White Paper

Testing Polarization Mode Dispersion on Aerial Cables

Introduction

Polarization Mode Dispersion (PMD) is a limiting parameter of high bit rate optical transmission system. Testing PMD is essential in order to characterize the fiber's suitability to support high speed transmission such as 10 Gb/s, 40 Gb/s or even 100 Gb/s. Polarization related effects can be sensitive to a number of environmental constraints, such as movement in cables that causes a change in the State of Polarization (SOP) of the light in the fiber. This change in the SOP can affect some PMD test methods (and also some advanced transmission systems!). Understanding the dynamics of these polarization related effects and their impact on measurements and systems is one of the most complex issues in fiber optics today.

How do environmental constraints and mechanical variations influence PMD?

An optical fiber link can be decomposed of short discrete sections or individual pieces of fiber. Each section has a slightly different core asymmetry, resulting in what is known as birefringence, a change in the refractive index of the fiber for different polarization states of light. When polarized light (with a State of Polarization at any given point) travels down the fiber from one section to another one, strong polarization mode coupling variations occur, changing the SOP of the optical signal.

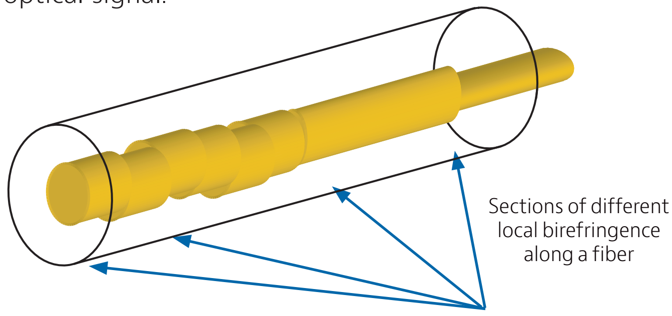

Figure 1: Birefringent section randomly concentrated

Environmental factors or external stresses (such as temperature or wind effects for aerial cables) may cause some stress-induced birefringence on the fiber as well as causing random variations in the polarization mode coupling along the fiber link. A change in the fiber's birefringence will change its PMD. However, it should be noted that a good cable that has been well installed will be designed to isolate the fiber from the stresses and strains that cause a change in the PMD of the fiber.

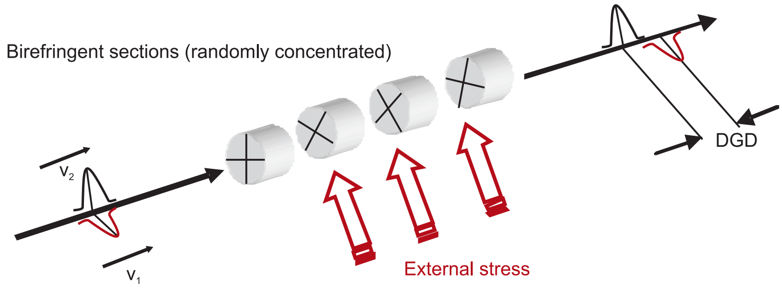

Figure 2: Strong mode coupling in telecommunications optical fiber

An optical fiber can have several propagation modes, a coupling can occur between different modes and also between different polarization states.

Weather-induced Oscillations on Aerial Cables

Aerial cables are widely developed for fiber links. Their installation is less expensive than underground cables. Various types of cables are deployed in the field such as OPGW, ADSS, Wrap and ribbon cables. A lot of telecommunication companies and carriers use such links for their network.

Figure 3: Picture of an OPGW

Optical Power Ground Wire (OPGW)

An optical power ground wire (also known as an OPGW or, in the IEEE standard, an optical fiber composite overhead ground wire) is a type of cable that is used in the construction of electric power transmission and distribution lines. Such cable combines the functions of grounding and communications. One design of OPGW cable contains a tubular structure with one or more optical fibers in it, surrounded by layers of steel and aluminum wire. Another design replaces some of the wires with stainless steel tubes containing fibers as shown in Figure 5. The OPGW cable is run between the tops of high-voltage electricity pylons.

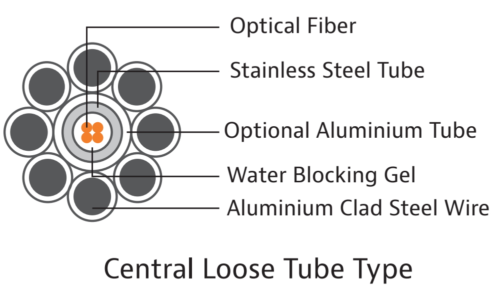

Figure 4: Schematic of an OPGW cable

Figure 5: Example of an OPGW cable

Wind Velocity

Under certain conditions if the wind reaches a high speed, some effects can disturb the fiber transmission. Oscillations created by the wind effect may cause a resonance and a deformation of the cable, for instance bends. Thus, the fiber under stress and twisted will undergo changes of its birefringence: A parameter which modifies the distribution of the DGD as function of wavelength, and even the PMD of the fiber.

Wind Gust

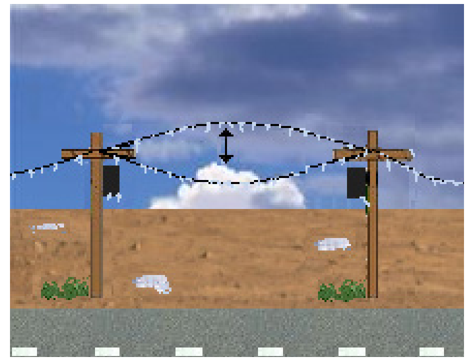

Figure 6: Ice galloping effects on an aerial cable

A gust is defined as a sudden and brief increase of wind. A gust can reach a speed 50% higher than the mean wind. The speed of a gust is expressed in km/h or mi/h. When the instantaneous wind speed exceeds of 18.5 to 27.8 km/h the wind speed average, meteorologists use the word "gust". The term "strong gusts" is used when the difference reaches 27.8 to 46.3 km/h and "violent gusts" when it exceeds 46.3 km/h (Meteo France).

Gusts have an influence on cables as they may cause oscillations and high amplitude movements. They create bends and slight modification in the cable shape. This obviously has consequences on birefringence and polarization, hence on PMD.

Cable Galloping (Vibrations)

Galloping is a phenomenon which appears when temperature is sufficiently low and when particular wind conditions occur. In terms of mechanics, galloping changes the static force coefficients and induces deformations which tend towards something elliptic. The galloping uncontrolled vibrations are characterized by low frequencies and large amplitudes. Although there are different ways of reducing the galloping effect on OPGW, such as 'dog-bones' or Stockbridge dampers devices, the uncontrolled vibrations are characterized by low frequencies and large amplitudes. It will induce a significant impact on SOP and possibly the PMD of fibers in cables that are experiencing such effects.

Current-induced Oscillations (Hum)

Hum is a very audible underneath high voltage line phenomenon which can make cables to vibrate. In some aerial cables, where fiber and copper are both present, oscillations due to electricity can occur at 50 Hz or 60 Hz (frequencies on the electricity network). Thus, oscillations of SOP linked to the electric signal frequency are generated. Many field observations show that the spectral power density S varies proportionally with the square of the intensity I^2. It Implies that SOP varies linearly with the current $I(t)$.

This coupling is carried by the magnetic field around the current-bearing cables. Such a magnetic field may affect the optical transmission in at least two different ways: either indirectly, through some sorts of mechanical vibrations, or directly through magneto-optic coupling in the fiber.

The magnetic induction thus created is $B = \dfrac{I.\mu_0}{2\pi.d}$, where d is the distance and μ_0 is the vacuum permeability.

Faraday's effect could explain a linear dependence of polarization on B. Due to non perfect parallelism of the transmission line; B has a spatial varying component in the direction of the fiber. This induces a Faraday rotation which adds a random effect which can be strong enough to explain 50 Hz oscillation of the SOP. Therefore, magnetically induced circular birefringence may also influence the statistic variation of PMD.

Impact on polarization and dispersion

As presented above, wind on an aerial cable may induce birefringence changes and polarization coupling changes as function of time. These directly translate into temporal changes of the map of the DGDs vs. wavelengths, but also of map of the Principal States of Polarization vs. wavelength. More globally the mean DGD (PMD) of the link fluctuates. These fluctuations are real and characteristics of the dynamics of the PMD of the link.

Of course one would expect from the perfect measurement tool to be able to monitor these fluctuations accurately. As we will see below, different measurement tools are affected differently by cable movements.

Theoretical Sensitivity to Mechanical Disturbances on PMD Test Methods

Depending on the test method in use, the test instrument can be perturbed by the fluctuations of the cable. Let us distinguish two types of disturbances:

Type I disturbances

Some instruments are sensitive to polarization launch conditions at the input and at the output of the fiber under test. For such test instruments, the fluctuations of the cable from measurement to another one will induce changes of the PMD reading, no matter if the PMD itself has changed or not. This must be seen as a measurement repeatability issue. Since the PSPs vary with wavelength and this variation gets faster when PMD is high, the type I disturbances is lower when the wavelength span of the measurement or the PMD is large. Simulations and measurements confirmed that this disturbances scales inversely with the square root of the wavelength Span x PMD.

This disturbances can be reduced with the use of polarization scramblers or controllers and by averaging PMD measurements over several launch conditions.

Type II disturbances

Some other methods are sensitive to fluctuations of the polarization transfer properties during the measurement. In this latter case a variable measurement offset is introduced, affecting both the repeatability and the absolute uncertainty of the measurement.

Fixed Analyzer (FA) Method

Defined by the IEC 61280-4-4, the Fixed Analyzer method records an optical spectrum through a polarizer representative of the typical polarization variations as function of wavelength. In order to remove any dependency to the spectral shape of the source, the spectrum is also recorded (without polarizer), and the spectrum passing through the polarizer is then normalized. Neither the polarization state of the source nor the orientation of the polarizer are controlled with respect to the fiber PSPs, this method therefore exhibits a dependency to launch conditions. However the Fixed Analyzer can have an effective measurement span of 190 nm (VIAVI solution) and the type I disturbances is then significantly reduced.

Wind may generate polarization state rotation during the spectrum recording. In practice, the scan of a tunable filter or a tunable laser always requires a finite time. If the scan isn't performed fast enough, then the instrument would record the temporal variations of the polarization and assimilate them with a spectral variation of the polarization, leading to an overestimation of the PMD. The important parameter characterizing the robustness of a Fixed Analyzer-based instrument is therefore the speed of the tunable filter scan. Typically the scan rate of the VIAVI solution is of 200 nm/1.5 s = 133 nm/s.

Jones Matrix Eigen Analysis (JME) (or Stokes Parameter Evaluation) Method

Defined by the IEC 61280-4-4, this method provides the complete information of the optical frequency dependence of the polarization dispersion vector. The magnitude of this vector is the differential group delay (DGD) and its orientation yields the principal states of the fiber under test. At each of these frequencies, a polarization controller is adjusted to 3 different polarization states (linearly polarized light to the fiber under test 0°, 45°, and 90° for instance). The 3 known states of polarization at the input, and the polarimetric information recorded at the output provide the complete transfer matrix of the fiber under test as function of wavelength.

In principle, there is no Type I disturbances in this measurement. This method suffers from the same dependency as the Fixed Analyzer to fiber movements during the recording. In order to achieve the same robustness as a Fixed Analyzer solution, the JME needs to perform a wavelength scan in a very short timeframe, with the added difficulty that 3 spectra must be taken for the 3 input states.

Interferometry: Traditional (TINTY) Method

Defined by the IEC 61280-4-4, this method records the interferogram of the transmitted spectrum through a polarizer. It is known since Chamberlain's work on Interferometric Spectroscopy, that an interferogram is equivalent to the Fourier transform of the spectrum; therefore the information obtained is mathematically equivalent to the Fixed Analyzer. Without any control of the polarization launch conditions, the method suffers from the type I disturbances. A major difference with the Fixed Analyzer is that interferometer works in the time domain rather than in the spectral domain. This difference has several consequences:

- No spectral shape normalization is possible with the Interferometric setup. The shape of the transmitted spectrum creates an auto-correlation peak in the interferogram. An algorithm is often used to remove the central autocorrelation peak, which contains no PMD information.
- The effective wavelength span is the width of the source, which corresponds to about 60 nm Full Width Half maximum (FWHM) for a regular SLED. Compared to a Fixed Analyzer solution with 190 nm wavelength span, it is nearly a factor 2 penalty on the type I disturbances.

Interferometry: Generalized Method (GINTY)

Defined by the IEC 61280-4-4, the generalized method provides an alternative solution to get rid of the auto-correlation peak: It uses 2 signals of a polarization diversity detection scheme. However, since the width of the auto-correlation peak is a matter of ~100 fs, the real benefit of this method would only be perceivable when using additional polarization scramblers at each end of the fiber under test, allowing to improving absolute uncertainty of the measurement results.

As the TINTY, the generalized method provides the same drawback of a relatively small wavelength span (Type I uncertainty) and the advantage of a theoretical immunity to fiber movements.

Wavelength-scanning OTDR and States-of-polarization Analysis (WSOSPA)

This is a single ended method based on OTDR principle; a pulse from a tunable light source is launched into the fiber and reflected at the far end. The round-trip transfer function of the fiber is characterized by analyzing the polarization changes as function of wavelength, as perceived by a polarization diversity detector. The forward path PMD of the fiber is deduced from the round-trip PMD that is measurable.

A polarization scrambler is used and the average data are compiled. Therefore, there is no type I uncertainty introduced at the front end of the fiber. However, the polarization launch conditions at the far end is not controlled, resulting in a type I uncertainty of a different kind than the Fixed Analyzer and the Interferometric (INTY) methods, introduced as the round-trip uncertainty. In the math processing, data from pairs of wavelengths are considered, and it is essential that the polarization transfer function of the fiber remains stable during that time otherwise resulting in a large type II uncertainty.

Here again the tuning time is the important parameter. According to TIA-455-243, it takes about 0.2s to measure at two wavelengths separated by typically 270 pm (the wavelength step is PMD dependent, here is a typical value for a fiber under test with 3 ps PMD), this would correspond to a scan rate of 1.35 nm/s. Meanwhile, software countermeasures have been implemented in order to double all measurements and drop the data points when temporal SOP movements are detected. This solution does not avoid the fact that if the disturbances are constant, the number of measurement points will be much reduced, increasing the absolute uncertainty of the estimated PMD, and ultimately the measurement will be impossible.

Review of PMD Measurement Sensitivity to Wind

Every method has a given level of sensitivity and dependency to fiber movement.

The table 1 summarizes the sensitivities to disturbances of the various test methods and the solutions effectively implemented on field units to counter these effects.

Type I Disturbance				**Type II Disturbance**		
Method	***Sensitive***	***Possible Solutions***	***Observed in Practice***	***Sensitive***	***Possible Solutions***	***Observed in Practice***
FA	YES	Large span pol. scramblers	Up to 190 nm VIAVI high-resolution includes scramblers	YES	Fast acquisition	133 nm/s typical
JME	NO			YES	Fast acquisition	NA
TINTY	YES	Large span pol. scramblers	60 nm none	NO		
GINTY	YES	Large span pol. scramblers	60 nm none	NO		
WSOSPA	YES	Large span pol. scramblers	146 nm On one end	YES	Fast acquisition Drop data	1.35 nm/s typical Implemented

Table 1: Sensitivities of the various test methods to disturbance

Field test campaign in Scotland

During the first week of December 2008, a PMD comparison campaign between various test methods was organized in the Glasgow suburbs (Scotland). The tests were performed upon request of the TIA TR42.11 Subcommittee. Various measurements for each method were made on different spans using various types of aerial cables. Whilst the PMD was being tested on one fiber, the rate of change of the SOP was being measured on another parallel fiber. The goal was to determine the repeatability of the PMD measurement and the sensitivity to SOP changes for the various test methods.

A practical example

One of the spans measured was an 80 km loop back from Lambhill to Wyndyhill. The fiber was fairly new and low PMD value was expected. This is by the way what should be expected for any new fiber cable deployment, especially when looking at high bit rate transmission.

Figure 7: Location of the span C inter-comparison campaign

SPAN C	
Location A: Lambhill	***Location B: Windyhill***
Date	December 4, 2008
Length of fiber route	20 km nominal
Description of cable route underground, aerial (OPGW/ADSS/Wrap)	OPGW – fairly new route so should have low PMD. Test config is looped back twice to provide 80 km route.
Weather conditions (temperature, precipitation, wind...)	Grey, wet, just above freezing, very little wind

Table 2: Test conditions of Span C measurements.

VIAVI Test Results

The broadband source was an OBS-500 stand-alone unit and the receiver module was an 81DISPAP module housed in a T-BERD®/MTS-6000 mainframe, it provided the following results:

PMD Test Method 5 – VIAVI (FA) Thursday, December 4, 2008					
	Test 1	***Test 2***	***Test 3***	***Test 4***	***Test 5***
Total PMD (ps)	1.55	1.54	1.54	1.48	1.53
PMD coefficient (ps/root km)	0.17	0.17	0.17	0.17	0.17
Data file name	5Cf1r1	5Cf1r2	5Cf1r3	5Cf1r4	5Cf1r5
Time of Test	11:00:00	11:02:00	11:04:00	11:06:00	11:08:00
Instrument settings	1449.2 to 1640 nm wavelength range				
Mean value					
1.528					

Table 3: VIAVI FA measurement results of Span C

These field tests have demonstrated that VIAVI Fixed Analyzer measurement method is stable and provides a good repeatability. Indeed, DISPAP module shows a good behavior and low sensitivity to polarization states. This is to be expected as previous lab tests have shown that the VIAVI solution provides stable results even when the rate of change of the SOP goes up to 1000 degrees per second of rotation on the Poincare sphere, as shown in Figure 8.

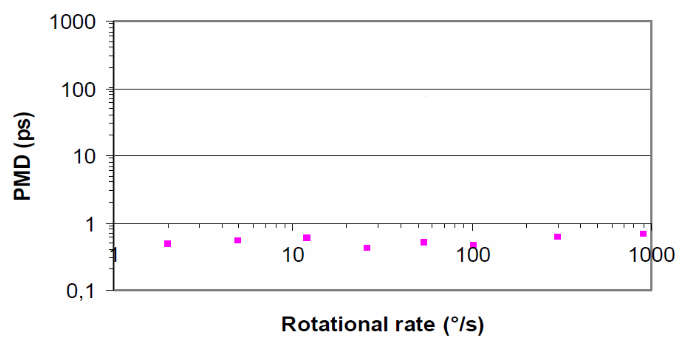

Figure 8: Sensitivity of a PMD measurement to a rotating half-wave plate placed before a 50 km fiber – Total insertion loss = 12 dB.

The analysis of the rate of change of the state of polarization on the Span C fiber shows that even at the windiest part of the day before the main measurements started that the rate of change of the SOP was well below this, as show in figure 9.

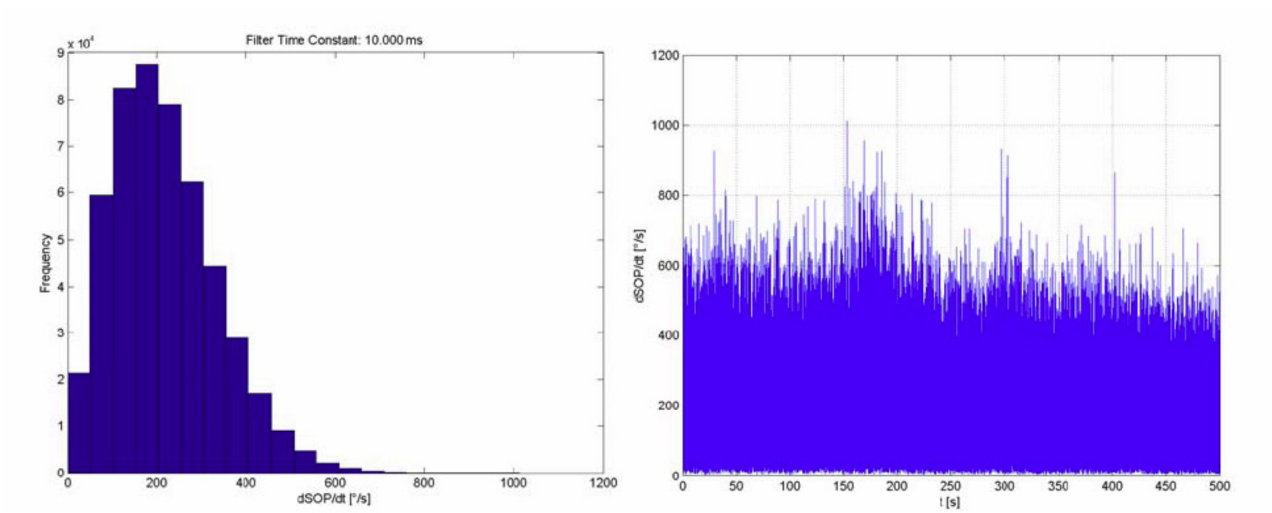

Figure 9: Route C – rate of change of SOP a histogram and over time (500 s)

PMD Methods Inter-comparison

Figure 10 represents the evolution of PMD measurement as function of time of the variation measurement methods. The results are shown with error bars taken from the published experimental uncertainties.

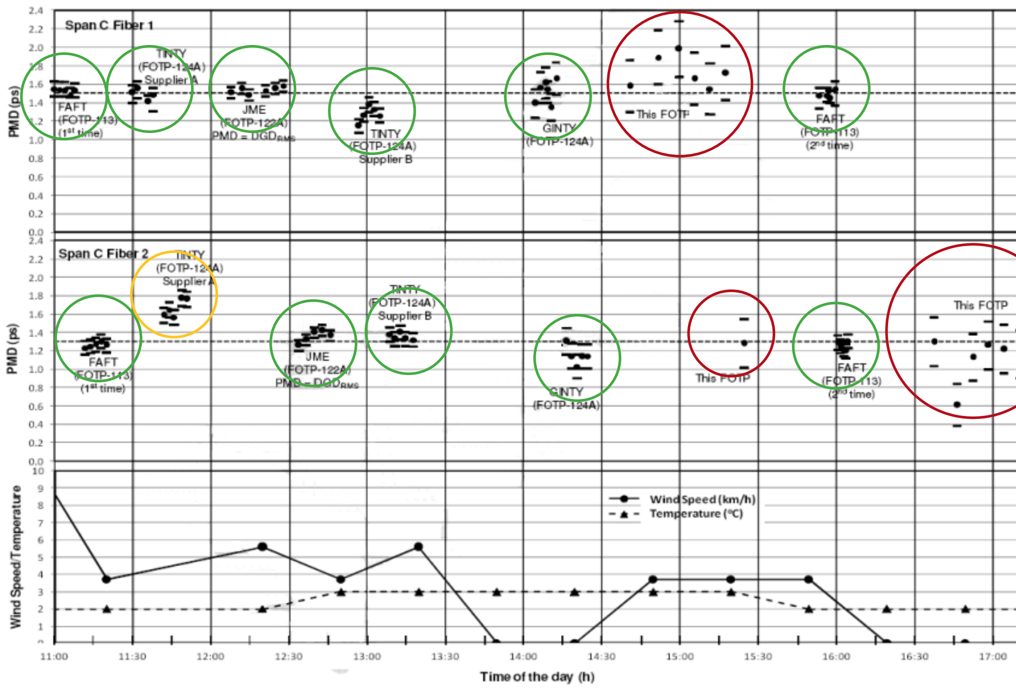

Figure 10: PMD test results from Different Methods during the Scotland inter-comparison Campaign – Span C

Note: On the graph, “this FOTP” correspond to a WSOSPA-based measurement method

The results clearly highlight the differences in uncertainty and repeatability from one method to the other. JME and FA methods provide the most stable results, while also being best aligned with the average measurements of all methods with TINTY and GINTY methods not far off (all encircled in green).

The WSOSPA method gives the worst results (encircled in red). The wind level was not significant in order to explain such high unrepeatability and deviation from the average measurements of all other methods. We can’t impute to temperature variation (almost stable during the trial) or the wind speed (lower than 10 km/h) the lower accuracy of the WSOSPA method. Presumably the WSOSPA, despite the internal scrambler, remains highly sensitive to launch conditions, and in particular the round-trip uncertainty introduced by the unknown polarization coupling at the far end of the fiber.

Conclusion

As transmission speeds increase, characterizing any optical fiber for PMD is essential. They are different field test methods suitable for this job despite various limitations or dependencies to disturbances. The recent inter-comparison field tests confirm that under normal conditions JME, FA, and in a lesser extent Interferometric methods offer good agreement. Meanwhile, it clearly raises questions about the reliability of the new WSOSPA method.

Acronyms

DGD	Differential Group Delay
GINTY	Generalized Interferometry
FA	Fixed Analyzer
JME	Jones Matrix Eigen analysis
OPGW	Optical Power Ground Wire
PMD	Polarization Mode Dispersion
PSP	Principal State of Polarization
SOP	State of Polarization
WSOSPA	Wavelength-scanning OTDR and States-of-Polarization Analysis
TINTY	Traditional Interferometry

Authors

Vincent Lecoeuche – PhD, Gabriel Jagot – Application Engineer, Gregory Lietaert –Product marketing

Related Documents

1. *VIAVI, Testing Polarization Mode Dispersion (PMD) in the Field*
2. *IEC 61280–4–4. 2006–02, Cable plants and links – Polarization mode dispersion measurement for installed links*
3. TIA-455–243 SP-3–0305, FOTP-243; Polarization-mode dispersion measurement for installed single-mode optical fibers by wavelength-scanning OTDR and states-of polarization analysis.
4. Polarization Oscillations in Aerial Fiber Caused by Wind and Power-Line Current Joachim Wuttke, Peter M. Krummrich, and Jörg Rösch, Member, IEEE PHOTONICS TECHNOLOGY LETTERS, VOL. 15, NO. 6, JUNE 2003
5. Wikipedia – OPGW cable
6. Cables vibrations due to wind action? M. Belloli, A. Collina, F. Resta, Politecnico di Milano, O.I.T.A.F. SEMINAR. Grenoble 27 April 2006
7. Field trial of PMD test methods and investigation into the dynamics of polarization effects in a variety of installed cable environments. Richard Ednay- Optical Technology Training Ltd. Terena Networking Conference, Vilnius, Lithuania, June 2010

VIAVI Solutions

Contact Us **+1 844 GO VIAVI**
(+1 844 468 4284)

To reach the VIAVI office nearest you,
visit viavisolutions.com/contact.

pmdaerial-cables-wp-fop-tm-ae
30162995 900 0818