IARJSET ISSN (O) 2393-8021, ISSN (P) 2394-1588

International Advanced Research Journal in Science, Engineering and Technology

Impact Factor 8.066 ⁜ Peer-reviewed & Refereed journal ⁜ Vol. 11, Issue 2, February 2024

DOI: 10.17148/IARJSET.2024.11205

REDUCTION OF POLARIZTION MODE DISPERSION (PMD) IN OPTICAL FIBER THROUGH INTROFEROMETRIC TECHNIQUE

SONAMUTHU.K.*[1], GEENA VIDYA.S[2]

J N R Mahavidayalaya, Port Blair, South Andaman, India.744104[1]

Sathyabamal Engineering College, Chennai-600066[2]

Abstract: The basic measurement system of PMD is the interferometric technique. The interferometric technique is capable of measuring PMD of components. If a component has an operational bandwidth of just 0.2 nm then the coherence time of the source is such that the minimum PMD measurable is 40 ps. If the coherence source having wavelength of 10 nm then the PMD is reduced to 0.08 ps. Further it is concluded that as a working coherence wavelength of a source is increased then the P.M.D. is reduced. The *PMD* is the limiting factor for the high bit rate optical transmission systems. The precise measurement of the *PMD* is important for the design and maintenance of these systems. They are several methods developed to this time for the *PMD* measurements. They differ mutually in many aspects - precision, reliability, repeatability, stability, prize and the possibility of use in field conditions. It allows not only to measure precisely the *PMD* but it also gives the complete view on the distribution of the total birefringence along the fiber.

Keywords: Polariztion Mode Dispersion, interferometric, coherence source, optical transmission systems, orthogonal polarization modes, non-return to zero, differential group delay, optical fiber, autocorrelation peak, Birefringen,etc.

I. INTRODUCTION

Single mode fiber supports two orthogonal polarization modes. In a perfectly circular core fiber, each of these modes experiences the same propagation delay. In real fiber, deformations from the ideal shape occur, resulting in a difference in the propagation speed of each of the two polarization modes. The associated difference in the propagation delays of these modes broadens any pulse sent through the fiber and impairs transmission. The difference in propagation delays is known as polarization mode dispersion. The extent of PMD within a fiber varies from manufacturer to manufacturer. It arises from fiber core deformations. Such deformations are inevitably produced during the fiber manufacture, but are also the result of stress on a fiber when it is packaged into a cable, and manipulated during cable laying operations. PMD is mainly characterized by the differential group delay (DGD) between the fast and slow states of polarization (SOP). If this delay difference is a significant fraction of a symbol period, then PMD can be expected to seriously degrade the performance of the transmission link over what it would be without PMD. For the non-return to zero (NRZ**)** binary data transmission schemes typically utilized in optical links, we can regard PMD to be a significant problem when the DGD approaches one-tenth of a bit duration, as a rule of thumb. In many optical fiber, the mean DGD does not exceed 40 ps, which is one tenth of an OC-48 bit-period. However, OC-192 transmission, with a bit duration of 100 ps, is jeopardized for fibers having a mean DGD of 40 ps or more. While the DGD dong a fiber is a fixed function at any instant, due to the random origins of the fiber geometric disturbances, over the ensemble of like fibers the DGD may be viewed as a random process evolving over time, wavelength, and various their parameters. With respect to time and wavelength, we can see that the DGD can be expected to be stationary (and thus would have a mean which does not Vary with these parameters). The DGD has a Maxwellian distribution, which is uniquely characterized by its mean. The random nature of PMD also requires that the variation of DGD over time and wavelength be characterized, although the literature has neglected this aspect so far.

The PMD of a system consisting of a cascade of optical fibre components is a function of the PMD of each of its components. If we assume the statistics of the PMD of each subsystem to be statistically unrelated, then we can derive an expression for the PMD of the total system in terms of the PMD of the subcomponents. Several methods of measuring PMD exist. The methods vary in their practicality and utility. Since the goal of this work cannot be attained without measurements, a discussion of the major PMD measurement techniques.

From these possible techniques, a method is selected and then used for measurements of PMD reported in the subsequent sections of the work The general structure of an optical fiber is a core with a high index of refraction, surrounded by a lower index cladding. Transport fiber is made of fused silica with a refractive index of approximately 1.5. When a wave propagates along the fiber core and approaches the interface between the two mediums, the lower refractive index permits total interna1 reflection of the wave back towards the core. This is the basic principle of how a fiber serves as an optical waveguide. An optical mode is a particular solution of the electro-magnetic wave equation which satisfies the boundary conditions pertinent to a propagation medium [1]. Optical fiber modes can generally either be guided, such that they propagate with relatively little attenuation, or radiative, such that light is absorbed into the cladding.

Multi-mode fiber has a wide core such that the wave equation has many guided modes. An applied signal will produce components in many of these modes. The different modes propagate along different spatially distributed paths, making full use of total interna1 reflection as shown in Figure 1.1. Since any two such paths will generally have different lengths, the wave-fronts of components doing these two modes will arrive out of phase at the exit. The two modes effectively propagate at different speeds along the length of the fiber, and the disparity in arriva1 times of a signal is defined as multi-mode dispersion.

As the name suggests, single mode fiber (SMF) was developed to support only a single guided mode along which a light wave can travel successfully. The core of the SMF is made sufficiently small that the only solutions of the wave equation are (a) a guided mode and (b) multiple leaky modes. At the exit of the fiber, only the guided mode persists, as illustrated in Figure 1.2(b) (the curved lines represent wave-fronts).

In the expressions "multi-mode fiber" and "single mode fiber", the modes referred to are named "spatial modes" since the waves propagating along them can be thought of as taking different paths. The elimination of multi-mode dispersion through the use of SMF is key to high bit-rate digital communications.

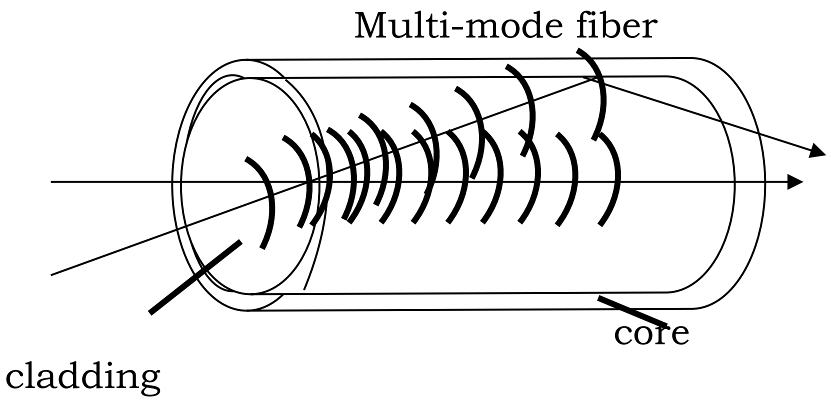

Figure 1.1(a) Single-mode fiber

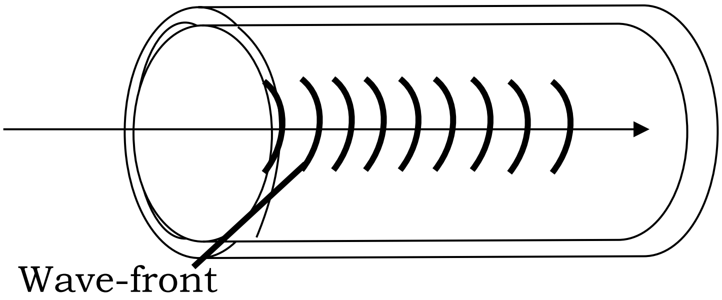

Figure1.2(b) Muiti-Mode vs. Single Mode Fiber

However, in a real fiber, deformations of the core geometry exist. Ellipticity in the fiber core causes birefringence, a difference in refractive index from one polarization mode to the other. Since the speed of light is înversely proportional to the index of refraction, a light wave containing components in both polarization modes launched at one end of the fiber will propagate with two different speeds, and the modes will arrive out of phase at the far end. This phase difference is the result of a propagation delay difference which is the main effect of polarization mode dispersion. naturally, this effect will cause signal degradation in a digital communications system. Figure 1.3 shows the physical model of PMD within a single mode fiber. The birefringence in each section is characterized by the differential time delay between $\Delta\tau$ both polarization modes.

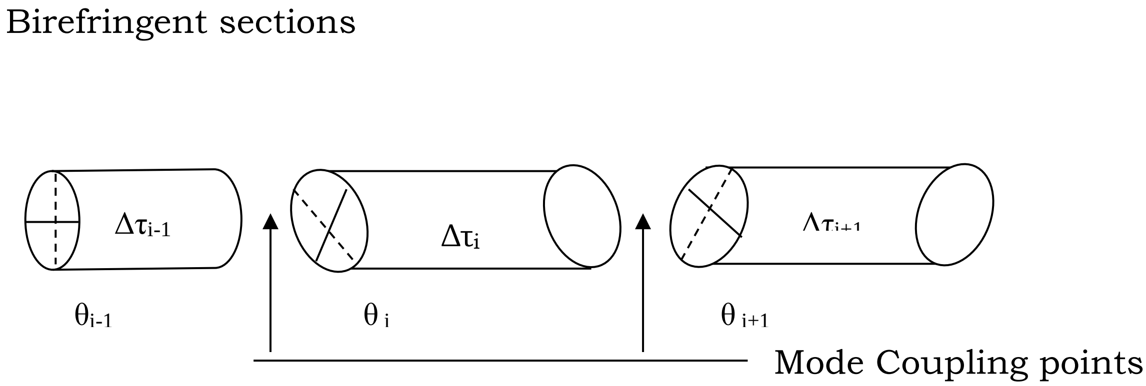

Figure1.3 SMF Physiçal Model

II. MEASURMENT OF POLARIZTION MODE DISPERSION (PMD)

Several methods have been devised to measure the PMD within an optical fiber component. These methods vary in complexity and utility. Three methods will be discussed here, namely the Jones matrix eigen-analysis method, the wavelength scanning method and the interferometric method. The theory behind them, the equipment setup, dynamic range and step size will be discussed, and typical results from their application given.. Based on the latter fluctuation, an expression is given to test the real-world validity of a DGD measurement, knowing the bandwidth over which the measurement is taken. The goodness of fit test used on the measured distributions is also explained.

III. INTERFEROMETRIC METHOD

Interferometry is a method of measuring the autocorrelation of an optical electrical field with respect to time, using the interference pattern created when adding a waveform to a delayed copy of itself. The interferometer splits an incoming light wave along two paths, and recombines the light at the output. The optical intensity of the recombined wave is measured while varying the spatial length of one path with respect to the other. The differential spatial length results in a time delay between the two paths, and is controlled through the movement of a mirror [2]**.** For a perfect monochromatic wave, the interferogram over delay resembles the coherence spectral characteristics of the source over time centered about O. The autocorrelation peak appears when the spatial delay between the two paths is null. However, such a monochromatic wave is highly coherent, and will therefore have a large coherence time, which is reflected in the FWHM of the autocorrelation peak. A spectrally wide source with a small coherence time will have a narrow autocorrelation peak. As mentioned earlier, PMD causes an optical wave to be split into two polarization states, adds a differential delay between the states, and recombines the two waves at the output.

Therefore, at the exit of a fiber, if a polarization mode can be recombined with its orthogonal mode, and assuming the polarization modes are constant over the spectral bandwidth, the interferogram of a spectrally wide optical wave propagating through the fiber is expected to have, in addition to a central autocorrelation peak at a spatial delay of 0, two autocorrelation peaks where the magnitude of the spatial delay is equivalent to the value of the DGD**.** This is the principle behind the interferometric PMD measurement technique. If a source with a wide spectral width, such as a light-emitting diode (LED),is used, peaks appear at spatial delays equivalent to al1 of the DGDs within the spectral range of the source. In the case of a polarization maintaining fiber, the DGD is constant over wavelength, and thus a perfect PMD interferogram for this device has two predominant peaks besides the central autocorrelation peak**.** More autocorrelation peaks show up in the presence of random mode coupling.

IV. EXPERIMENTAL SETUP

The interferogram is based on the phenomenon of irradiance. The intensity of the fringes of an interferograrn are proportional to the dot product of the resultant electric field vector by its complex conjugate. At a given location in space, if an electrical wave has components along two orthogonal States of polarization, the dot product of one component of the field by the complex conjugate of the other is nul1 due to the orthogonality of the vectors.

To combine the electrical field in one polarization state with the field in the orthogonal mode, a method must be put into place to rotate the polarization of one path of the interferometer with respect to the other. In the setup shown in Figure 1.4, a 1/8th wave plate is used. A wave plate is an optical device made of birefringent material which has two linear axes perpendicular to the direction of propagation, namely the fast and slow axes. When *an* optical wave propagates through the plate, the component of the wave along the slow axis is retarded with respect to the component dong the fast axis, by a phase dictated by the thickness of the wave-plate. The Jones matrix of a wave plate is:

$$T_{\text{wave plate}} = \begin{bmatrix} 1 & 0 \\ 0 & \exp(-j\Gamma) \end{bmatrix} \qquad (1)$$

where Γ is the phase (in radians) by which the slow axis is retarded over the fast axis $\Gamma = 2\pi/8 = \pi/4$).

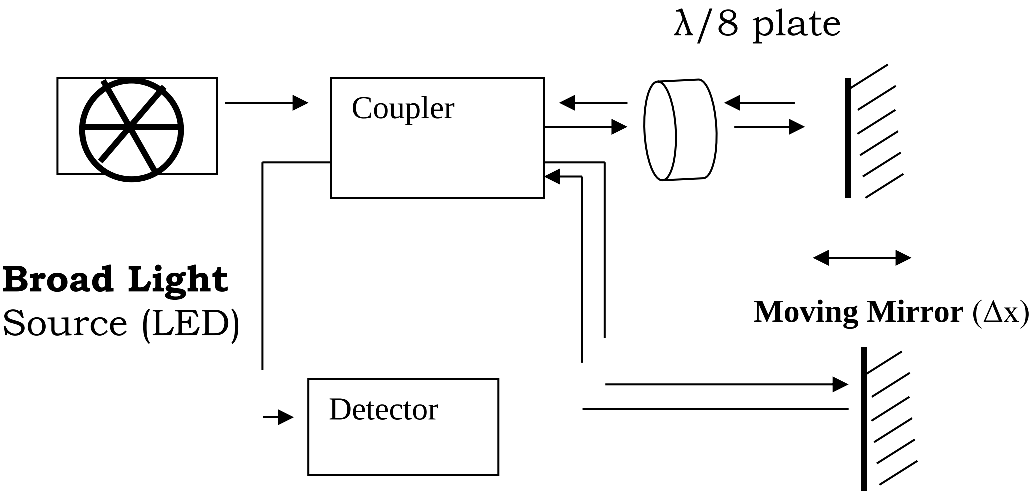

Figure1.4 Interferometric Measurement Setup

When used in conjunction with a mirror, whose Jones matrix is, ideally:

$$T_{\text{mirror}} = \begin{bmatrix} -1 & 0 \\ 0 & 1 \end{bmatrix} \qquad (2)$$

the 1/8th wave plate acts as a quarter-wave plate: a light wave propagating through the 1/8th wave plate, reflected off the mirror, and propagating through the same wave plate in the opposite direction, as described in Figure 1.4. wilI have effectively passed through the equivalent of a quarter-wave plate:

$$\text{Tequiv} = T_{\lambda/8}\ .\ \text{Tmirror}\ .\ T_{\lambda/8} = \begin{pmatrix} 1 & 0 \\ 0 & e^{-j\frac{\pi}{4}} \end{pmatrix} . \begin{pmatrix} -1 & 0 \\ 0 & 1 \end{pmatrix} . \begin{pmatrix} 1 & 0 \\ 0 & e^{-j\frac{\pi}{4}} \end{pmatrix} = -1 \begin{pmatrix} 1 & 0 \\ 0 & j \end{pmatrix} \quad (3)$$

while the optical wave traveling through the other arm of the interferometer will be subject to the polarization transformation. The experimental setup shown in Figure 1.4 resembles the one used in [3].

An LED is used as the source at the input of the device under test. Linearly polarized light, making an angle of 45^0 with respect to the two axes of the plate, is transformed by the effective quarter-wave plate into circularly polarized light (the converse applies for incident circularly polarized light). Since circularly polarized light can be broken down into linearly polarized components (and vice-versa), if the output PSPs of the fiber have linear (at 45^0**)** or circular polarization States, then, as the two arms of the interferometer recombine, the delayed signal component will have a polarization component parallel to the non-delayed signal component.

Therefore, at a fixed wavelength, as long as both output PSPs of the fiber each have components along the two axes of the interferometer's wave plate, and as long as the light source has components along the two PSPs, the optical source component along the fast PSP can be partially recombined with the delayed component along the other PSP, and the DGD at that wavelength will correspond to a set of peaks in the interferogram. Fortunately, in highly mode-coupled fibers, the wide spectrum of the LED will explore a wide range of PSPs, such that the interferogram will contain several peaks corresponding to various DGDs. This reduces the necessity to monitor launch conditions of the optical source into the fiber.

The envelope of the resulting interferogram resembles a Gaussian. The half-width of this Gaussian can be shown to be related to the mean of the square DGD [2]. As mentioned, if the source is spectrally wide, then a multitude of DGDs will be explored by the interferometer over the frequency range of the source. The resulting interferograrn will have the expected central peak superimposed upon a Gaussian representing the various DGDs [2].

The mean DGD of a highly mode coupled fiber is measured by calculating the second moment of the Gaussian after removal of the central peak. Due to the limited spectrum of the LED, the uncertainty in the estimate of the mean DGD is identical to that calculated using other methods.

It is only necessary to substitute the spectral width of the source for the wavelength range used with the JME or wavelength scanning methods. In addition, interferometric measurements contain additive noise and random amplitude as explained in [3], which must be compensated for. The central autocorrelation peak must also be eliminated.

In the setup described above, assuming nominally equal branch distances in each arm of the interferometer, such that the waves propagating down the two branches are subject to approximately the same attenuation, the mirror displacement Δx is related to the delay τ by

$$\tau = 2\,\frac{\Delta x}{c} \qquad (4)$$

Therefore, in order to measure DGDs above τ ps, the mirror displacement must be capable of exceeding where ***c*** is the speed of light in air.

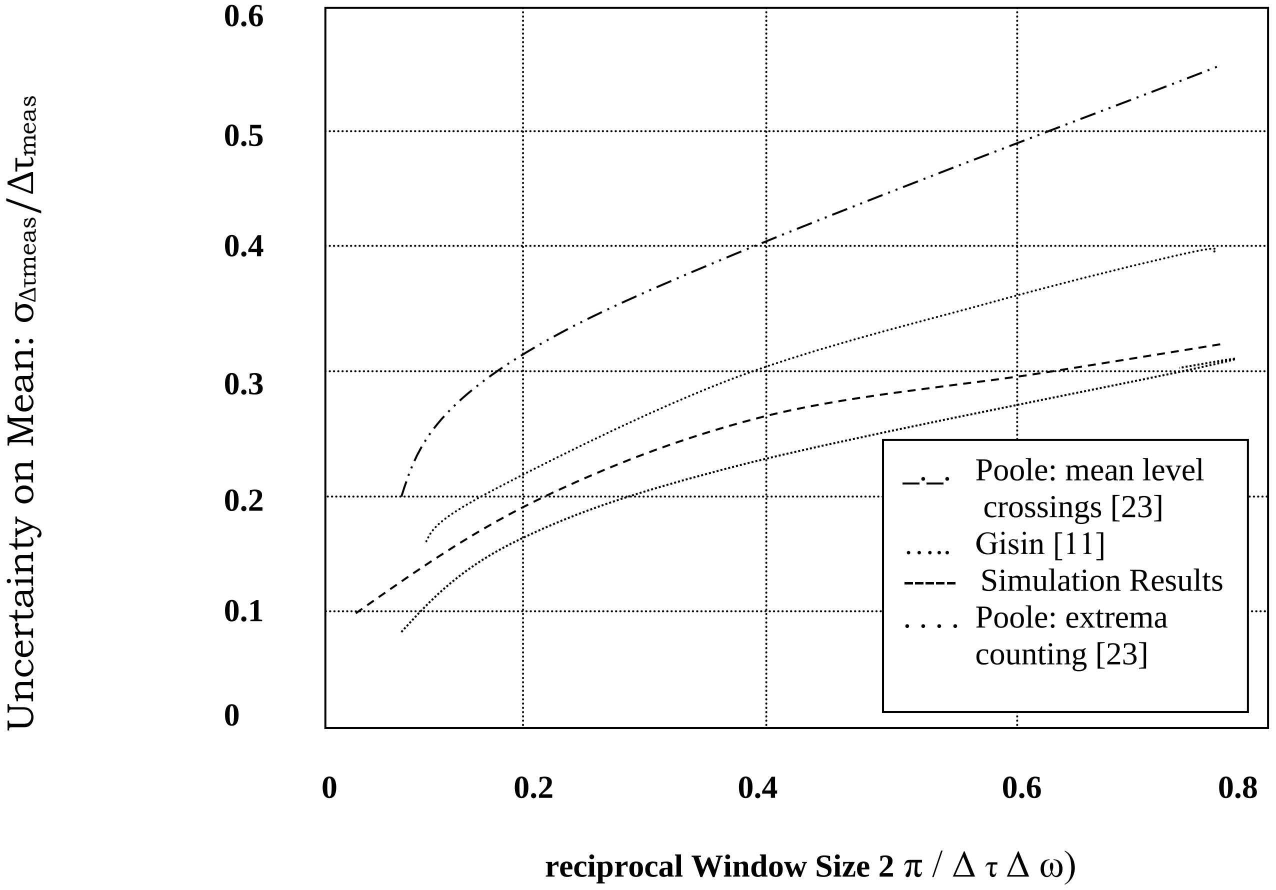

Figure 1.5 Uncertainty of the Estimate of the Mean

V. RESULT AND DISCUSSION

In measuring PMD, the first choice to be made is deciding which measurement technique to use. Here, the various techniques have been described so as to illustrate their relative merits. Generally, decisions are made based on measurement time, spectral resolution, and what quantities are measurable. Once a measurement technique is chosen, it is most important to understand the sources of measurement error (and minimize them).

Four possible solutions will be considered for measuring Polarization Mode Dispersion in components: the Interferometric, Fixed Analyzer, and Stokes Parameter Evaluation techniques, which are usually used to measure PMD of single mode fiber, and the Phase Shift method, which is often associated with Chromatic Dispersion measurement of single mode fibers.

Fixed analyzer is another technique to provide the solution to PMD. In exploring the capacity of this technique the PMD for a different wavelength ranges from 80 nm, 8 nm, 0.2 nm and 0.08 nm are used in calculating the PMDs.

The wavelength 80 nm, 8 nm, 0.2 nm and 0.08 nm corresponds to PMD values 0.1ps, 1ps, 40ps, and 100ps respectively. With this it is concluded that as the wavelength decreases then the PMD value increases.

Again the above shown conclusion is conformed by stokes parameter evaluation. Stokes parameter evaluation is the general term for the frequency domain measurement technique of JME value analysis the basic principle of stokes parameters are used to determine the differential group delay and can be use to provide a definite answer, when there are complicity arises in the fixed analyzer and interferometric technique. It is derive that the wavelength 0.2 nm correspondence to the PMD 191 fs.

DOI: 10.17148/IARJSET.2024.11205

VI. CONCLUSION

Apart from the several techniques shown in our work the interferometric technique is capable of measuring PMD of components. However, it relies on using a broadband source without ripples, which severely limits the techniques effectiveness in characterizing PMD in components of restricted wavelength and it is concluded that if a component as a operational bandwidth of 0.2 nm then the PMD measured is 40 ps.

If the coherence source having working wavelength of 100 nm then the PMD reduced to 0.08 ps. Further it is confirmed by the method of interferometric that as a working coherence source is increased then the PMD is reduced by means of which the speed of the communication of the optical signal through the optical fiber can be increased.

REFERENCES

[1]. G.P. Agrawal, Fiber-Optic Communications Systems, New York: John Wiley & Sons, 1997.

[2]. N. Gisin, J. P. Von der Weid, J. P. Pellaux, "Polarisation mode dispersion of short and long single-mode fibers," Journal of Light wave Technology, Vol. 9, No. 7, pp. 82 1-827, JUIY 199 1.

[3]. B.L. Heffner, "Compensation formula for noise threshold bias of interferometric PMD measurement," in NIST Technical Digest: Symposium on Optical Fiber Measurements 1996, Vol. 905, pp. 135-138, 1996.