PMD Study & Measurement – Fixed Analyzer Method

Rastislav Motuz, Petr Munster, and Miloslav Filka

Abstract: **The paper theoretically describes Polarization Mode Dispersion (PMD) which is important parameter in high-speed optical networks. Furthermore, compensation methods and measurement principles are presented. Main attention is given to Fixed Analyzer (FA) method that uses common research laboratory equipment in setup. We performed practical measurement of the PMD by using Optical Spectrum Analyzer (OSA) Anritsu MS9740A, in-line polarizers and a polarization controller. To verify the accuracy of measurements Reference Measurement (RM) using a modular platform EXFO FTB-200 in combination with CD/PMD module EXFO FTB-5700 was performed. Moreover, PMD etalons with defined values of delay was used for measurement. All results were evaluated in comparison with defined limit values.**

Index terms: **PMD measurement, Fixed Analyzer method, fiber, polarization, dispersion, DGD**

I. INTRODUCTION

Dynamic evolution of fiber optical communication brings high transmission rates and wide bandwidth for new services. But with increasing transmission rate is necessary to deal also with issues as Chromatic Dispersion (CD) or PMD. The PMD is optical phenomenon which affects optical transmissions with transmission bitrates up 2.5 Gb/s.

PMD causes optical signal degradation especially nowadays, when bitrates in a core or metro networks commonly exceed 40 Gb/s. It is recommended to measure this parameter not only after fiber fabrication but also after its installation in order to keep demanded quality of service. There are several methods of PMD measurement. Each of them offers advantages or disadvantages and the selection depends on specific conditions and requirements [1].

There are no any recent publications focusing directly on the FA method using the OSA and with practical measurement or comparison the FA method with other measurement method. In publication [2] the authors reported an improvement of the FA measurement technique. With suggested modification the measurement uncertainty was reduced of more than 40%.

Authors in [3] presented an interesting relation between the PMD and the Raman gain. It was found that the increase of

PMD value reduces the value of a gain, which negatively affects the signal integrity while being transmitted. For practical verification the FA method was.

This paper is organized as follows: Section I contains introduction and State of Art. Necessary background to the PMD including important parameters and a description of polarization phenomenon is provided in Section II. Section III deals with possibilities of PMD compensation. Following section, Section IV, discusses PMD measurement techniques with focusing on the FA method. In addition, theoretical advantages and disadvantages are stated. Measurement methodology of the FA and RM is described in section V. Section VI contains experimental results and Sections VII concludes the paper.

II. POLARIZATION MODE DISPERSION

In ideal optical fiber both orthogonal polarization planes (two polarization modes) of light beam propagate with same speed, and hence no dispersion occurs. Unfortunately, a real optical fiber has non ideal circular shape which causes different spreading speeds of both planes. One plane of polarization represents a fast-axis, the other plane is a slow-axis. The obvious fact is that the optical signal spreads in different speeds of the both planes of polarization. This situation is shown in Fig. 1.
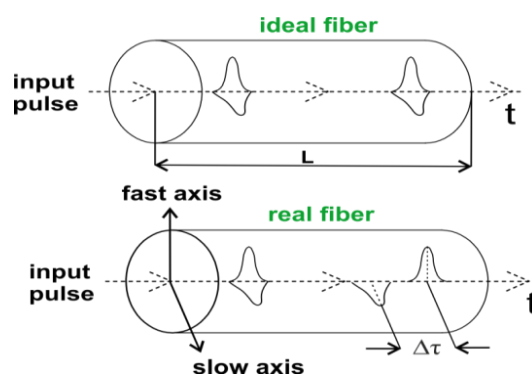

Fig. 1. Optical pulse spreading through an ideal and a real fiber [4].

The main cause of this effect is a birefringence which means that each plane of polarization has a different refractive index [5].

The $\Delta\tau$ indicates the time delay called DGD (Differential Group Delay), which is expressed in *ps*. Spectral mean value of DGD is called PMD. This phenomenon causes the OSNR (Optical Signal to Noise Ratio) degradation and the increase of

the BER (Bit Error Rate). The DGD value changes slowly in comparison to its wavelength dependence [4].

The PMD value is unstable in time, because it is affected by a number of other factors like non-circularities of the fiber shape (core stress, cladding eccentricity, elliptical fiber design), micro air bubbles or externally applied stress on the fiber, micro and macro bending, twisting and variations of temperature [6], [7].

Mathematical expression of the PMD for relatively short lengths of optical fibers (up to 10 km) is given by the following formula:

$$D_{\text{PMD}}(\lambda) = \frac{\Delta\tau}{L}, \quad \left[\frac{\text{ps}}{\text{km}}\right] \qquad (1)$$

where $D_{\text{PMD}}(\lambda)$ is the PMD coefficient, $\Delta\tau$ is the DGD and L is the fiber length. For standard telecommunication optical fiber (G.652.D) is typical weak or none polarization mode coupling, which usually means that fiber exhibit little or none wavelength dependence of the DGD. Moreover, PMD grow linearly with the fiber length.

Strong polarization mode coupling occurs in case the fiber length is longer than 10 km. This usually exhibit standard telecommunication fibers when DGD varies randomly with wavelength. Furthermore, PMD rises with the square root of the fiber length as is described below:

$$D_{\text{PMD}}(\lambda) = \frac{\Delta\tau}{\sqrt{L}}. \quad \left[\frac{\text{ps}}{\sqrt{\text{km}}}\right] \qquad (2)$$

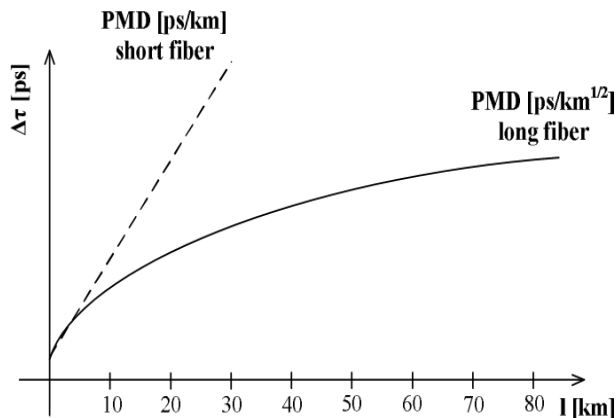Fig. 2 shows dependence of the PMD on the fiber length.

Fig. 2. PMD dependence on the fiber length [4].

Limiting value of the PMD (λ) for a conventional fiber (G.652.D) according to ITU (International Telecommunication Union) is 0.2 ps/$\sqrt{\text{km}}$ [5], [8].

Polarization is an optical phenomenon defining the direction of electric field oscillations which occurs when, for example, the light passes through the birefringent environment. The light is considered to be depolarized, if the state of polarization changes too fast. As was mentioned above, birefringent material splits the light beam into two polarization modes, as is depicted in Fig. 3.

According to oscillation way of an electrical vector, we can define linear polarization (E oscillates in a straight line, in the

XY plane and Ex and Ey oscillations are in phase) or elliptical polarization (oscillations Ex and Ey are not in phase). Moreover, elliptical polarization can be levorotatory or dextrorotatory [5].
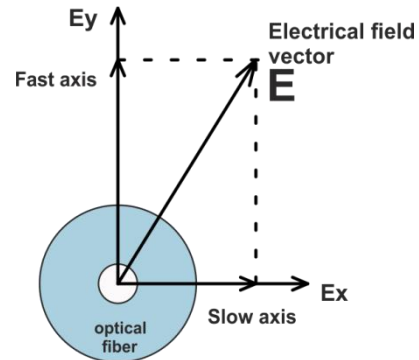

Fig. 3. Illustration of the electric field vector [4].

III. PMD COMPENSATION

In the case of strong polarization mode coupling, polarization states and the DGD vary randomly with a time and also with wavelength, which makes the PMD very difficult to compensate. However, a few compensation techniques were developed and they can be summarized in these categories:

- electrical PMD compensation using direct detection receivers,
- electrical PMD compensation via coherent receivers,
- optical PMD compensation before the detection in the receiver [5], [7].

IV. PMD MEASUREMENT TECHNIQUES

PMD is a statistical and random variable phenomenon and therefore requires monitoring by using practical measurement. For this purpose, there are several methods of measurement – detail description can be found in [5]:

- Jones-Matrix-Eigen Analysis,
- POTDR (Polarization-sensitive Optical Time Domain Reflectometer)
- traditional interferometry – TINTY,
- general interferometry – GINTY,
- fixed analyzer method.

Fixed Analyzer Method

This technique is standardized by ITU-T G.650.2 or IEC 60793-1-48 and often is called the Wavelength scanning method. The basic principle is to monitor optical power in dependence on the wavelength. The wavelength dependence of the PMD causes transformation of various wavelengths of input polarized light into different states of polarization at the

fiber output. Then the optical power after polarizer changes randomly with the wavelength.

According to ITU-T G.650.2, the mean DGD can be calculated by equation:

$$\Delta\tau = \frac{k_2 \cdot N_e \cdot \lambda_1 \cdot \lambda_2}{2 \cdot c \cdot (\lambda_2 - \lambda_1)}, \quad [\text{ps}] \qquad (3)$$

where N_e is the number of the extremes (maxima and minima) minus one, c is the speed of the light, k_2 represents a constant with the value of 0.82 (long fibers and strong mode coupling) or 1.00 (short fibers with weak mode coupling). Wavelengths λ_1 and λ_2 define the set frequency range.

Another way of calculating the mean DGD value is to use the FFT (Fast Fourier Transformation).

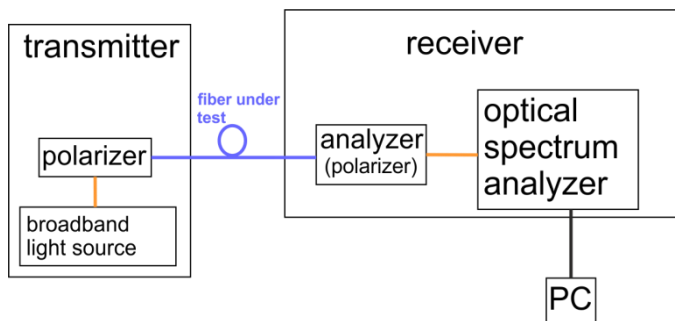The Fixed Analyzer method schema is shown in the Fig. 4.

Fig. 4. Basic scheme of the Fixed Analyzer method [5].

Instead of a broadband light source (e.g. SLED – Superluminescent Light Emitting Diode), the ASE (Amplified Spontaneous Emission) from EDFA (Erbium Doped Fiber Amplifier) can be used.

Although the angular position of polarizers should be fixed, their orientation is not critical to know. Polarizer in the transmitter part is necessary only if the input light is not polarized.

Some of optical spectrum analyzers show the wavelength dependence of the optical power directly.

Main advantage of the FA measurement technique is possibility of measuring an optical path through multiple EDFAs. Also, this measurement is very fast and exhibits a good absolute uncertainty. The sensitivity to input polarization state seems to be a major disadvantage. This measurement technique is suitable for telecommunication fibers, but there is a possibility of limitation caused by high PMD values [5] [7].

V. A MEASUREMENT SETUP

A. FA Method

In Fig. 5 can be seen the setup of the FA measurement method – experimental topology. The core of this topology is OSA MS9740A.

Optical source is realized by the SLED (Superluminescent Light Emitting Diode) as a broadband light source. Next component is in-line polarizer determining the initial conditions in terms of the polarization state. Polarization controller is an optional element, which serves to maximize the difference between the measured spectrum maximum and

minimum values. The second polarizer is called analyzer and polarizes light again. The fiber under test can exhibit strong mode coupling which causes the light depolarization [5].
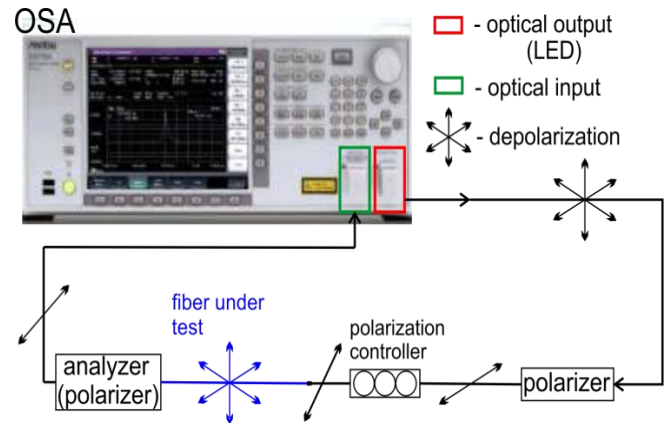

Fig. 5. Fixed Analyzer method using OSA MS9740A [5].

B. Reference Measurement

In this measurement we used a modular platform EXFO FTB–200 in combination with CD/PMD module EXFO FTB–5700. This equipment is able to detect CD (chromatic dispersion) and PMD quickly and accurately in laboratory or real environment. The CD/PMD analyzer can measure optical paths with a length up to 150 km.

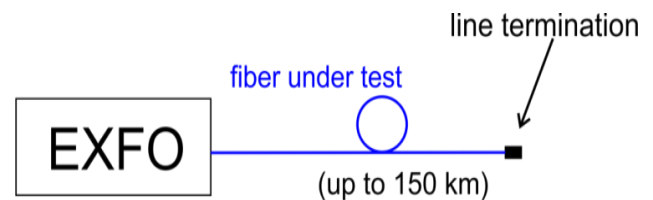This measurement is single-ended and is shown in the Fig. 6.

Fig. 6. PMD reference measurement [5].

VI. MEASUREMENTS RESULTS

Experimental setup for the FA method differed from the general setup in several points. Firstly, the polarizer (placed after optical source) was replaced by a polarization synthesizer Agilent N7786B. This active device is able to store and maintain the current state of polarization, even if some polarization changes occur on the device input (set-and-forget mode), or to set fixed state of polarization via Stokes parameters. Also, this device can act like a synchronous scrambler. The Stokes parameters were used for the input polarization setting.

Next change, against general setup, was omission of polarization controller, which is optional part of the topology.

However, the FA method, specifically OSA required Span parameter setting. It sets the wavelength range from which the OSA calculates the number of peaks. Several measurement with different values of the Span parameter were performed to compare its impact.

Input polarization stayed fixed during all FA method measurements. Thanks to the speed of the measurement, we were able to get an average of 10 values.

Fig. 7 shows the arrangement of the measurement workplace.

Fig. 7. The measurement workplace for the Fixed Analyzer method.

Fig. 8 illustrates a typical wavy behavior of the optical power depending on the wavelength, which is a product of strong polarization mode coupling. This screenshot was taken from the OSA [5].
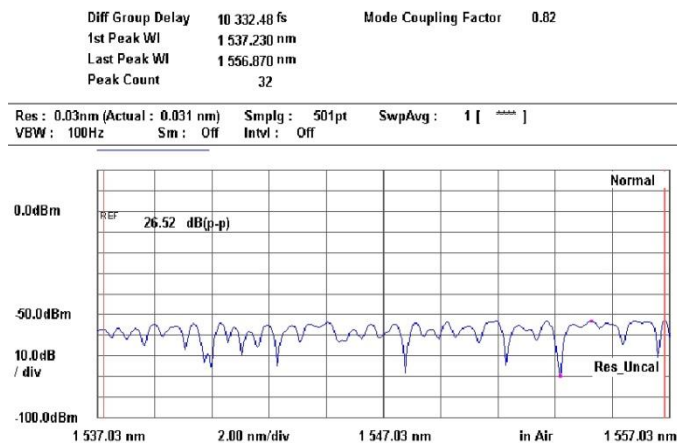

Fig. 8. The example of an OSA output, 20 km line, Span 20 nm.

A. 20 km length optical path

In the Table I, output data of the measurement for the length of 20 km are presented.

TABLE I
MEASUREMENTS OF 20 KM PATH FOR DIFFERENT SPANS.

	RM (FTB-5700)	FA, Span 100 nm	FA, Span 200 nm	FA, Span 500 nm
$D_{PMD} \left[\frac{ps}{\sqrt{km}} \right]$	0.0659	0.0846	0.0800	0.0727
PMD [ps]	0.29	0.38	0.36	0.32

According to the equation (2) and the guaranteed value of $D_{PMD}(\lambda)$ by ITU we get a PMD limit value of the optical path with a length of 20 km:

$$PMD_{20\,km} \leq 0.2 \cdot \sqrt{20} \rightarrow PMD_{20\,km} \leq 0.8944. \quad [ps] \qquad (4)$$

All values are according with the standard. In case of the FA method, with increasing value of the Span parameter, PMD value decrease. Fig. 9 shows graphic comparison of the output data.
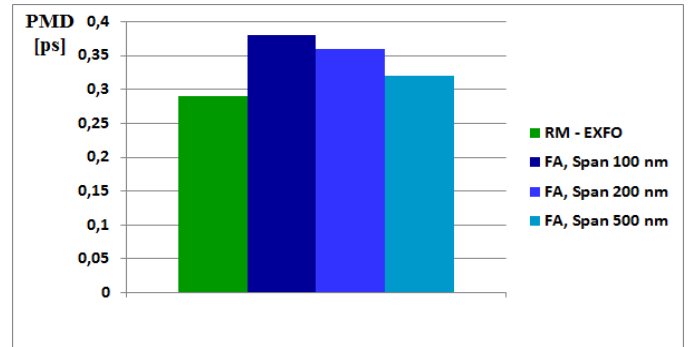

Fig. 9. PMD output values shown in the comparative graph [5].

All values are close enough and, therefore, it can be concluded that the FA method is accurate at this point [5].

B. Measurement with PMD Emulator

For this measurement a PMD emulator was used, as can be seen in the Fig. 10, in combination with 20 km of optical fiber. PMD emulator enables to emulate predefined PMD values. Concretely, with this etalon 1, 5 and 10 ps delay was possible to emulate. Table II shows theoretical and real etalon values obtained by the SSA (Scrambled State-of-Polarization Analysis) method of measurement. Fig. 10 shows the PMD emulator.

TABLE II
VERIFICATION OF PMD EMULATOR VALUES.

PMD etalon [ps]	1	5	10
Real PMD value [ps]	0.89	5.06	10.43

Fig. 10. PMD emulator including 1, 5 and 10 ps delay lines.

Tables III and IV show measured PMD values of the 20 km fiber optic path with integrated PMD emulator, using the RM and FA measurement methods.

In order to verify the output data, we calculated the theoretical value by the formula:

$$PMD_L = \sqrt{PMD_F^2 + PMD_E^2}, \quad [ps] \qquad (5)$$

where PMD_L represents an unknown PMD value of the whole optical line, PMD_F is a well-known PMD value of the optical fiber (see table I) and PMD_E is a true PMD value obtained by the SSA measurement (Table II).

In case of the FA method, the PMD_F parameter was considered to be FA Span 100 nm (0.38 ps) from Table I.

TABLE III

REFERENCE MEASUREMENT WITH PMD EMULATOR

PMD 1 [ps]	PMD$_L$ 1 [ps]	PMD 5 [ps]	PMD$_L$ 5 [ps]	PMD 10 [ps]	PMD$_L$ 10 [ps]
0.95	0.94	5.14	5.07	11.48	10.43

TABLE IV

FA METHOD WITH PMD EMULATOR FOR DIFFERENT SPANS.

PMD 1 [ps] Span 50 [nm]	PMD 1 [ps] Span 100 [nm]	PMD$_L$ 1 [ps]
0.87	0.86	0.97
-	-	-
PMD 5 [ps] Span 5 [nm]	PMD 5 [ps] Span 20 [nm]	PMD$_L$ 5 [ps]
6.15	5.70	5.07
-	-	-
PMD 10 [ps] Span 5 [nm]	PMD 10 [ps] Span 20 [nm]	PMD$_L$ 10 [ps]
10.02	10.07	10.44

The RM seems to be accurate at this point too, however, for 10 ps etalon the value was over limit. The difference between measured and calculated PMD values exceeds 1 ps. On the other hand, the FA method results exhibit a similar problem for 5 ps etalon measurement. This can be caused by the effect of stress elements on the fiber which could cause an extra birefringence in the fiber and PMD increasing.

VII. CONCLUSION

In this paper, the Fixed Analyzer method for PMD measurement was presented theoretically and also experimentally. This technique brings accurate results and has many advantages. However, there are also disadvantages like, for example, the problem with the correct span parameter settings, which can affect measurement. Moreover, laboratory optical spectrum analyzers are quite robust devices and therefore this configuration is suitable only for measurement in laboratory. Commercially available CD/PMD analyzer FTB-5700 is a compact and resistant device. Moreover, using this device is intuitive and user-friendly, which means that it is suitable not only for researchers but also for internet service providers.

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