POLARIZATION MODE DISPERSION (PMD) IN FIBER OPTIC

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Abstract - Polarization mode dispersion (PMD), in single mode optical fibers, is phenomenon that can limit the bit-rate-distance product of amplified, light wave communication systems. In optical fibers, waveforms broaden over long distances, making these signals difficult to interpret by the time they reach the receiving end. The result is distorted data signals that results in transmission errors at the intended receiver. As network speeds and span lengths increase, dispersion becomes more severe. This applies to chromatic dispersion (CD) which occurs because different wavelength of light travel at different speeds-its subset, slope mismatch dispersion, and polarization mode dispersion (PMD), which is cause by light traveling faster in one polarization plane than another. Polarization mode dispersion, in high data rate systems, can significantly diminish the data carrying capacity of telecommunications network. A fundamental property of single mode optical fiber and component, Polarization Mode Dispersion (PMD) is a broadening of the input pulse due to a phase delay between input polarization states. The main objective of this project is to study and analyze the nature of the Polarization Mode Dispersion problems and the behaviors of the PMD in optical fibers. Next, the experiment and data collection will be doing at the optical fiber.

1. INTRODUCTION

Fiber optic technology has caught the imagination of many people. The ability to shine a light through a small glass fiber over considerable distances has been utilized for diverse applications.

Single mode optical fiber and components support one fundamental mode, which consists of two orthogonal polarization modes. Ideally, the core of an optical fiber is perfectly circular, and therefore has the same index of refraction for both polarization states. However, mechanical and thermal stresses introduced during manufacturing result in asymmetries in the fiber core geometry. This asymmetry introduces small index of refraction differences for two polarization states, a property called *birefringence.* External mechanical stresses and environmental conditions exacerbate the problem. Birefringence creates differing optical axes that generally correspond to the fast and slow axes. (These axes can also be thought of as corresponding to the *linear Polarization* (LP) modes or *Principle States of Polarization* (PSP).

Dispersion presents a major challenge because not all fiber is created equal. Approximately 20% to 30% of the single mode fiber manufactured before the mid 1990s is deficient because the core of this fiber is not perfectly round [8] this imperfection becomes problematic as bit rates and span lengths increase.

2. DEFINATION OF PMD

A single mode fiber is designed to support only one mode of propagation of light. The principal advantage of letting light propagate along only one mode is that intermodal dispersion can be avoided. Inter-modal dispersion happens as a result of relative delay between the lights propagating in the various modes in a multimode fiber. In single mode fibers, as there is only one mode available for light propagation (theoretically), inter modal dispersion is non-existent.

In reality, however, there are two modes of propagation of light even through a single mode fiber. In spite of the measures taken to provide asymmetrical core cross section, there is some asymmetry. Figure 1 illustrate how stress can induce asymmetry in the fibber core). The consequence of these asymmetries of core cross-section is the existence of birefringence. As a result, when a light pulse is input into a fiber core, it is decomposed into two orthogonally polarized components that propagate with different propagation characteristics.

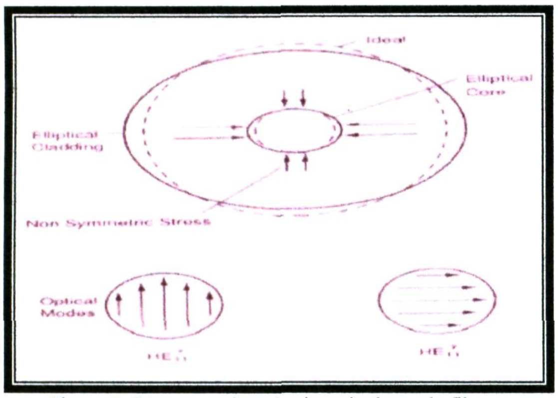


Figure 1: Stresses and modes in a single mode fiber.

The pulses arrive at the output differentially delayed. This difference between the delays is termed as the differential group delay (DGD).It is this DGD that causes an input pulses to appear broadened at the output. And this effect on the pulse is commonly called **PMD.**

BACKGROUND.

Polarization Mode dispersion, PMD, is a parameter of great importance in modern optical communications. It imposes limitations on both analog (CATV) and digital (telecommunication) optical systems.

PMD can significantly limit fiber optic transmission performance by limiting the distance data can travel without regeneration, especially at 10- and 40-Gbps. It is caused by natural or induced ***birefringence*** in the optical transmission medium, which in turn causes polarization components of a signal to travel at different group velocities.

PMD could be effectively compensated for by using special fibers called dispersion compensating fibers and other novel devices. Non-linearity could also be minimized with careful power budget consideration.

With all these measures, the upward surge of the data rate would have seemed unstoppable. However, at very high data rates (above 10Gbps) even minute phenomena have to be taken into consideration to ensure error-free transmission. Examples of such phenomena are polarization-dependent broadening and polarization dependent loss of the optical signal. The optical fiber has some inherent properties like birefringence, which leads to what is called **polarization-mode dispersion (PMD).**

Problem statement
A major concern for network planners

PMD becomes a limiting factor of major concern to fiber and cable manufactures. Companies specializing in cable installation, maintenance and troubleshooting also need to be concerned about PMD for a number of reasons:

- PMD is statistical in nature.
- Environment factors such as temperature extreme or vibration can create PMD.
- Cable can be crushed, stressed or physically damaged during transportation and installation, resulting in PMD.
- Cable handling causes variations in PMD.
- Large variations in PMD values can be observed during the life cycle of a fiber.

Problems in the past included huge fiber loss, inter-modal dispersion, chromatic dispersion, electronic repeaters, etc. As the bit rate approaches >10Gbps per channel, current fiber optic systems face a different dispersion impairment called 'polarization-mode dispersion' (PMD).

PMD CONCEPTS

When light travels down a single mode fiber toward the receiver, it has two polarization modes that follow the path of two axes. They move towards the receiver at right angles to each other. When the core of the fiber that bounds the light is asymmetrical, the light traveling along one polarization axis moves slower or faster than the light polarized along the other axis. This effect can spread the pulse enough to make it overlap with other pulses or changes its own shape enough to make it undetectable at the receiver.

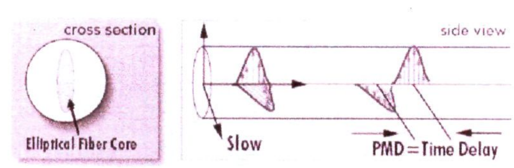


Figure 2 : The cross section fiber and graphical representation of the effect of PMD on optical pulse.

From the figure 2, the optical pulse and its constituent photons travel from the sources, or transmitter at distances=0, along the single mode optical fiber. At some distance after PMD has affected the pulse, the polarized energy is separated by some time. This time is known as **Differential Group Delay (DGD).**

DGD (Differential Group Delay)

DGD is the fundamental measure of PMD and is measured in Pico seconds (10-12 seconds). If DGD is severe, the receiver at some distance L cannot accurately decode the optical pulse, and bit errors can result.

Birefringence

Birefringence causes one polarization mode to travel faster than the other, resulting in a difference in the propagation time called the differential group Delay (DGD), **DGD is the unit that is used to described PMD.**

- Despite their name, 'single mode' fibers support two orthogonal modes of propagation.
- Loss of degeneracy of two modes is called birefringence
- Intrinsic and Extrinsic factors
- PMD is typically larger in older fibers

CAUSES OF PMD

The major cause of PMD is the asymmetry of the fiber-optic strand.

The mechanical stress on the optical fiber can originate from a variety of sources. One source that is very difficult to control is the diurnal (day/night) and seasonal heating and cooling of the optical fiber. Although much fiber is deployed in the ground and often within conduits, it is still subject to temperature variations and corresponding mechanical stress.

Another source of mechanical stress can originate from nearby sources of vibration. For example, much fiber is deployed alongside railroad tracks because of the ease of right-of-way and construction. However, vibration from passing train can contribute to stress on the optical fiber. Fiber that is not buried next to railways and highways may be deployed aerially; in this scenario, wind can cause swaying of the fiber cable and can contribute to PMD.

OBJECTIVES OF THE PROJECT

The main objective of this project is to analysis the nature of the Polarization Mode Dispersion problem, what causes PMD, and the behaviors of the PMD in optical fibers. Thus the objectives are:

- To study and investigates the behaviors of the PMD and the causes of PMD
- To study and investigate the effect of the dispersion on the different bit rate on different length of fiber.
- To study how to compensate the PMD effect in optical fiber.
- Also to study the need of compensation in dispersion

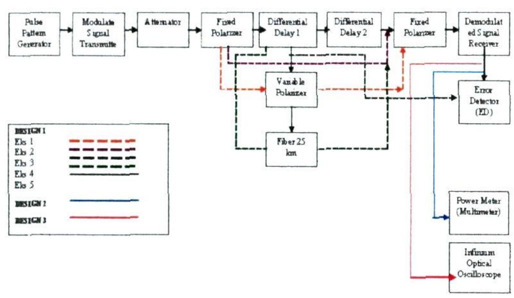
3. METHODHOLOGY

The only method used in this project is called fixed analyzer method also known as wavelength scanning. In this method several experiment were developed in order to recognize the characteristic and behavior of PMD in optical fiber. There are 3 main experiments have been done, they are:-

a) To study the effect of BER on PMD value

b) To look at the PMD effect on the "Eye Diagram".

c) To investigate the PMD effect on the output power.



The result is presented by graph and eye diagram.

4. RESULT AND CONCLUSION

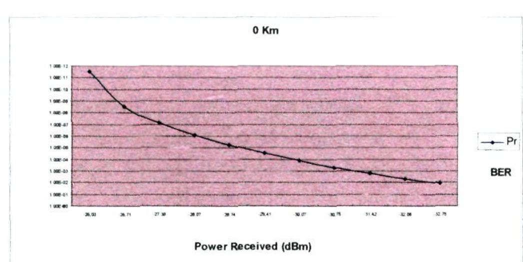


Chart 4.1 :Experiment result for the system Transmitter to Receiver without Fiber and PMD system for 0 km

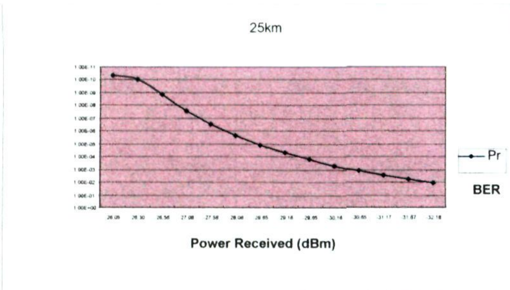


Chart 4.2 :Experiment result for the system Transmitter to Receiver without Fiber and PMD system for 25 km

From and chart 4.1 and chart 4.2, the result for the BER and Power Received look same, but attenuation for the range 0km and 25km are different. This is because the fiber it self has its fiber coefficient value, for about 0.22 db/km and for the test on 25km,the fiber itself produce 5.5 db for the attenuation.

DESIGN 1: To study the effect of BER on PMD value

Experiment 1: Using Fixed Polarizer – Variable Polarizer

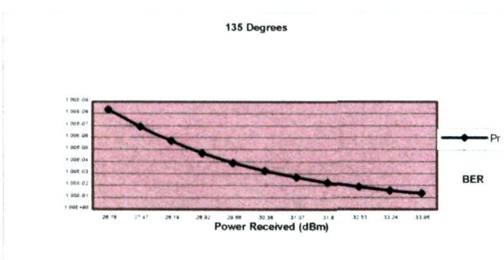


Chart 4.3 :Experiment result for the design that involved with Fixed Polarizer – Variable Polarizer at 135°.

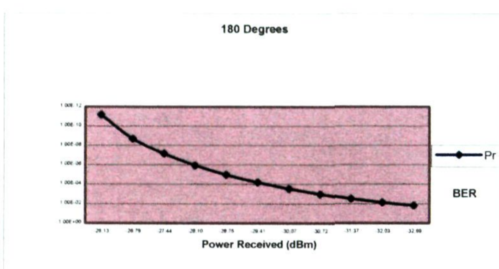


Chart 4.4 :Experiment result for the design that involved with Fixed Polarizer – Variable Polarizer at 180°.

Experiment 2 : Using Fixed Polarizer-Fixed Polarizer

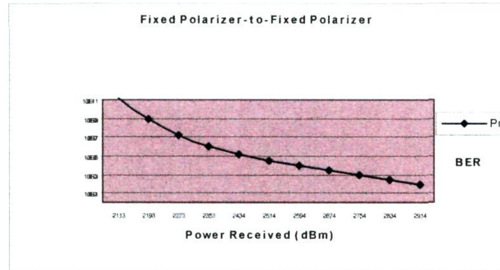


Chart 4.5: Experiment result for the design that involved Fixed Polarizer – Variable Polarizer at 135°.

Discussion for experiment 1 and experiment 2

The purpose of Experiment 1 and Experiment 2 is to look at the differences using the variable polarizer and without the variable polarizer. A polarizer is any device that will accept a unpolarized (collimated) beam of light emerging from a polarizer will be polarized. Of course, in the process, as much as half of the power of the beam will be lost. There are many different types of polarizer. In laser technology, the most common type of polarizer is birefringent crystal. The ordinary and extraordinary beams are polarized at right angle, and propagate in slightly different directions. By blocking one of the beams, one obtains a beam polarized in a well-defined direction.

From experiment 1,where the variable Polarizer was introduced, the result for every degrees are likely same for the power received, where there are some increasing for the power received.

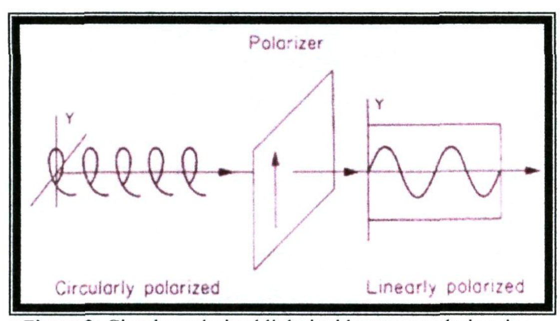


Figure 3: Circular polarized light incident on a polarizer is transmitted as linearly polarized light

The maximum power received is –26.13dBm where the variable polarizer is on 180° and the minimum power received is –33.96dBm at 135° degrees. A simple polarization rotator consists of a half wave plate in linear polarized light. Rotating the half wave plate causes the polarization to rotate to twice the angle of the half wave plate's fast axis with the polarization plane, as shown in figure 4.We achieve variable polarization rotation by aligning the fast axis of a variable retarded at 45° degrees to the incoming polarization and following this component with a quarter wave retarded with it slow axis aligned with the incoming polarization as seen in figure 5.

For the result from experiment 2,the maximum power received is –21.13dBm and the minimum power received is –29.14dBm.If two polarizers have their orientation axes aligned parallel to each other, the first will absorb half the unpolarized light and transmit linearly polarized light which is then transmitted without absorption through the second polarizer. The second polarizer is referred to as an "analyzer". If the analyzer is rotated by 90° so that the two polarizers are crossed with their axes perpendicular, the second polarizer will absorb all the light transmitted by the first.

The amount of rotation achieved depends on the amount of retardance exhibited by the first retarder. The polarization axis is rotated to an angle that is one-half the phase shift provided by the variable retarder. To produce linearly polarized light; the unpolarized light is sending through a polarizing medium whose axis is in line with the desired linear polarization. Passing this polarized light through a second polarizer allows only the components, which are parallel to the polarizing axis to emerge while the orthogonal component is absorbed. For example if vertically polarized light is sent through a polarizer oriented at 45° the emerging light is reduced in amplitude by a factor of 12,has the 45° polarization intensity, which is 50% of the original intensity. Similarly, if vertically polarized light is sent through a horizontally oriented polarizer, no light emerges.

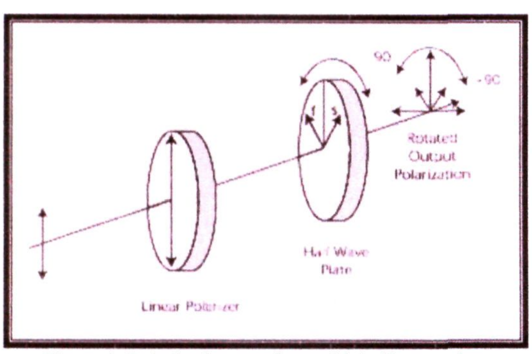


Figure 4: Polarization rotations with half wave plate

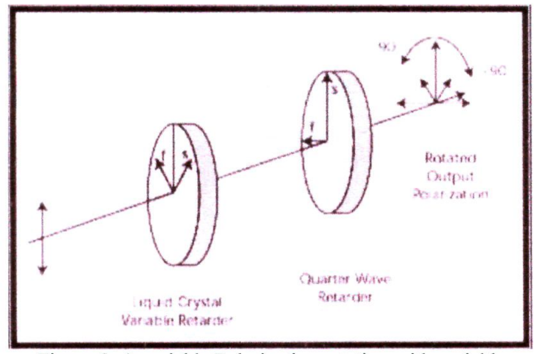


Figure 5: A variable Polarization rotation with variable retarder

Experiment 3: Differential Delay Line1(DDL1) to Error Detector (ED)

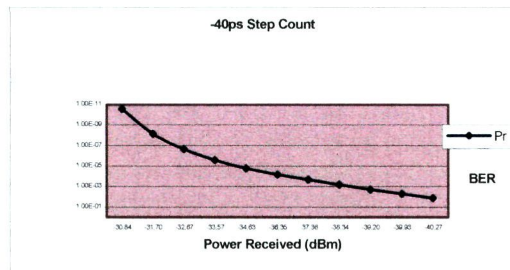


Chart 4.6: Experiment result for the design that involved DDL connected directly to Error detector for -40ps step count

Experiment 4: Differential Delay1 (DDL1) to 25 km of fiber

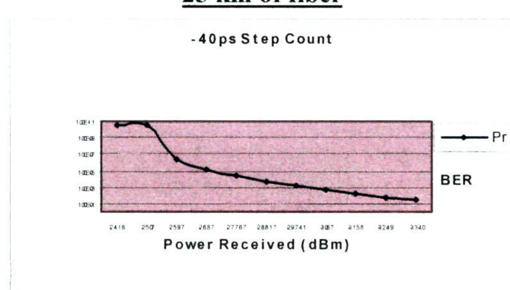


Chart 4.7: Experiment result for the design that involved DDL connected to 25km of fiber for -40ps step count

Experiment 5: Combination DDL1 and DDL2 without fiber

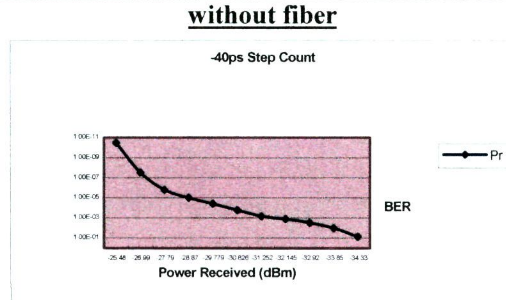


Chart 4.8: Experiment result for the design that involved DDL1 and DDL2 connected directly to Error Detector for -40ps step count

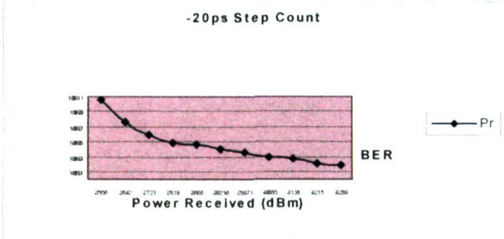


Chart 4.9 : Experiment result for the design that involved DDL1 and DDL2 connected directly to Error Detector for -20ps step count

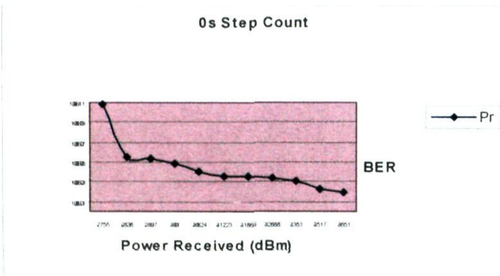


Chart 4.10: Experiment result for the design that involved DDL1 and DDL2 connected directly to Error Detector for 0s step count

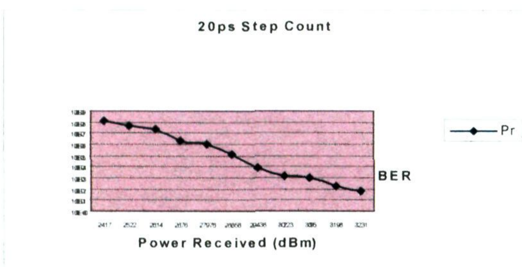


Chart 4.11: Experiment result for the design that involved DDL1 and DDL2 connected directly to Error Detector for 20ps step count

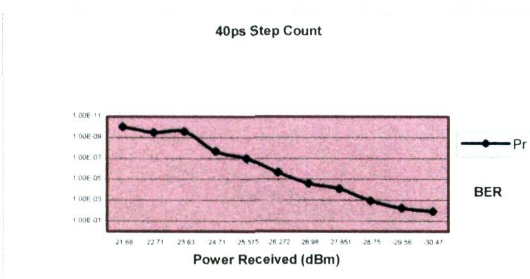


Chart 4.12 : Experiment result for the design that involved DDL1 and DDL2 connected directly to Error Detector for 40ps step count

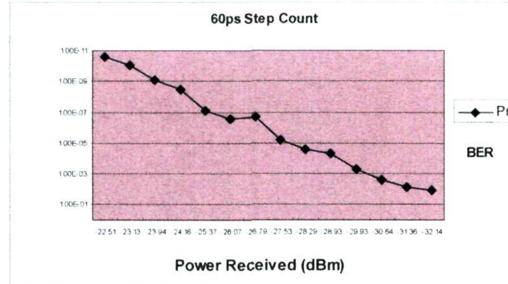


Chart 4.13: Experiment result for the design that involved DDL1 and DDL2 connected directly to Error Detector for 60ps step count

Discussion for experiment 3,4,5

In experiment 3, the transmitter is connected to the DDL (Differential Delay Line) and directed to the receiver and for the experiment 4, the transmitter is connected to the DDL and the 25km of fiber and it's directed to the receiver. The differential delay line function is controlling polarization mode dispersion in optical networks. The device splits the light within a fiber into orthogonal polarizations, and then actively varies the time that one polarization travels compared to the other polarization before combining the two polarizations together again. From experiment, the power received between these two experiments is different for the certain value of step count. The step count is in Pico second unit (ps). For example, two situations we take for comparison. From chart 4.6, the maximum power received is –30.84dBm and the minimum power received is -40.27dBm.This can be achieved because there is no loss from DDL and the signal is directly flow to the receiver. But when the 25km of fiber is installed between the DDL and the receiver, the value for the maximum and minimum power received is less than what we received in Experiment 3.From the chart 4.7, the maximum value for power received is –24.18dBm and the minimum value are – 33.40dBm and this is because the fiber has 6.25db of loss. The DDL is a time delay generator for digital signals.

When there are two DDL are installed without fiber, the charts from chart 4.8 until chart 4.13 show that the power received for minimum and maximum value are little bit decreases.

DESIGN 2: To find and investigate the PMD effect on the Output Power

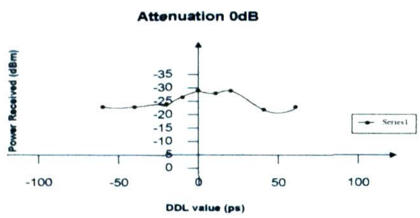


Chart 4.14 : Experiment result for the attenuation of 0dB

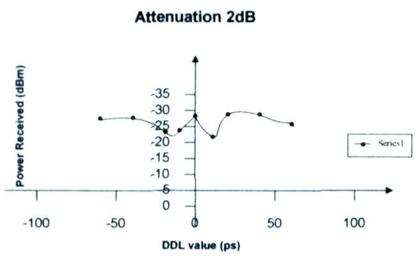


Chart 4.15 : Experiment result for the attenuation of 2dB

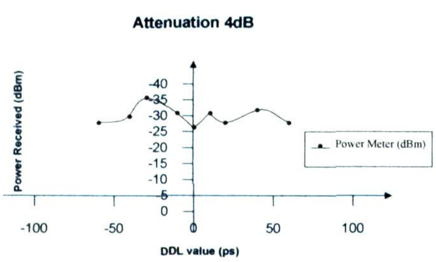


Chart 4.16 : Experiment result for the attenuation of 4dB

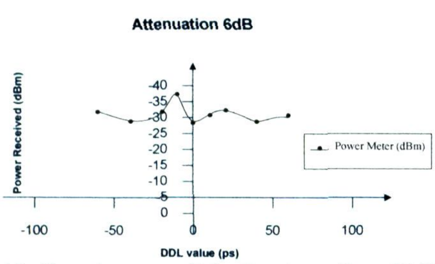


Chart 4.17 : Experiment result for the attenuation of 6dB

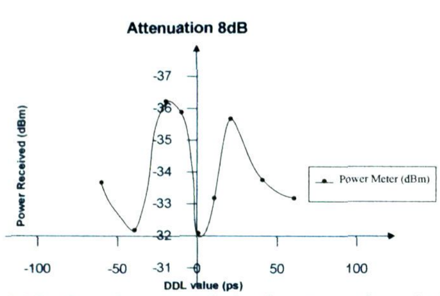


Chart 4.18 : Experiment result for the attenuation of 8dB

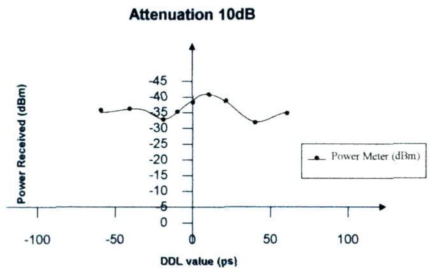


Chart 4.19 : Experiment result for the attenuation of 10dB

Discussion for design 2

From the experiment, the value for the output power received decreases as the value for the attenuation varies. This is because the attenuator is the device that introduces the loss to the system. An optical attenuator is built by combining two linear polarizers and a half wave plate. The input and output polarizers are crossed so that no light passes through them, however, inserting the half wave plate allows light to pass through the device. The amount of light is determined by the angle between the optical axis of the incoming polarizer and half wave plate. Placing the half wave plate's optical axis at 45 degrees to the incoming polarizer achieves a maximum transmission; aligning the optical axis of the half wave plate with either of the input or output polarizers optical axes gives the minimum transmission. How close the minimum is to zero transmission depends on the quality of the polarizers and half wave plate used in the device.

Replacing the half wave plate with a device that varies the polarization, such as a variable retarder, creates a variable attenuator. This configuration is shown in figure 6.When we align the fast axis of the variable retarder at 45 degrees to the input polarizer and modulate the retardance between half wave and full wave, transmission varies between maximum and minimum creating an optical shutter chopper.

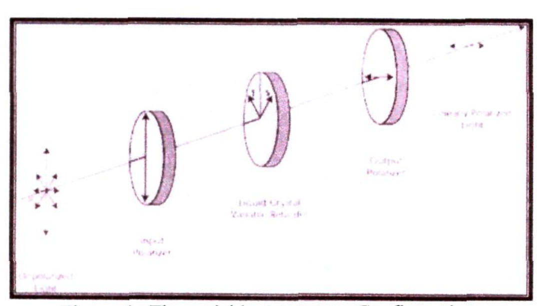


Figure 6 : The variable Attenuator Configurations

Design 3 :To look at the PMD effect on the Eye Diagram

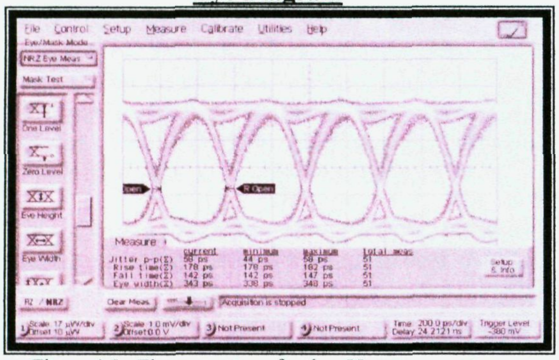


Figure 4.5 : The eye pattern for the -55ps step count on DDL1 and 55ps on DDL2

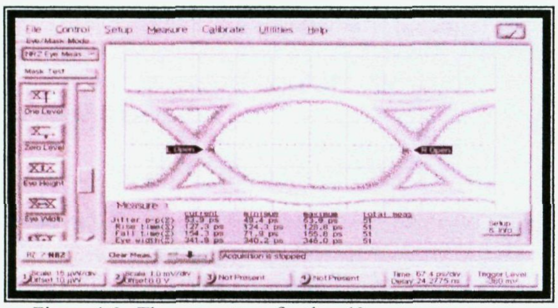


Figure 4.6 : The eye pattern for the -40ps step count on DDL1 and 40ps on DDL2

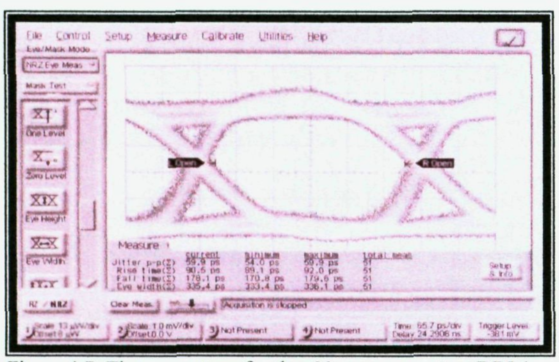


Figure 4.7: The eye pattern for the -20ps step count on DDL1 and 20ps on DDL2

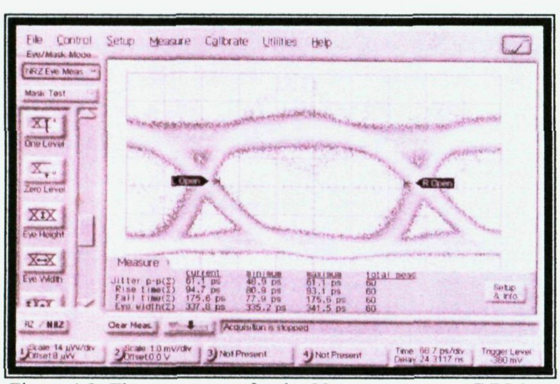


Figure 4.8: The eye pattern for the 20ps step count on DDL1 and -20ps on DDL2

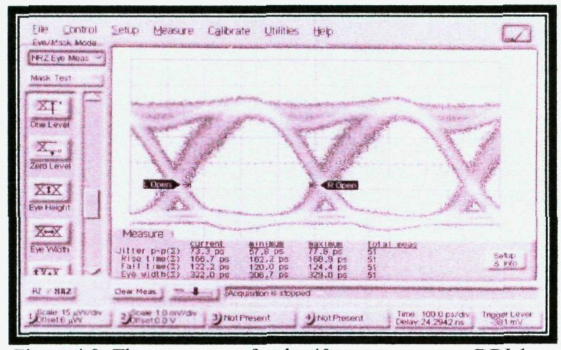


Figure 4.9: The eye pattern for the 40ps step count on DDL1 and -40ps on DDL2

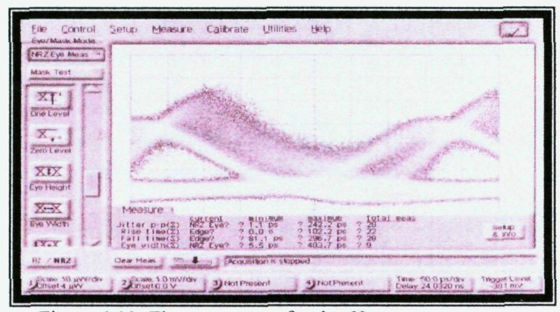


Figure 4.10: The eye pattern for the 60ps step count on DDL1 and -60ps on DDL2

Discussion for design 3

For this design, the transmitter is connected to the DDL, fixed polarizer and connected directly to DCA, which is Infinium Optical Ossiloscope. This equipment is used to show the eye pattern from the transmitter. From the experiment, the optical eye pattern of a PMD, limited signal exhibits the effects of DGD by "closure" of the eye, and this will increases the bit error rate (BER). The effect of the eye closure is caused by the separation of the polarized axes of photons, as the DGD becomes higher, separation becomes greater and the optical pulses start to interfere with each other, causing the eye to close. In this experiment, the value for the attenuation and both DDL1 and DDL2 are varies. For information, the PMD value is the differential group delay (DGD) values and the DGD varies randomly with wavelength and times. In the real world, fibers are far from being perfect, and consequently, polarization modes travel at slightly different speeds and this difference in speed translates into a difference in transmission time through the fiber system, which known as Differential Group Delay (DGD).

CONCLUSIONS

Analysis of polarization modes dispersion can be carried out from any kind of method. The method that have been used in this analysis is Fixed Analyzer method, where this is the simplest method from the other. In measuring PMD, the first choice to be made is deciding which measurement technique to use. Generally, decisions are made based on measurement time, spectral resolution, and what quantities are measurable. Because PMD is the average of random value, the PMD value that one obtains from measurements is somewhat random.

It is important to point out that PMD is statistical measurement and it will naturally vary during measurement. Their standard deviations will characterize these measurements as a group of statistical data. For a correct interpretation of the measurement, PMD must not be viewed as a single, direct measurement, but rather as a group of measurement to stabilize both the measurement system and the test device against movement or anything that can affect the measuring value.

FUTURE DEVELOPMENT

Currently, there is no really simple solution/component available to correct a link which has a high PMD value. This is still under consideration and development. So PMD is clearly limiting the distance (or the transmission bit rate) of a given network application.

Moreover, if there is a PMD issue, there is no simple method to locate the part of the link which is generating the problem.

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