asymmetry of the optical fiber introduced during its fabrication. Monitoring this parameter allows the manufacturer to improve or better characterize the fiber-drawing process in order to reduce undesirable birefringence. During the assembly process, even if the individual fibers present low PMD, additional PMD may be induced through stress. It has been demonstrated that, in a large cable, inner fibers have higher PMD delays than outer fibers.

The last two levels take place in the field. In order to detect problems caused while installing the cable, PMD measurement is advised after installation. This is also useful to determine fiber characteristics when upgrading network systems to operate at higher bit rates. Fibers that have never been tested for PMD may have extremely high PMD delays.

Conclusion

PMD is now an important consideration in high-speed digital and analog networks. It has to be measured not only after manufacturing but also after cabling and installation, since mechanical bends and pressure points can change the birefringence, thus affecting PMD. With the use of erbium doped fiber amplifiers (EDFAs) to increase fiber span, all sources of dispersion must be minimized and controlled (or at least compensated for) otherwise improvements in range will be undermined by bandwidth limitations. ❑

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