A NEW TEST METHOD FOR THE QUANTITATIVE DETERMINATION OF “BAD” PMD SECTIONS ALONG AN INSTALLED FIBER LINK

André Girard, Senior Member of Technical Staff–Optical Business Unit
Hongxin Chen, Principal Research Scientist–Research Group
Francis Audet, Senior Product Manager–Optical Business Unit
Gregory W. Schinn, R&D Director–Research

For high bit-rate optical transmission, such as 40 Gbit/s and beyond, polarization mode dispersion (PMD) becomes the last major physical-plant issue for network carriers. In particular, legacy fibers installed at a time when PMD was not of concern for the prevalent bit rates, often exhibit such high PMD values that they are not suitable for upgrade to the high bit rates of contemporary backbone optical networks. The solution to this PMD problem is to either use PMD-tolerant transmission systems (e.g., using PMD compensators or advanced modulation schemes) or to renew the fiber infrastructure by replacing those cable links, spans or sections whose PMD values exceed the PMD limit for high-speed transmissions.

Replacement of the fiber of an entire link is extremely costly and time-consuming and, therefore, is not a viable solution. Fortunately, the PMD of a link is generally localized in a few discrete cable sections [1]. Consequently, a much more cost-effective approach is to identify and quantify these localized ‘bad’ PMD sections and, if necessary, to replace these sections. Hence, there is clearly a need for a polarization optical time-domain reflectometer (POTDR)—capable of not only qualitatively identifying ‘bad’ PMD sections but more importantly, also quantifying the PMD of such cable sections at the same time, measuring the cumulative PMD of the whole link in a single cost-effective field operation.

This white paper introduces a novel measurement method using a tunable random-scrambling POTDR (RS-POTDR) [2-4]. The test method is based on the recently-developed theory of random scrambled state-of-polarization analysis (SSA) [5-10] and is implemented in a compact, robust and economical design suitable for field applications: EXFO’s FTB-5600 Distributed PMD Analyzer. Experimental results demonstrate its capability for measuring distributed PMD along fibers. Field trial measurements have enabled to identify ‘bad’ PMD sections. Once identified, these ‘bad’ sections can then be replaced.

The tunable RS-POTDR is first comprised of a tunable pulsed laser, having a modulated output that is amplified by a semiconductor optical amplifier (SOA) to produce a standard OTDR light pulse, e.g., from 5 ns to 20 μs, with a spectral width of ~4 GHz (FWHM). The light pulses are routed by a circulator to the input/output states of the polarization (I/O-SOP) scrambler (polarizer and polarization scrambler), which randomly sets the pulse SOP before they are launched into the fiber under test (FUT) via a beam splitter (BS) and a launch fiber (i.e., 500 m of low-PMD fiber).

The Rayleigh backscattered light from the FUT travels back along the fiber and is then split into two parts by the BS: one is sent back through the same I/O-SOP scrambler and then is routed to the first photodetector and another one is directly sent to the second photodetector. The setup ensures simultaneous signal detection and sampling as a function of time to obtain traces—as with any conventional OTDR.

Measurement Principle

Several OTDR traces, i.e., backreflected power as a function of distance (z), $P_j(z_n)$, are acquired for different combinations of the optical-pulse wavelength, λ, and I/O-SOP (i.e., both launched-SOP and detected polarization components). The transmission of the analyzed signal, $T_j(z_n)$, is computed from the traces measured from the two photodetectors. These traces, $R_j(z_n)$ are obtained from each trace measured from the photodetectors–P_1 being divided by its correspondent trace P_2, point by point. Then normalized transmissions are obtained as follows:

$$T_j(z_n) = T_0 \frac{R_j(z_n)}{\langle R_j(z_n)\rangle_J}$$

For the polarization beam splitter (PBS) design, the transmission is calculated directly from each P_1 trace divided by the sum of P_1 and P_2, the two traces from the PD_1 and PD_2.

In its simplest implementation, the OTDR traces are acquired in pairs. The wavelengths of the two traces in each pair are closely spaced, and the mean wavelength of each pair is different than that of any other pair. Additionally, the I/O-SOP corresponding to traces within each pair is the same, but it is different from pair to pair. The actual detected signal corresponds to the backreflected signal transmitted through the analyzer. For each pair of OTDR traces, a corresponding local transmitted normalized power difference, $\Delta T_k(z_n)$, is calculated for each distance point z_n. Data is acquired from a large number of pairs, $K > 50$. K differences are obtained for a random set of independent combinations of wavelengths and I/O-SOPs. 'Closely-spaced' means $PMD_m \cdot \delta\nu < 0.1$ to 0.15, where PMD_m is the largest value to be measured and δν is an optical-frequency difference for all pairs. For example, for a PMD value of 1 ps, δν is approximately equal to 125 GHz, and for a PMD value of 10 ps, δν is 12.5 GHz.

In practice, each of the two traces in each pair is acquired twice consecutively in time, in order to produce a repeated pair having a difference $\Delta T'_k(z_n)$, which differs from $\Delta T_k(z_n)$. In this way, any change in the local difference between repeated pairs, which would be caused only by noise, can be eliminated.

Experimental Results

The method used in the tunable RS-POTDR for measuring cumulative PMD along installed fibers has been first demonstrated using laboratory experiments. The setup shown in Figure 1 is a concatenation of single-mode fiber (SMF) sections of different types with two PMD emulators inserted at 6.7 km and 13.7 km.

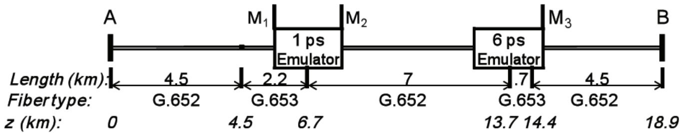

Figure 1. Experimental setup for laboratory demonstration of the tunable RS-POTDR

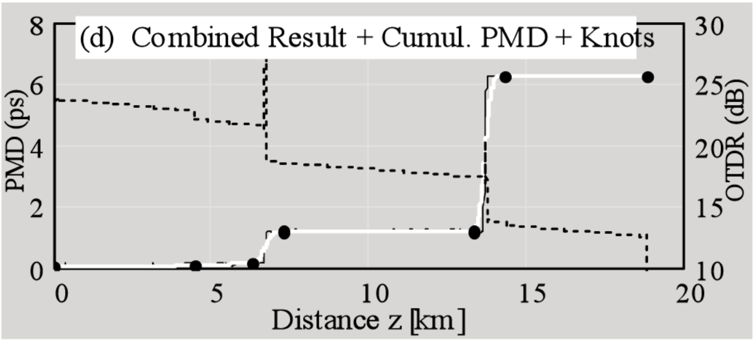

Figure 2. Result of cumulative PMD (white line), knots (•) are end-points of sections

The PMD values agree well within the experimental uncertainty on the two different measurement methods used. With 400 independent combinations of wavelengths and I/O-SOPs and with PMD levels averaged over a few km, the main uncertainties are:

- Roundtrip factor uncertainty given the optical frequency range
- Uncertainty on optical-frequency difference $\delta\nu$
- Uncertainty resulting from the use of large optical-frequency differences

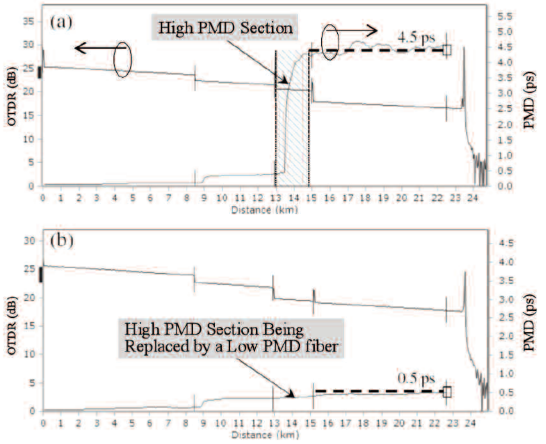

Figure 3. (a) FUT has ~2 km high PMD section at link location of along 14 km. (b) The identified high PMD section is replaced by a low PMD fiber.

In order to transform a "bad" link into one with low-PMD, the detected high PMD fiber sections may be replaced by low PMD fibers. Figure 3(a) shows a fiber link of ~23.5 km having a total PMD of 4.5 ps. This link contains a concatenation of four SMF sections where a ~2-km fiber section between 13 km and 15 km has high PMD of about 4.45 ps. This 'bad' PMD section is made from a ~2 km SMF and a PMD emulator. A low PMD fiber link with a total PMD of ~0.5 ps can be obtained by simply replacing the 'bad' PMD section by a similar length of low PMD fiber with PMD <0.1 ps (see Figure 3(b)).

Field Trials

Field tests were also performed on many legacy fibers located at various network operator sites during the last two to three years [1]. Two typical examples are illustrated herein. The tested links have lengths of ~31 km and ~38 km for link 1 and link 2, respectively. Each cable contains 16 SMFs, although not all of them are accessible. PMD of both links was measured first with an EXFO FTB-5500B PMD Analyzer using the GINTY-based interferometric method [11-16]. OTDR traces were retrieved with an EXFO FTB-7400 Metro OTDR test set. PMD ranged from 3.8 ps to 14.7 ps for link 1 and from 2.3 ps to 6.7 ps for link 2. The results show that link 1 is typically not suitable for 40 Gbit/s transmission. The distributed PMD of each tested fiber was measured afterwards with the tunable RS-POTDR.

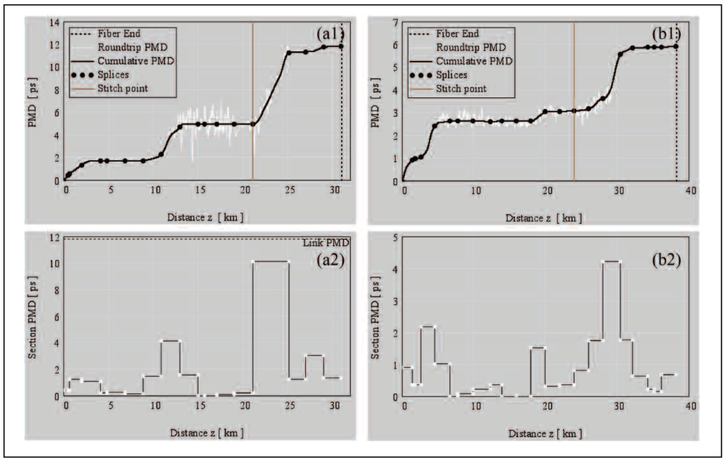

Figure 4. (a1 and a2) link 1: Cumulative PMD and splice locations (a1), PMD of the selected sections (a2). (b1 and b2) link 2: Two-sided result. Cumulative PMD and splice locations (b1), PMD of the selected sections (b2).

To illustrate the measurement of the links' distributed PMD, the measured cumulative PMD was obtained in the forward and backward directions. The results obtained are shown in Figure 4 (a1) and (b1). The PMD of each individual section, computed from the square-PMD curve, is also shown in Figure 4 (b1) and (b2). The sections which contribute the most to the overall link PMD are clearly identified (see Figure 4 (b1) or (b2), with high 'square-type peaks' in (b2). The estimated link 1 PMD is 11.8 ps using the tunable RS-POTDR, while in the case of link 2, the link PMD is found as 5.9 ps.

Conclusion

The RS-POTDR meets the need for a field-suitable instrument that can accurately measure cumulative PMD along an installed fiber link. Two key aspects of the method are:

- Relatively long pulses used to achieve a practical dynamic range
- Single I/O-SOP used for each independent wavelength-pair, reducing the time interval during which the fiber must be stable

It was also demonstrated that the tunable RS-POTDR provides results that are in agreement with the conventional one-way PMD measurements at different points, despite the fundamental roundtrip uncertainty and old fibers in the field. Results obtained in the field by the tunable RS-POTDR demonstrate that 'bad' PMD sections can be clearly and quantitatively identified, thereby providing the opportunity to replace these sections with close to 100% confidence level. Thus, this new cumulative PMD measurement method based on tunable RS-POTDR is well suited for the quantitative characterization of problematic sections in a field-installed optical link.

References

[1] D. Fritzsche, M. Paul, L. Schuerer, A. Erhardt, D. Breuer, W. Weiershausen, N. Cyr, H. Chen, G.W. Schinn, "Measuring the Link Distribution of PMD: Field Trial Using an RS-POTDR". OFC'08, San Diego, CA, USA, February 24-29, 2008, paper NThE2.

[2] N. Cyr, H. Chen and G.W. Schinn, "Random-Scrambling Tunable POTDR for Cumulative-PMD Measurement of Installed Fibers", in Proc. Optical Fiber Measurement Conf. (OFMC'07), Teddington, U.K, 2007, pp. 109-113.

[3] N. Cyr and H. Chen, "Random-Scrambling Tunable POTDR for Distributed Measurement of Cumulative PMD", accepted by J. Lightwave Technol., Dec. 2008.

[4] N. Cyr and H. Chen, "Polarization optical time domain reflectometer and method of determining PMD", Intern. appl. published under patent coop. treaty (PCT), WO/2007/036051, Apr. 2007.

[5] A. Girard and H. Chen, "Proposal of a new SOP Scrambling Analysis (SSA) PMD test method for future revision of Rec. G.650.2", Intern. Telecom. Union, ITU-T, Study Group 15, Working Party 2, Question 5 meeting, Geneva, Switzerland, Contribution 862, COM 15 – C 862 – E, Source Canada, Jan. 2008.

[6] A. Girard, "Single-End I/O-SOP Scrambling Analysis (SSA) PMD Test Method", Telecom. Indus. Asso. (TIA), FO-4.1 Sub-committee meeting, Contribution FO41-2008-02-011, Tampa FL, Feb., 2008.

[7] TIA-455-243, FOTP-243, "Polarization-mode dispersion measurement for installed single-mode optical fibers by wavelength-scanning OTDR and states-of-polarization analysis", project SP-3-0305 to be published.

[8] A. Girard, "Proposal for single-ended PMD measurement", Intern. Electrotechn. Commission (IEC) Sub-Committee 86C ,Working Group 1 meeting, Contribution SD-19, San Diego, CA, Feb. 29 to Mar. 1, 2008.

[9]. Girard, "Presentation on single-ended PMD measurement", IEC Sub-Committee 86C ,Working Group 1 meeting, Contribution SD-19B, San Diego, CA, Feb. 29 to Mar. 1, 2008.

[10] N. Cyr and H. Chen, "Method and apparatus for determining differential group delay and polarization mode dispersion", WO 2008/116314 A1, Intern. appl. published under patent coop. treaty (PCT), 43pp, Oct. 2008.

[11] N. Cyr, "Polarization-Mode Dispersion Measurement: Generalization of the Interferometric Method to Any Coupling Regime", J. Lightwave Technology, Vol. 22, No. 3, 794-805, Mar. 2004.

[12] ITU-T Recommendation G.650.2, "Definitions and test methods for statistical and non-linear related attributes of single-mode fibre and cable". 71pp, Jul. 2007.

[13] ITU-T Recommendation G.650.3, "Test methods for installed single-mode optical fibre cable links". 13pp, Mar. 2008.

[14] IEC 61280-4-4 Ed. 1.0: Fibre optic communication subsystem test procedures - Part 4-4: Cable plants and links - Polarization mode dispersion measurement for installed links, 2006.

[15] IEC TR61282-9, "Fibre optic communication system design guides – Part 9: Guidance on polarization mode dispersion measurements and theory", 128pp, Jul. 2006.

[16] TIA-455-124-A, "Polarization-mode dispersion measurement for single-mode optical fibers by interferometry", 51pp, Feb. 2004.

[17] IEC 60793-1-48 Ed2: "Optical fibres - Part 1-48: Measurement methods and test procedures - Polarization mode dispersion", 100pp, Jun. 2007.

[18] ANSI/TIA-455-122-A-2002, FOTP-122, "Polarization-mode dispersion measurement for single-mode optical fibers by Stokes Parameters Evaluation", 35 pp, 20.

EXFO Corporate Headquarters > 400 Godin Avenue, Quebec City (Quebec) G1M 2K2 CANADA | Tel.: +1 418 683-0211 | Fax: +1 418 683-2170 | info@EXFO.com

Toll-free: +1 800 663-3936 (USA and Canada) | www.EXFO.com

EXFO America	3701 Plano Parkway, Suite 160	Plano, TX 75075 USA	Tel.: +1 800 663-3936	Fax: +1 972 836-0164
EXFO Asia	151 Chin Swee Road, #03-29 Manhattan House	SINGAPORE 169876	Tel.: +65 6333 8241	Fax: +65 6333 8242
EXFO China	No. 88 Fuhua First Road Central Tower, Room 801, Futian District	Shenzhen 518048 P. R. CHINA	Tel.: +86 (755) 8203 2300	Fax: +86 (755) 8203 2306
	Beijing New Century Hotel Office Tower, Room 1754-1755 No. 6 Southern Capital Gym Road	Beijing 100044 P. R. CHINA	Tel.: +86 (10) 6849 2738	Fax: +86 (10) 6849 2662
EXFO Europe	Omega Enterprise Park, Electron Way	Chandlers Ford, Hampshire S053 4SE ENGLAND	Tel.: +44 2380 246810	Fax: +44 2380 246801
EXFO Service Assurance	285 Mill Road	Chelmsford, MA 01824 USA	Tel.: +1 978 367-5600	Fax: +1 978 367-5700

WHITEPAPER.1AN

Printed in Canada 09/03

EXPERTISE REACHING OUT