Dispersion Compensation Techniques: A Comprehensive Review

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ABSTRACT

Optical fiber is one of the most important media used for communication. It offers high potential bandwidth and flexibility for high bit-rate transmission. However, their performance slows down due to some parameters like dispersion, attenuation, scattering and unsynchronized bit pattern. In long haul applications, dispersion is the main parameter which needs to be compensated in order to provide high level of reliability of service (ROS). Dispersion causes pulse broadening and pulse distortion, thus degrading the performance of the optical fiber. Dispersion compensation in optical fiber communication system has become a topic of great importance because any presence of dispersion might cause inter-symbol interference (ISI) leading to signal degradation. It is the most important and challenging aspect of the optical fiber communication to maintain a high optical SNR for good quality of the signal. There are various methods for dispersion compensation. Although dispersion compensating fiber is a reliable and mature technology but it gives high insertion loss and introduce non-linear distortion when the input power is high. Consequently other techniques such as Electronic Dispersion Compensation, Fiber Bragg Grating Dispersion Compensation and dispersion compensation using digital filter are also in use.

Keywords-OSNR, ISI, Wavelength Division Multiplexing, Dispersion Compensation, FBG, DCF, Electronic Equalizer.

1. INTRODUCTION

Optical Fiber Communication is a method of transmitting information in the form of light pulses through an optical fiber from one place to another. The light forms an electromagnetic carrier wave that is modulated for carrying information. Fiber is advantageous over electrical cables when long distance, high bandwidth or immunity to electromagnetic interference are required. An optical fiber is a transparent fiber made by drawing glass (silica) or plastic to a very small diameter, having a transparent core surrounded by a transparent cladding with a lower index of refraction. Light travels in the core by the phenomena of total internal reflection. A single fiber can carry many independent channels, each having a different wavelength of light, known as wavelength division multiplexing (WDM).

Chromatic dispersion is the main factor which limits the data rate and bandwidth of an optic fiber communication link. It occurs because of the different wavelengths in a light beam which arrive at the destination at slightly different times. The result is spreading, or dispersion, of the light pulses that convey digital information. It has become a matter of great concern to overcome dispersion so as to enhance the performance of optical fiber communication link and to improve OSNR. The existing dispersion compensation techniques are use of Dispersion Compensating Fiber (DCF), Fiber Bragg Grating (FBG) and Digital filters. Many digital filter techniques such as raised cosine filter, optical all pass filter (OAPF) are also used for dispersion compensation. Dispersion is categorized into three types which are –

A. Intermodal Dispersion

This type of dispersion occurs in multimode fibers and in other waveguides, where the signal spreads in time because the propagation velocity of optical signal is not same for all the modes. In multimode fibers, the different beams of light travelling at different propagating angles reach the output at different times, which ultimately leads to dispersion. This limits the bandwidth of multi mode fibers.

B. Intramodal Dispersion

This type of dispersion is present in both single mode fiber (SMF) and multimode fiber (MMF). The pulse spreading in intramodal dispersion arises because the...
The paper is organized as follows: Literature survey is discussed in section 2. In section 3, various dispersion compensation techniques are being explained. Results are given in section 4. Conclusion and future directions is given in section 5.

II. LITERATURE SURVEY
Dispersion compensation is an important issue for fiber-optic links. Without dispersion compensation, each symbol would be broadened so much that it strongly overlaps with a number of neighboring symbols. This causes inter-symbol interference (ISI) which can strongly distort the detected signal. Due to inter-symbol interference, the data rate of the fiber optic communication link cannot be increased beyond a certain limit. Therefore, dispersion is a limiting factor on the data rate of the fiber optic communication link. Therefore, it is essential to compensate the dispersion before detecting the signal.

III. DISPERSION COMPENSATION TECHNIQUES
The various existing techniques which are used to compensate dispersion are being discussed in detail.
1) Electronic Dispersion Compensation: Equalization is a simple method for controlling inter-symbol interference in bandlimited channels. EDC can be used to compensate PMD in the fiber by cancelling it out with a complementary PMD vector produced at the receiver end. The use of Asymmetric Mach-Zehnder Interferometer is another EDC technique. One of the simplest techniques to
compensate dispersion using EDC is by use of Feed Forward Equalizer (FFE) and Decision Feedback Equalizers (DFE). 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, \( x(t) \) is the input value.

2) Dispersion Compensation Fiber: They have negative dispersion ranging from -70 to -90ps/nm/km and can be used to compensate the positive dispersion of transmission fiber. There are basically three schemes which are used to install a dispersion compensating fiber (DCF) – Pre, Post or Symmetrical. In Pre-compensation scheme, the DCF is placed before the SMF for compensating dispersion in the standard fiber. In Post-compensation scheme, the DCF is placed after the SMF. In Symmetrical compensation, DCF is inserted both before and after the SMF. All the three schemes are shown in Fig. 6.

Fig. 6: Feed Forward Equalizer (N=5) [3]

3) Fiber Bragg Grating: It is a reflective device which is composed of an optical fiber that contains modulation of its core refractive index over a certain length. It can also be used as an inline optical filter which blocks certain wavelengths, or as a wavelength-specific reflector. The reflected wavelength (\( \lambda_R \)) is called the Bragg wavelength, and is defined by the relationship:

\[ \lambda_R = 2n\Lambda \]

where \( n \) is the effective refractive index of the grating in the fiber core and \( \Lambda \) is the grating period.

The different types of Fiber Bragg Gratings are shown in Fig. 8.

1) Uniform Fiber Bragg Grating

2) Chirped Fiber Bragg Grating

3) Tilted Fiber Bragg Grating

4) Superstructure Fiber Bragg Grating

Fig. 8: Types of Fiber Bragg Gratings [10]

The use of Fiber Bragg Grating in the optical fiber communication is shown in Fig. 9.

Fig. 9: Use of Fiber Bragg Grating [7]

4) Using Digital Filters: Digital filters have also been used to compensate chromatic dispersion using digital signal processing. It is a new class of digital filters implemented in the optical domain.
known as all pass filters. All pass filters are lossless filters which gives the flexibility to tune a desired phase response arbitrarily close by increasing the number of stages and keeping the magnitude response of a system unchanged.

IV. RESULTS AND DISCUSSIONS
The three dispersion compensation schemes i.e., pre-compensation, post-compensation and symmetrical-compensation have been simulated and analyzed in terms of received maximum Q-factor value and Minimum Bit error rate. The quality factor is a measure of ratio of separation between digital states to the noise associated with the state in electrical domain. Q-factor decides the performance of system parameter such as accumulated optical noise generated by optical amplifiers, polarization dependent losses and polarization mode dispersion which occurs in the cannel in long haul transmission. The bit error rate (BER) is a measure of the probability that any given bit will have been received in error. The parameters used in simulation are given in Table 1.

Table I: Parameters used for simulation [9]

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wavelength</td>
<td>1550nm</td>
</tr>
<tr>
<td>Bit Rate</td>
<td>40Gbps</td>
</tr>
<tr>
<td>Modulation Format</td>
<td>NRZ</td>
</tr>
<tr>
<td>Length of SMF</td>
<td>100km</td>
</tr>
<tr>
<td>Length of DCF</td>
<td>20km</td>
</tr>
<tr>
<td>Dispersion coefficient of SMF</td>
<td>16ps/nm/km</td>
</tr>
<tr>
<td>Dispersion coefficient of DCF</td>
<td>-80ps/nm/km</td>
</tr>
<tr>
<td>Attenuation factor of SMF</td>
<td>0.2db/km</td>
</tr>
<tr>
<td>Attenuation factor of DCF</td>
<td>0.6db/km</td>
</tr>
</tbody>
</table>

The Comparison of different compensation schemes on the basis of above simulation in terms of Q-Factor and BER is given in Table 2.
Table II: Comparison of different Dispersion Compensation schemes [4]

<table>
<thead>
<tr>
<th>Scheme</th>
<th>Q-factor</th>
<th>Bit Error Rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pre-compensation</td>
<td>4.8720</td>
<td>$4.08 \times 10^{-7}$</td>
</tr>
<tr>
<td>Post-compensation</td>
<td>4.9843</td>
<td>$2.32 \times 10^{-7}$</td>
</tr>
<tr>
<td>Symmetric compensation</td>
<td>5.0224</td>
<td>$1.91 \times 10^{-7}$</td>
</tr>
</tbody>
</table>

V. CONCLUSION AND FUTURE DIRECTIONS

There are many techniques that can be utilized to compensate dispersion in an optical fiber communication link. Dispersion compensating fibers (DCF) 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. Fiber 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 use of feed forward equalizer or decision feedback equalizers or both in conjunction to compensate dispersion. According to the simulation results, it has been observed that symmetric compensation scheme is the best dispersion compensation scheme than pre and post schemes because maximum Q-factor and minimum BER can be achieved using symmetric compensation.

REFERENCES