Performance Analysis of Polarization Mode Dispersion (PMD) For Four Channels Using Emulator at 10 Gbps

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Abstract
This paper deals with the effects and compensation of Polarization Mode Dispersion (PMD), which has found to be a considerable attention in high data rate systems, now-a-days. In general, a small amount of PMD is to be considered in high data rate systems, since it limits the data rate. Unlike the chromatic dispersion phenomenon, the PMD is found to be a time varying and an unstable phenomenon. Thus compensation of PMD is required since it distorts the signal and broadens the pulse in a statistical manner. In this paper we analyze the PMD effects and compensate the effect of PMD using the OPTSIM simulation for 10 Giga bits per second (Gb/s) transmission systems. Here the Compensation of PMD is done by an optical compensation method called Deterministic Differential Group Delay (DDGD) and the results have been simulated and analyzed.

I. INTRODUCTION
PMD is a kind of modal dispersion usually associated with single mode fibers. The PMD is measured in picoseconds per square root of kilometer (ps/√km) as it is proportional to the square root of the length of the fiber. The typical values of PMD range from 0.05ps/√km to 1.0 ps/√km. Polarization Mode Dispersion is one of the most serious impairments which limit the data rate in long distance transmission and high speed transmission systems. Increase in PMD causes pulse broadening and severely degrades the system performance. In low data rate systems (100 Mb/s) PMD is negligible but in high data rate systems it affects the bandwidth distance product severely. It normally increases the bit error rate in long distance communication, since it is time varying. Thus compensation of PMD is required to avoid such problems. In this paper we have analyzed and proposed an optical compensation method for compensating the PMD effects which produces a deterministic delay (DDGD) between the two polarization states using OPTSIM simulation. In this method PMD is efficiently and successfully compensated.

II. THEORY
A telecommunication signal propagates in an optical fiber in the form of modulated beam or wave of light. The light is a form of electromagnetic radiation which is characterized by wavelength and frequency. All the electromagnetic waves are characterized by polarization that is nothing but the direction in which the electric field of the wave is oriented perpendicular to the transverse wave of light which is travelling. Thus the electromagnetic waves are characterized by two polarizations along the X axis or along the Y axis and if the electric field E is not aligned with either axis the electromagnetic wave would contain both polarizations. The speed at which the light travels through an optical fiber is mostly dependent on the refractive index of the fiber. The higher the refractive index of the fiber, the slower will be the speed of light and vice-versa. Thus the Polarization Mode Dispersion depends on the change in the refractive index of the fiber. The causes of PMD are birefringence and DGD and they are discussed below.

A. BIREFRINGENCE
Certain environmental conditions such as variations in the temperature and stresses in the fibers can change the refractive index of the fibers. When the temperature increases, the refractive index varies randomly over the wavelengths which results in varying wavelength speeds. Thus the refractive index will have a different value across the horizontal and vertical axis of the fiber core. This difference in the refractive index will result in two orthogonal states of polarization. This will cause birefringence in which the light gets split up into fast axis (n_x) and slow axis (n_y), when a ray of light enters a fiber. This phenomenon is also known as double refraction. When the birefringence varies then the PMD also varies randomly. The birefringence effect can be shown in Fig.1.

The equation for birefringence in terms of difference in the refractive index is given as

$$\Delta \beta = \beta_s - \beta_f$$

(1)
B. DIFFERENTIAL GROUP DELAY

The birefringence effect of the fiber will cause Differential Group Delay (DGD) between the two polarization states Fig.2. The DGD is nothing but the difference in propagation times between the two polarization states. This differential time delay between the propagation modes is called as first order Polarization Mode Dispersion.

\[ \Delta \tau = \Delta \beta L \]

Where L is the length of the fiber, DPMD is the amount of PMD incurred in the fiber. It is expressed in terms of ps.

C. COMPENSATION OF PMD

Currently manufactured low PMD fibers have the PMD values ranging between 0.05 and 0.1 ps/\( \text{km} \) but for a large percentage of fielded fiber systems the PMD values vary between 0.5 and 1.0 ps/\( \text{km} \). Generally PMD is measured after installation, since it is unstable. Since the PMD is time varying and random it is difficult to compensate it, compared to chromatic dispersion. This is because of the fact that PMD varies with wavelength and slowly drifts randomly with time on the order of milliseconds. Thus this effect can then be minimized by employing adaptive or dynamic compensation techniques. The compensation of PMD can be done either electronically or optically. Generally electronic PMD compensation using adaptive electronics has been demonstrated at 10 Gb/s and optical compensation techniques were used in field trials that transmitted data rates of 10, 40, and 160 Gb/s over standard G.652 single mode fiber. In an electronic PMD compensation process, intersymbol interference caused by the overlapping of the pulses can be minimized by using an equalizer. Since equalization is the standard technique for mitigating intersymbol interference in electronic digital systems, a similar equalization process can be used to compensate for PMD effect. Generally equalization is done after the photo detection process which uses filter. The selection of the filters is quite complex due to noise effects and statistical variation of PMD. Though these techniques are simple to implement, low cost and compatible they can operate at a maximum of 10 Gb/s data rate. However this electronic bottleneck in these compensation effects, make this technique more unfamiliar. Thus optical compensation techniques are preferred. These optical compensators are independent of bit rate and modulation formats and thus they can compensate more channels simultaneously. Thus they are widely used for PMD compensation high data rate systems. In optical PMD compensation process, the basic procedure is to divide the received signal into its fast and slow polarization components. The fast polarization mode is then delayed in order to allow the slow mode to catch up. Ideally, the resulting PMD value should be zero. However, in practice since the Differential Group Delay changes with time, the separation and delay of both polarization modes can be estimated with only a limited accuracy and limited bandwidth.

III. EXISTING METHODS

Nowadays, PMD compensation methods are adopted by decreasing the modulation and demodulation methods. Since PMD is time varying and statistical in nature, the above method is ineffective in real time applications. The FiberBragg Gratings [1], are also used to compensate the PMD effects. But this method is particularly meant for chromatic dispersion compensation and also they are bulky, heavy and costly. An adaptive compensation system visualized with an electronic Si-Ge equalizer integrated circuit, which including a 4-tap transversal filter operating at 10 Gb/s, is described in [2]. A brief description of PMD compensation systems, working in optical domain, structures and requirements for automatic compensation, is given in [3]. Overall, electrical signal processing has become an alternative for PMD compensation due to possible compact and cost-effective implementation of the equalizer in the receiver electronics [4] and the need of individual compensation in WDM systems. In [5] & [6] the PMD is discussed and compensated up to the value of 50 ps. But in this paper, analysis and compensation of PMD up to 100 ps is discussed. Feedback and feed forward PMD compensators [7], are also ineffective, since they reduce only a small amount of PMD. Generally all the electrical, electronic compensation methods are very difficult to implement and cost effective [8]. Thus effective and simple PMD compensation techniques are necessary.

IV. PROPOSED METHOD

This method is based on concept of splitting up of the optical signals into fast and slow polarization components. Specifying the Principal State of Polarization (PSP) it applies a deterministic delay between the optical signal components.
with respect to the PSPs. The component behaviour is represented in the Fig.3. Here the input optical signal gets split up into two branches and sent to the two polarisers POL1 and POL2. These two polarisers are complementary to each other in such a way that the POL1 polarization can be set up in the Stokes space representation, whereas the POL2 is automatically set to the corresponding orthogonal polarization. More precisely, for the polarizer POL1 it is necessary to specify the two angles $2\alpha$ and $2\phi$ in the Stokes space using a spherical coordinate system (azimuth and zenith angles) required to determine the state of polarization. An optical delay element is inserted, whose delay $\tau$ is set by the delay parameter, whereas the signal exiting from POL2 is not delayed and set to the value orthogonal to POL1. Finally the two signals are summed up. As a result the two components experience a differential delay. Since the delay set up is deterministic, it is called as Deterministic Differential Group Delay (DDGD). Notice that the optical delay actually applied in the simulation is an integer multiple of the simulation time sampling step, so the delay effectively used $\tau'$ is related with the simulation bandwidth through the following relationship:

$$\tau' = \text{NearestInteger}(\tau \times BWVBS / 0.8) \times (0.8 / BWVBS)$$  \hspace{1cm} (3)$$

where, $BWVBS$ is the VBS simulation bandwidth. This DDGD method is used widely for compensating the PMD effects effectively and thus reduces the bit error rate. The DDGD behaviour is effective if and only if the parameters set in the optical delay element and in the polarizers are optimized. The polarizers may be of circular right, circular left or linear depending upon the variation in the PMD effects. Since this technique provides a deterministic DGD between the fast and slow polarization components, the PMD is effectively and successfully compensated up to 100 ps and thus reduces signal distortion and pulse broadening effect due to PMD.

V. SIMULATION LAYOUT

![Fig 4: OPTSIM layout for PMD compensation using DDGD](image)

The layout shown in Fig. 4 has been implemented by using the software called OPTSIM which is one of the costliest simulation softwares, exclusively meant for the optical communication purposes. It is specially designed, supported and marketed worldwide by RSOFT Design Group. It is also focused entirely on productivity tools for telecommunication and data communication engineering. The components in the layout is for four channels of which we have shown the output of the second channel before and after the emulation. The data source used here is a Pseudo Random Binary Sequence (PRBS) generator. The period of the waveform, duty cycle, amplitude levels and data rates can be set in this generator. The Direct modulator laser component normally simulates a simplified continuous wave laser and a modulator component, which generates a continuous wave of constant amplitude and modulates the signal. Generally a fiber is after all a transmission medium which should bring the same status of the signal (both if the time domain as well as in frequency domain) at the input and output. At the transmitter end the bit rate is 10Gb/s, center frequency is 193.55. The fiber used in this experiment is of length 100 km. The attenuation, dispersions such as chromatic and PMD dispersions, Raman effects, SPM, birefringence effects can be set in the fiber, as parameters. This fiber is normally a complex structure and all the effects such as attenuation are caused only because of the fiber nonlinearity. So handling of this component is very important. Generally fiber used here will be the single mode fiber. Since this layout is meant for PMD analysis and compensation, the parameters corresponding to PMD such as birefringence, polarization effects should be switched ON and whereas other nonlinearity effects should be switched OFF. For the polarizer we have taken the value of azimuthal angle is -230 degrees and of zenithal angle as -20 degrees. The delay at DDGD is 10 ps. The output from the fiber can be split by means of an optical splitter and can be sent through the polarizer 1, delay element and polarizer 2 (DDGD) and then combined by using a multiplexer and the required controlled and optimized parameter settings depending on the bit rate and PMD values can be made here. After the simulation, the broadened and compensated pulses can be viewed before and after the use of emulator with the help of signal BER estimator, Q estimator and electrical power meter which are shown below.

VI. RESULTS AND DISCUSSIONS

The experimental results shown in the figures Fig.5 to Fig.10 using OPTSIM have been demonstrated for 100 km fiber optic link for 10 Gb/s transmission systems in this paper. When the output of the fiber is passed through DDGD, the PMD gets compensated to the original pulse duration of 100 ps. The same layout could be scaled up to 100 Gb/s data rate. We have shown the increase in the Q factor, decrease in BER and Electrical power after the use of emulator.
VII. CONCLUSION

Thus from the experimental simulation using OPTSIM, the PMD effects are analyzed and compensated efficiently by DDGD method up to 100 ps. Work is on progress to further analyze the PMD deeply for the high bit rate system (100 Gb/s), and reduce its value. Analysis of PMD for the WDM system has to be carried out by increasing the number of channels. After obtaining the optimum settings in the DDGD, it could be implemented in real-time hardware.

REFERENCES


