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Using the OFS TruePhase® IPLM Inline Polarimeter for PMD Measurement

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Small form factor, all-fiber device for real-time, high-speed optical signal monitoring

Abstract

Today, it has become an imperative for fiber-optic network planners to consider physical layer attributes such as dispersion. As network infrastructures increase adoption of 40Gb/s and 100Gb/s solutions, impairments due to dispersion seriously impact the bandwidth capacity of the network as well as the quality of service. Therefore, characterization and subsequent mitigation of dispersion impairments on a fiber-optic link continue to be critical issues for network operators, especially for fiber segments that are prone to environmental conditions. Presently, there are several techniques, from simply lowering the speed of the fiber to using expensive coherent receivers for electronic compensation, which may only compensate to a certain limit. An alternative solution is to use a small form factor device for real-time, high-speed monitoring of dispersion impairments, which can then be used effectively to make compensative corrections. This white paper discusses the TruePhase IPLM Inline Polarimeter from OFS, which is just such a solution that can be easily integrated to make optical networks much more reliable.

Introduction

As terrestrial and submarine fiber-optic networks are planned and deployed, specifications for critical physical layer attributes such as the waveguide dispersion of the installed fiber plant must be considered. Such attributes are now even more critical as 40Gb/s and 100Gb/s deployment increases due to bandwidth demand for a number of applications. Polarization mode dispersion (PMD) is one form of dispersion, the other being chromatic dispersion (CD). They can cause serious impairments in optical network infrastructure performance, especially over long distances.

The effect of PMD is to broaden an input pulse due to a phase delay between the polarization states of the signal. While this impairment can significantly impact legacy optical fiber links, it imposes even more stringent requirements at 40Gb/s.

As network operators leverage and upgrade their network infrastructure to offer more services, the tolerance of impairments such as CD and PMD has a significant effect on their upgrade strategies. For instance, when mean PMD exceeds a certain value for a link, the OSNR allowance set aside for this degradation at a given data rate is also exceeded.

(a) Without PMD (b) With PMD

Figure 1 Fiber with and without PMD

Figure 1 shows an example of a fiber with and without PMD. Differential Group Delay (DGD) is the difference in propagation time between pulses propagating in the two orthogonal polarization modes. DGD is also known as first-order PMD. Second-order PMD (SOPMD) describes the wavelength dependence of DGD and has two components, namely depolarization and polarization dependent chromatic dispersion.

When CD exceeds system tolerance, dispersion compensating modules (DCMs) may be used to correct CD related degradations. However, effective compensators for PMD have been elusive, resulting in high PMD links being de-rated to operate at lower speeds. This is a less expensive proposition than replacing the fiber, likely making it the only option. Presently, the industry is investigating the use of coherent receivers that have the ability to partially compensate PMD electronically. However, these solutions are immature and expensive to deploy as well as operate. In addition, it is also unclear how well coherent receivers can accommodate a wide range of PMD characteristics. Thus, coherent detection may compensate PMD only up to a certain limit. Therefore, PMD characterization and its mitigation remain critical issues for a subset of optical links in virtually any network.

PMD is a complex and random effect, as polarization changes are influenced by the interplay of a wide range of parameters, such as fiber manufacturing imperfections, birefringence properties of the fiber and slight changes in environmental conditions including mechanical stresses (bending, twisting or pinching) and thermal fluctuations. In addition, the overall link is crafted by splicing a number of shorter fiber sections for practical deployment into ducts or in-ground conduits. Each of these fiber sections may have different PMD properties as they are pulled randomly from inventory. Such variances in deployment, drives an added need for effective link characterization as only a few cable sections can cause high PMD for the entire link.

PMD Measurement

Fiber PMD is similar to the effects of optical birefringence and may be measured with the aid of polarimetric devices. The usual method of measuring fiber PMD is to analyze the evolution of the state of polarization (SOP) as a function of wavelength. The SOP is described by using the Stokes parameters, S_0, S_1, S_2, and S_3, where S_0 is simply the total optical power.

SOP evolution is best represented by a point moving on the Poincaré Sphere. Complete sphere coverage, implying light randomly visiting all states of polarization as it would occur for unpolarized light, also enables accurate measurement of SOP. For fully polarized light ($S_0 = 1$) the point lies on the surface of the sphere, whereas for partially polarized light ($S_0 < 1$) the point lies inside the sphere. **Figure 2** shows examples of E-field evolution for various polarization states.

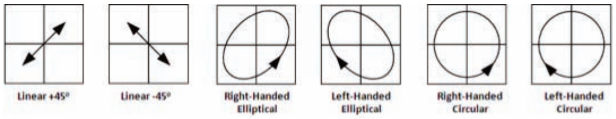

Figure 2 Examples of various Polarization States

In reality, telecom signals are not fully polarized or fully unpolarized. A parameter related to SOP, the degree of polarization (DOP), measures the ratio of optical power that is fully polarized (or the intensity of polarized light) to the total power of the signal (intensity of polarized and unpolarized light).

DOP can be used as a measure of PMD signal degradation, regardless of format and bit rate, as long as the light signals were initially fully polarized at the transmitter. This can occur in a system using single polarization DPSK modulation. A DOP of 100% indicates a fully polarized wave whereas a DOP of 0% indicates a completely unpolarized wave. The DOP can be represented on the Poincaré Sphere as the distance from the co-ordinate origin of the sphere to the sphere surface, varying from zero (unpolarized light) to unity at the surface of the sphere (fully polarized light). One advantage of DOP measurement is that it can be performed at a rate in excess of most PMD changes in a system (>1MHz).

OFS TruePhase® IPLM Inline Polarimeter

Real time monitoring and mitigation of PMD requires a high speed performance monitor (>1MHz). OFS offers patented technology, the TruePhase IPLM Inline Polarimeter, which is the industry's first commercial smallest form factor, low loss, in-line all-fiber polarimetric detector module. The TruePhase IPLM provides high-speed polarization characterization measurements without compromising the data traffic.

Since PMD is essentially a polarization effect, the full state of polarization measured by the TruePhase IPLM can be effectively used to measure real-time signal degradation. The TruePhase IPLM both measures the SOP and DOP of a signal, making it a versatile component for a broad range of applications such as PMD monitoring, DOP monitoring, PMD compensation, measurement of optical power and so on. By designing the TruePhase IPLM into proprietary circuitry, no additional components such as splitters or taps are required since it is an in-line module.

The TruePhase IPLM design combines a high birefringence fiber with Bragg grating taps and photodiode outputs for accurate polarization and PMD degradation measurements. The system engineer may integrate the TruePhase IPLM into appropriate circuitry, such as transimpedance amplifiers, analog to digital converters (ADCs) and a microprocessor. The raw signals generated by the TruePhase IPLM can then be used to calculate SOP and DOP using calibration data and the formula:

$$DOP = \frac{\sqrt{S_1^2 + S_2^2 + S_3^2}}{S_0}$$

Figure 3 shows an experimental setup, where the TruePhase IPLM produces a DOP signal related to the characteristics of PMD generated by a PMD emulator. A 40G DPSK signal, for example, is launched into a polarization controller (PC) and a PMD Emulator (PMDE) to generate PMD degraded signals. A New Ridge Technologies PMD Emulator NRT 40133A was used in this arrangement to simulate the effects of a legacy high PMD link in the network infrastructure. The TruePhase IPLM determines the Stokes parameters, DOP and related PMD degradation.

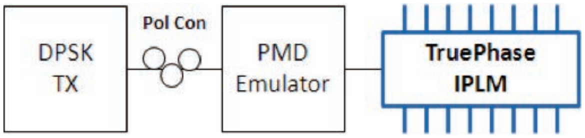

Figure 3 TruePhase IPLM Experimental setup

In real-world applications, an optional PMD Compensator (PMDC) can be integrated electronically by using the SOP and DOP signals as servo signals for the PMDC. In such an arrangement, the TruePhase IPLM is the critical element, which allows rapid changes to equalize a PMD degraded signal. Such a configuration is well suited for optical fiber links that require a fast monitoring solution, for example cable spans over aerial lines, railroads or bridge crossings.

Figure 4 shows the resulting DOP as a function of PMD for worst case setting of the Polarization Controller (Pol Con). It can be seen that the TruePhase IPLM DOP measurement tracks the DGD up to 30 ps. Similar tracking is possible for second order PMD as well.

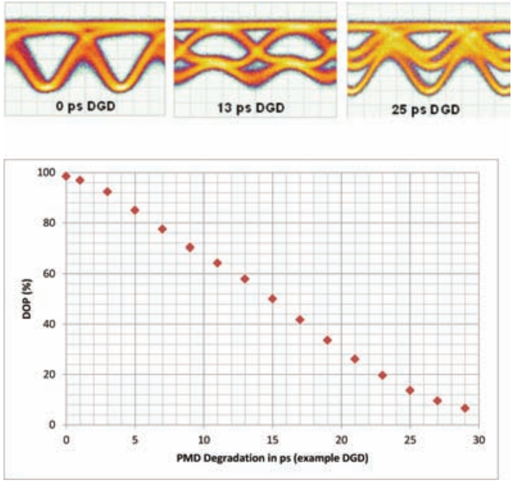

Figure 4 Measured DOP vs DGD and eye diagrams for a 40Gb/s DPSK signal

To indicate the level of PMD degradation, eye-diagrams are also shown in **Figure 4** for 0, 13 and 25 ps DGD. Note that in this setup, the initial signal was completely polarized (DOP = 100%) at the transmitter. A PMDC servo loop that maximizes the DOP will yield an improved, equalized eye diagram as shown.

Key TruePhase IPLM Features

Some of the key features of the TruePhase IPLM that make it an ideal component are:

- All-fiber integrated optical device,
- Industry's smallest form factor Polarimeter,
- Real-time, high-speed SOP, DOP measurement,
- Low insertion loss / low PDL,
- Large optical bandwidth (no channelization), and
- Hermetic packaging

Conclusion

PMD has long been a concern in optical networks for both current operation as well as upgradeability. As the optical infrastructure moves to 40Gb/s and 100Gb/s to handle increasing bandwidth demand, such concerns will only grow. A high-speed performance monitor is required to: accurately track SOP and DOP changes, qualify transmission link characteristics, provide real-time monitoring and improve transmission performance. An effective solution must have low power consumption, sufficient speed and a form factor that can be easily integrated into electronic circuitry for real-time PMD measurement and compensation. The OFS TruePhase IPLM Inline Polarimeter is just such a device. It can be easily designed into telecommunication systems for optical transport, diagnostics or test and measurement (T&M) solutions. OFS also has extensive expertise in understanding of polarization properties and characteristics, which can be leveraged to help design the TruePhase IPLM into proprietary circuitry for a wide range of specific applications.

About OFS Fitel, LLC.

OFS Specialty Photonics, a division of OFS Fitel LLC., is an industry leader for optical innovation as a world-leading designer, manufacturer and provider of specialty optical fibers, fiber-based devices, gratings, optical connectivity and specialty photonics products. The TruePhase IPLM Inline Polarimeter module is another patented innovation that leverages OFS competencies in fiber technologies, optical fiber design, fiber gratings and lasers.

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