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Different Dispersion Compensation Techniques in Fiber Optic Communication System : A Survey

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***Abstract*—In order to maintain high value of optical signal to noise ratio (OSNR) for having a signal of good quality it is important to compensate dispersion in optical finer communication system. Dispersion compensation in fiber optical communication system has become a topic of great importance and research these days because any presence of dispersion might lead to pulse spreading which might cause inter symbolic interference (ISI) which leads to signal degradation. In this manuscript, various types of dispersions are discussed in a brief way. Also different methods of dispersion compensation like-Dispersion compensation fiber (DCF), Electronic Equalizer, Fiber Bragg Grating (FBG) and digital filters are discussed in detail.**

***Index Terms*—:OSNR, Dispersion Compensation, ISI, DCF, FBG, Electronic Equalizer, digital filters**

I. Introduction

In Fiber Optic Communication system we transmit information from one point to another in form of light signals or pulses [1,2]. The light pulses are modulated by a electromagnetic wave which acts as a carrier signal. It is the large bandwidth that can be achieved b by using optical fiber communication that lead to a worldwide development and installation of fiber optic links. The performance of an optical fiber communication link in degraded by many factors such as scattering, bending losses, absorption, scintillation, non linear effects and chromatic dispersion. Out of them chromatic dispersion is the main limiting factor which limits the data rate and bandwidth of an fiber optic communication link. Polarization mode dispersion and chromatic dispersion are major performance limiting factors in an single mode fiber (SMF). The main reason for presence of chromatic dispersion is that the velocity of light carrying the information signal is dependent upon the reflective index of the core which in return is dependent upon wavelength of the light used to carry information. As a result light pulse carrying information spreads at the output of the fiber which results in dispersion. There are many ways to compensate dispersion such as use of Electronic Dispersion compensation (EDC), dispersion compensating fiber (DCF), fiber Bragg grating (FBG) and digital filters. Out of them DCF is considered to be most effective and easy to implement technique used to compensate dispersion. FBG is compact and least expensive to compensate dispersion. But these days many digital filter techniques such as raised cosine filter, optical all pass filter (OAPF) are used to compensate dispersion [3], [5]. Thus it has become a matter a great concern to overcome dispersion so as to enhance the performance of an optical fiber communication link. The rest of the paper is organized as follows: Need for dispersion compensation and literature survey is discussed in section 2.In section 3, types of dispersion is explained. Comparative analysis of different dispersion compensation techniques is presented in section 4. Concluding remarks are given in section5.

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II. Need for Dispersion Compensation

Due to the dependence of speed of information carrying signal on the refractive index of the fiber which depends on the wavelength of the signal carrying information, different signals having different wavelengths reach the output of the fiber at different times as in case of a multimode fiber. Even in a single mode fiber the information carrying signal does not consists of a single wavelength rather a continuous group of wavelengths called the spectral with of transmitting source. These wavelengths experience different refractive index and hence travel with different velocities and reach output of the fiber at different time causing the pulse to spread [5]. Now if the data rate of the information signal is increased, the pulses at the output may overlap with each other as shown in figure no.1. These causes inter symbolic interference (ISI). Due to inter symbolic interference we cannot increase the data rate of the fiber optic communication link beyond a certain limit. As a result dispersion is a limiting factor on data rate of fiber optic communication link. Thus in order to achieve high data rates, dispersion compensation is the most important requirement in fiber optic communication link.

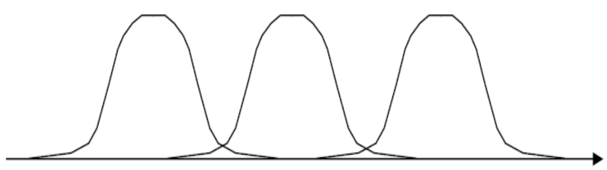


Figure No.1: Inter symbolic Interference due to Dispersion[1]

In2008, H. Bulow et al. [16] presented the capability of different electronic equalization schemes for 40 and 10 Gb/s optical communication over a SMF, to analyze their ability to compensate CD and PMD. In addition this paper discussed the impact of non linearity in fiber and types modulation format on equalization.In 2009, J. Zhao et al.

[17] discussed full field detection based likelihood sequence estimation in case of compensation of chromatic dispersion in a 10 Gb/s on–off keyed optical transmission systems. This paper proved that nearly 50% improvement in transmission distance can be achieved as compared to that of conventional direct detection MLSE without increasing the electronic compensation complexity. In 2011, R. Pawase et al. [18] discussed the ability of negative dispersion fiber used to compensate dispersion. In this paper test was conducted on a single span DCF and a single channel system transmitting at a speed of 10Gb/s with the transmission wavelength of 1550nm over 120km of conventional SMF. In 2011, A. S. Karar et al. [19] investigated electronic pre compensation for a 10.7 Gb/s system using a directly modulated laser. The nonlinear distortion which results from the direct modulation of the laser can be removed by using pre compensation electronic equalization and use of DSP to generate an approximate modulating current.In 2011, K. Khairi et al. [20] demonstrated experimentally the performance comparison between multichannel chirped fiber Bragg grating as means to compensate dispersion in pre compensation and post compensation schemes for long span optical communication system. They discussed that even though both methods have capability to compensate chromatic dispersion, the harmful effects of SPM on the signal were most effectively minimized in the pre compensation case.

III. TYPES OF DISPERSION

There are basically three types of dispersion namely:

1).Intermodal Dispersion
2).Intramodal Dispersion
3).Polarization Dispersion

A. *Intermodal Dispersion*

This type of dispersion is present only in multimode fibers. The light travelling in multimode fibers does not consists of a single beam rather a no of beams which travel at different propagating angles. The beam of light travelling parallel to fiber is known as fundamental mode and that travelling at critical propagating angle is known as critical mode. Figure no.2 shows different modes in an optical fiber. These different modes travel different distance within an optical fiber and hence reach output of optical fiber at different times causing pulse to spread at output which ultimately leads to dispersion.

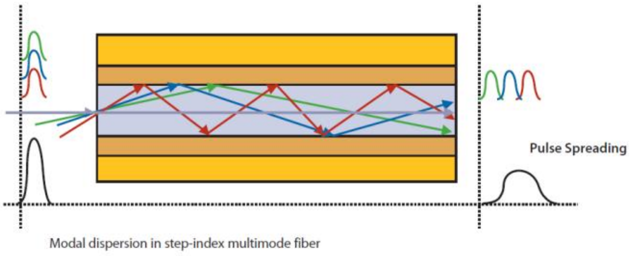


Figure No.2: Intermodal dispersion in step index fiber [3]

B. *Intramodal Dispersion*

Intramodal dispersion also known as chromatic dispersion is present in both single mode fiber (SMF) and multimode fiber (MMF) as compared to intermodal dispersion which is present only is a multimode fiber. The pulse spreading in intramodal dispersion arises due to the fact that the information carrying signal does not consists of a single wavelength but rather a finite spectral width of transmitter source. This leads to the phenomenon of group velocity dispersion [2], [4], [11] since dispersion is due to dependence of velocity of signal carrying signal to the wavelength of signal .Intramodal dispersion is farther of two types:

a) Material Dispersion:

Material dispersion is caused by dependence of silica's reflective index on wavelength. Alight pulse carrying information consists of a finite spectral width of light. Therefore different components will travel with different velocities and will reach output at different times causing the pulse to spread [7]. Figure no.3 shows example of material dispersion.

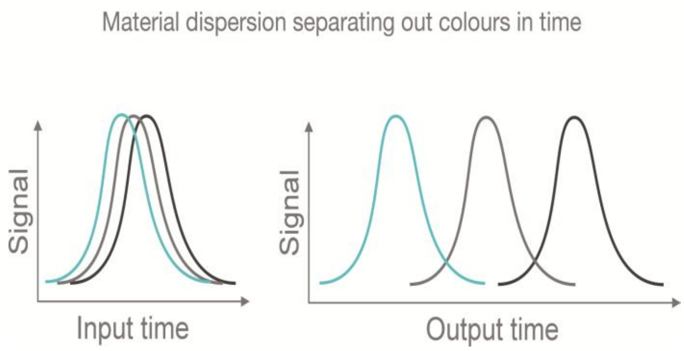


Figure No. 3: Material Dispersion [6]

a) Waveguide Dispersion:

After entering the fiber the information carrying signal is partially present in core and partially in core and partially in cladding. Its major portion travels with core and rest with cladding. Information signal in both core and cladding travel with different velocities due to different refractive index of core and cladding. The light will expand at output simply because the material in which light is confined has different refractive indexes- the core-cladding combination of fiber. Since the refractive index of cladding is always less than that of core, light travelling in cladding will reach the end of fiber earlier than that travelling in core. This results in dispersion.

Figure no.4 shows how different portion of light travels in an optical fiber.

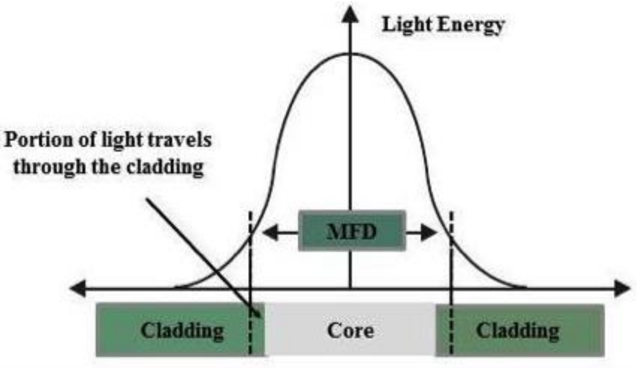


Figure no. 4: Mode Field Diameter [8]

C. Polarization Mode Dispersion

A single mode fiber carries two linear polarized waves that propagate within fiber in two mutually perpendicular planes as shown in figure no.4. Each mode carries half of total optical power. Due to asymmetry present in fiber during fiber cabling and splicing process, refractive index of both perpendicular planes are not same and this inequality causes polarization dispersion [10].

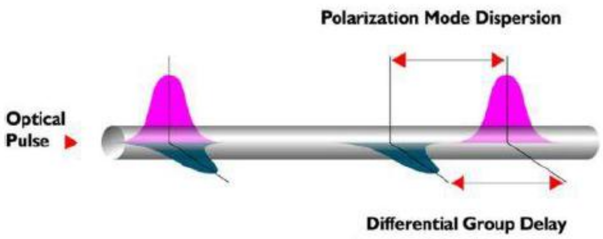


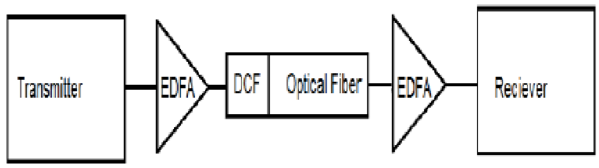
Figure No.5: Polarization mode dispersion [9]

IV. DISPERSION COMPENSATION TECHNIQUES

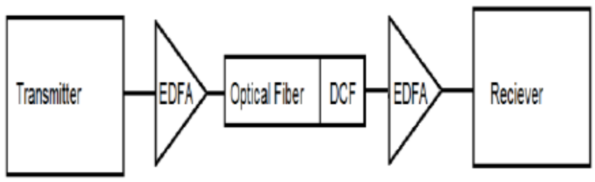
There are many techniques that can be used to compensate chromatic dispersion. Each of them has its own advantages and disadvantages. The most commonly implemented techniques in practical situation are discussed in detail:

A. Dispersion Compensating Fiber (DCF)

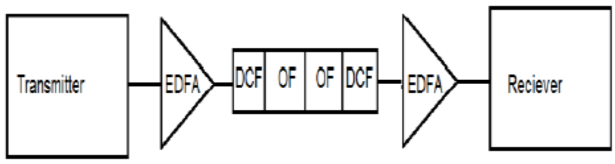
In dispersion compensating fiber technique we use a fiber having a large negative dispersion along with a standard fiber. The amount of light dispersed by a normal fiber in reduced or even nullified by using a dispersion compensating fiber having a very large value of dispersion of opposite sign as compared to that of standard fiber [6]. There are basically three schemes that can be used to install a dispersion compensating fiber-pre, post or symmetrical. In pre compensation technique DCF is inserted in the loop before the standard mode fiber as shown in figure no.6 (a). In post compensation technique the DCF is inserted in the loop after the standard fiber as depicted in figure no. 6 (b). In symmetrical compensation DCF is inserted both before and after the standard mode fiber as shown in figure no. 6 (c). out of these three schemes symmetrical compensation shows a better performance in compensating dispersion.



(a)Pre- Compensation



(b)Post- Compensation



(c) Symmetric Compensation

Figure No.6: Different dispersion compensation schemes[10]

The positive dispersion of standard mode fiber in C and L band can be compensated by using dispersion compensating fiber having high values of negative dispersion -70 to -90 ps/nm.km [9].

B. Fiber Bragg Grating (FBG)

The idea of Fiber Bragg Grating was initially presented in 1980 and has been utilized as a part of a few applications and generally inquired about. It comprises of a direct intelligent gadget whose intelligent record profile changes straightly concerning length of the fiber. The grinding mirrors the light contingent on the wavelength of the light entered in the grinding [12]. The light with bigger wavelength ventures a more prominent separation in the grinding before getting considered the other hand beam with littler wavelength voyages a shorter separation inside the grinding before getting reflected. Thus, the beam which is extended by the chromatic passing so as to scat in a SMF is packed through a Fiber Bragg Grating [12]. This is the fundamental standard of Fiber Bragg

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Gratings. The reflected wavelength (λ_b) otherwise called the Bragg wavelength is given by the relationship:

$$\lambda_b = 2n\Lambda \qquad (1)$$

Where n is the effective refractive index of the grating in the fiber core and Λ is the grating period. The main advantage of utilizing Fiber Bragg Grating as technique to compensate dispersion is that it requires a very less space and has a low value of insertion loss and they are compatible with single mode fiber and are very cost effective. FBG also find its application in different field such as WDM add/drop filters, pump lasers and wavelength stabilizers [8], [12]. Fig no.7 shows the basic principle of FBG.

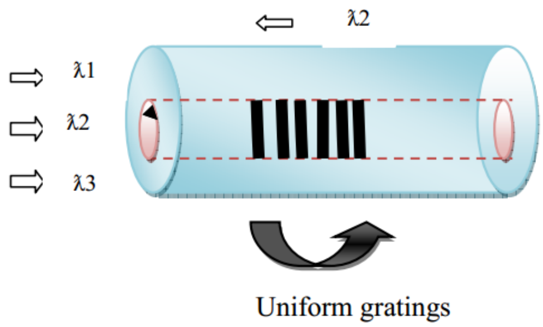

Fig no. 7: Principle of Fiber Bragg Grating [7]

The functioning of FBG depends upon the reflection of light from gratings and coupling of modes [6]. Forward and backward propagating fields of same mode causes coupling and they show strong coupling if they satisfy following condition:

$$\beta_1 - \beta_2 = {}^{2m\pi}/_{\Lambda} \qquad (2)$$

where β_1 *and* β_2 are phase constants of two modes. Now if we consider two modes which are counter propagating we have

$$\beta_2 = -\beta_1 \qquad (3)$$

And hence the Bragg Diffraction condition is given by:

$$2\beta = 2m\pi/\Lambda \qquad (4)$$

If effective modal index is given by n_{eff} then:

$$\beta_1 = 2\pi n_{eff}/\lambda \qquad (5)$$

Thus the Bragg wavelength which is strongly reflected by grating is given by:

$$\lambda_b = 2n_{eff}\Lambda \qquad (6)$$

This is the final condition of wave to be reflected inside of a Fiber Bragg Grating.

C. *Electronic Dispersion Compensation (EDC)*

Electronic compensation technique makes use of electronics in conjunction withoptics in order to compensate dispersion. There are many ways in which EDC can be used to compensate dispersion. One of them is compensating first order PMD in the fiber by cancelling it out with a complementary PMD vector produced at the receiver end. Dispersion compensation by use of equalization circuits is the most common technique used to compensate dispersion by EDC. Hui Wu proposed that Intersymbol Interference (ISI) which is produced due to dispersion can be reduced by transversal equalizers by making appropriate use of delay lines and gain at each stage. The use of Asymmetric Mac-Zender Interferometer (AZMI) which has a large differential time delay to suppress thermal noise and fiber non-linearity is another EDC technique which can be used to compensate dispersion. The improvement of the distortion in the system by use of MZI as a dispersion slope equalization in Specrta Amplitude Coding-Optical Code Division Multiple Access (SAC-OCDMA) which is integrated with Arrayed-Waveguide Grating (AWG) router is another way of electronic dispersion compensation. One of the simplest techniques to compensate dispersion using EDC is by use of Feed Forward Equalizer (FFE) and Decision Feedback Equalizers (DFE). Figure No. 8 shows a five-tap FFE. The FFE is referred as a delay line whose output is given by:

$$y(t) = \sum_{k=0}^{N-1} c_k . x(t - [k.\Delta t])$$

Where N is no of taps in FFE, x(t) is the value of input at time. A single stage DFE is shown in figure no. 9.

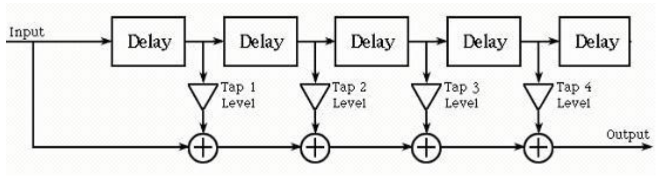

Figure no. 8: Feed Forward Equalizer (N=5) [11]

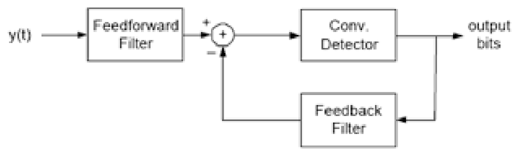

Figure No.9: Single stage Decision Feedback structure [11]

D. *Digital Filters*

C.H. Cheng, G. Lenz, C.K. Madsen, J.A. Walker, J.E. Ford, K.W. Goossen, T.N. Nielsen, A.J. Bruce, M.A. Cappuzzo, L.T.Gomez, R.E. Scoti [12], [13], [14], [15] implemented digital signal processing in order to compensate chromatic dispersion. The use of All Pass Optical Filter to compensate dispersion is the most effective way of dispersion compensation using digital filters. Optical all pass filters are lossless filters that are capable of tuning a desired phase response by manipulating the number of stages keeping magnitude response of the system constant. The free spectral range (FSR) of all pass optical filters is about 100 GHz and has a very minute polarization dependency of range +100 ps/km to -100 ps/km, with a 50 GHz passband width and group delay ripple value of less than 3 ps peak.

V. CONCLUSION

There are many techniques that can be utilized to compensate dispersion in an optical fiber communication link. Dispersion compensating fibers are considered to be the simplest as they are used in the fiber optical loop along with the standard fiber and posses opposite dispersion which is used to mitigate dispersion. But the insertion loss for a DCF is very high. Finer Bragg Grating is a very compact device with low insertion loss and compensates dispersion by compressing the pulse which passes through it. Electronic equalizer used in Electronic Dispersion Compensation (EDC) make used of feed forward equalizer of decision feedback equalizers or both in conjunction to compensate dispersion of about 1600 ps/km (80 km) for 10 Gbps at 1550 nm. These days digital filters are considered to be the best technique for dispersion compensation as they are capable of providing both fixed and tunable compensation of dispersion for WDM systems.

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