Comparison of different techniques of dispersion compensation

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Abstract- In this paper we will study the various method of dispersion compensation in single mode fiber created because of dependence of group index to wavelength known as chromatic dispersion. Various methods of dispersion compensation are Dispersion compensation fiber (DCF) which compensates dispersion at 1310nm and 1550 nm and Fiber Bragg gratings (FBG) which compensate dispersion at wavelength around 1550nm. Also we will study the comparison between the two. DCF techniques increases the total losses non-linear effects and costs of optical transmission system. FBG helps in decreasing the cost of the system and also have low insertion loss.

Keywords – Chromatic dispersion, Dispersion Compensation Fiber (DCF), Fiber Bragg Grating (FBG), Chirped FBG.

I. INTRODUCTION

Optical fiber is one of the most prominent topic in communication system in today’s era. Not only it helps in increasing the transmission speed but also helps in decreasing the overall cost of the communication system. When the signal is transmitted through fiber at transmitter, some losses are observed in receiver end and as a result data from original signal is lost.

In Single mode fiber (SMF), chromatic dispersion and polar mode dispersion takes place. Chromatic dispersion occurs due to dependence of group index Ng to wavelength [5]. Erbium doped fiber amplifier can be used to compensate dispersion in optical system. Also, chromatic dispersion can be compensated by dispersion compensation fiber and fiber Bragg gratings. DCF compensation needs very high negative dispersion coefficient with DCF’s to compensate dispersion in a narrow band frequency. This increases the overall losses nonlinear effects and the cost of the optical communication system. FBG is another method to compensate dispersion. In this, propagated light which satisfies the Bragg condition is resonated by grating structure and reflected and thus we get only a small part of the signal and rest all goes out of the fiber. So FBG’s which compensate the dispersion by the recompression of an optical signal for different architecture of FBG’s have to be introduced. It also gives low losses and decreases the cost of the transmission system.

The rest of the paper is organized as follows. Theory of the dispersion compensation methods are explained in section II. Table of Comparative analysis between DCF and FBG is given in section III. Concluding remarks are given in section IV.

II. DISPERSION

A. Theory:

Telecommunication systems change the intensity of light source in order to transmits information. Information is modulated and sent as a series of pulses representing binary encoded data. Data can be transmitted with few errors, as long as these pulses travel through the fiber without changing their shape. But usually, as they travel through the fiber, the pulses start to spread, losing their original shape and overlap each other becoming indistinguishable at the receiver input. Dispersion is the general term applied to this cause and this effect is known as inter-symbol interference.

Dispersion was initially a problem when multimode step index fiber were introduced. Multimode graded-index fiber improved the situation, but when they are well graded some limitations are added to the information capacity.
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of multimode fibers. Single-mode fiber eliminated the multipath dispersion and left only chromatic dispersion and polarization mode dispersion to be dealt with by engineers. Both of them causes distortion and broadening of pulse.

B. Chromatic dispersion:

Chromatic dispersion occurs due to the inherent property of silica fiber i.e refractive index varies with wavelength. Hence chromatic dispersion is a phenomenon in optical fiber which is created because of dependence of group index to wavelength which causes a temporal broadening of the pulses as they are propagating in the fiber. After a certain propagation distance, the broadening of the pulses causes a significant number of errors at the receiving end thus the information is lost. Figure 1 shows the broadening of pulses caused due to loss of information i.e chromatic dispersion. And this becomes a limitation to the channel count, bit rates and transmission distances in the fiber optic. Hence, dispersion needs to be compensated by various dispersion compensating techniques. They are usually one of two types. The first type is DCF or Dispersion Compensating Fiber and the second type is FBG or Fiber Bragg grating. DCF and FBG are explained in section C and D.

Figure 1: broadening of pulse due to chromatic dispersion.

C. Dispersion compensation fibers:

This is simply a special type of fiber that has very large negative dispersion. Compensation of dispersion at a wavelength around 1550nm in a 1330 nm optimized single mode fiber can be achieved by specially designed fibers whose dispersion coefficient (d) is negative and large at 1550 nm. DCF’s are used for upgrading the installed 1310 nm optimized optical fiber links for operations at 1550 nm. The higher the dispersion coefficient of the compensating fiber, the smaller will be required length of the compensating fiber.

Dispersion compensation have a high negative dispersion -70 to -90ps/nm.km and can be used to compensate the positive dispersion of transmitter fiber in C and L bands. Spans made of SMF and DCF are good source as their high local dispersion is known to reduce the phase matching giving rise to four-wave mixing in WDM.

Methodology:

Fiber based compensation is done by three methods [7]:
1. Pre-compensation: In this method, the DCF of negative dispersion is placed before the SMF as shown in fig. 2(a).
2. Post-compensation: In this method, the DCF of negative dispersion is placed after the SMF as shown in fig. 2(b).
3. Symmetrical or mixed compensation: In this method, the DCF of negative dispersion is once placed before SMF and then placed after SMF as shown in fig. 2(c).
Figure 2: Different methods of DCF a. Pre-compensation b. Post-compensation c. Mix-compensation

Different methods generate different non-linear effects. In this, mix-compensation method largely reduces the non-linear effects as compared to pre-compensation and post-compensation method. As the bit error rate increases, output of the optical fiber also increases. Symmetrical/mix compensation has minimum bit error rate indicating best performance in comparison to pre and post compensation. Similarly when the length of the fiber is increased, (by keeping EDFA constant) bit error rate also increases. This shows that symmetrical/mix compensation is best among the pre-, post- and mix-compensation.

Advantages of DCF are that they can be easily constructed and highly reliable. DCF provides continuous compensation over a wide range of optical wavelengths (i.e. Does not require precise laser wavelengths. A DCF module should have low insertion loss, low polarization mode dispersion and low optical non-linearity. In addition to these characteristics DCF should have large chromatic dispersion coefficient to minimize the size of a DCF module.

However DCF has high insertion loss. A 60 km compansator can exhibit 6 dB of loss or more. Because of this, DCM’s are usually co-located with EDFA’s which also increases the overall cost of the fiber. Since DCF has a small core size which may make it prone to certain types of nonlinearities. So DCF also has high optical nonlinearities. DCF compensation depends on the wavelength and they can perfectly act only in a narrow band of frequency.

D. Fiber Bragg gratings:
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Fiber Bragg gratings were introduced in 1980 and have been a subject of research with several applications. It is a reflective device composed of an optical fiber that contains a modulation of its core refractive index over a certain length. The Grating reflects light propagation through the fiber when its wavelength corresponds to the modulation periodicity. The reflected wavelength ($\lambda_B$) is called the Bragg wavelength, and defined by the relationship:

$$\lambda_B = 2n\Lambda,$$

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

Using fiber Bragg gratings for dispersion compensation is a promising approach because they are passive optical component fiber compatible, having low insertion losses and costs. They are used as sensors, as wavelength stabilizers for pump lasers, in narrow band WDM add/drop filters and also as filters for dispersion compensation. Advantages of FBG are that it helps in minimizing the overall cost of the fiber and also it also has low insertion loss. Principle operation of FBG is shown in figure 3.

![Figure 3: Principle operation of FBG](image)

**Formulation:**

The operation of fiber Bragg grating is based on the reflection of light from grating fringes and coupling of the modes [2]. The coupling occurs between the forward and backward propagating fields of the same mode. According to the mode coupling phenomenon the two modes show strong coupling if they satisfy the Bragg condition

$$\beta_1 - \beta_2 = 2m\pi / \Lambda \quad \ldots \ldots \quad (1)$$

Where, $\beta_1$ and $\beta_2$ are the phase constants of the two modes, $\Lambda$ is the period of the variation of the refractive index (it is assumed that the variation is sinusoidal), and $m$ is an integer which defines the order of diffraction. For first order, $m = 1$.

Now if we take two identical counter propagating modes

$$\beta_2 = -\beta_1 \quad \ldots \ldots \quad (2)$$

And the Bragg diffraction condition become

$$2\beta = 2m\pi / \Lambda \quad \ldots \ldots \quad (3)$$

Now if the effective modal index is $n_{eff}$,

$$\beta_1 = \frac{2\pi n_{eff}}{\lambda} \quad \ldots \ldots \quad (4)$$
The Bragg condition then gives the wavelength called the Bragg wavelength $\lambda_B$ which is strongly reflected by the grating as

$$\lambda_B = 2 \text{neff} \Lambda \quad \text{(5)}$$

Where, $\chi$ is the wavelength of the signal.

a. For uniform Bragg grating:

The amplitudes of the forward and backward waves are governed by the following coupled differential equation[5].

$$\frac{dR}{dz} + j\sigma R = -j\kappa S \quad \text{(6)}$$

$$\frac{dS}{dz} - j\sigma S = -j\kappa R \quad \text{(7)}$$

Where,

DC coupling coefficient: $\sigma = \frac{2\pi \delta n}{\lambda_B} + \delta \quad \text{(8)}$

AC coupling coefficient: $\kappa = \frac{\pi \delta n}{\lambda} \quad \text{(9)}$

Where, $\delta$ is called as detuning parameter.

b. For a non-uniform grating,

$$n(z) = \delta n(z) \left\{ 1 + \nu \cos \left( \frac{2\pi z}{\Lambda} + \phi(z) \right) \right\} \quad \text{(10)}$$

Here $\nu$ is called the visibility of the FBG and its value lies between 0 and 1, $\phi(z)$ is the spatial chirp of the FBG, and $\delta n(z)$ is a slowly varying function of $z$.

The DC coupling coefficient becomes

$$\sigma = \frac{2\pi \delta n(z)}{\lambda_B} + \delta - \frac{1}{2} \frac{d\phi}{dz} \quad \text{(11)}$$

And the AC coupling coefficient becomes

$$\kappa = \frac{\pi \delta n(z)}{\lambda} \quad \text{(12)}$$

Methodology:

The structure of the FBG can vary via the refractive index, or the grating period. The grating period can be uniform or graded, and either localized or distributed in a superstructure. The refractive index has two primary characteristics, the refractive index profile, and the offset. Typically, the refractive index profile can be uniform or apodized, and the refractive index offset is positive or zero.

On the basis of grating period fiber Bragg grating can be of four types:

1. Uniform gratings: In this gratings are done in fixed interval shown in fig 4(a).
2. Chirped gratings: In this gratings are done non-uniformly as shown in fig 4(b).
3. Tilted gratings: In this gratings are done in uniform manner but tilted as shown in fig 4(c).
4. Superstructure: In this gratings are uniformly grouped as shown in fig 4(d).
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Advantage of FBG as dispersion compensator:

The most common advantage of FBG is low insertion loss (IL). Typically, a 120-km FBG-DCM has an insertion loss in the range of 3 to 4 dB, depending on type. Furthermore, the FBG-DCM holds an advantage is that it has virtually constant IL versus span length, whereas the IL of the DCF-DCM grows linearly with span length. Residual dispersion is another key parameter for compensators. Due to the very flexible grating process developed by approximation, the chirp characteristics can readily be chosen according to fiber specifications, i.e. dispersion level and dispersion slope can be tailored to fit any fiber type. The ability to tolerate high optical powers without any loss caused by nonlinear effects is also one prominent characteristic separating the FBG-DCM from the DCF-DCM. Although a DCF will display nonlinearity effects at rather low optical powers, the FBG-DCM won’t introduce such effects even at the highest power levels present throughout optical network. Dispersion requirements increase with higher bandwidth, the focus on dispersion compensation is high. There’s also increased use of longer fibers, which means higher expense associated with the placement of amplifiers along the fiber routes. FBG-based DCMs may be concentrated in a single location. That equates to fewer compensation points and fewer amplifiers to upgrade with the DCMs, which leads to cost savings.
Table 1: Comparison of DCF and FBG

<table>
<thead>
<tr>
<th>CHARACTERISTICS</th>
<th>DCF</th>
<th>FBG</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bandwidth</td>
<td>Wide band, 20 nm</td>
<td>Narrow band, 0.1-5 nm</td>
</tr>
<tr>
<td>Fiber length</td>
<td>17-20 km</td>
<td>10-15 cm</td>
</tr>
<tr>
<td>Construction</td>
<td>Complex</td>
<td>simple</td>
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<tr>
<td>negative dispersion</td>
<td>+15 to +25 ps/nm/km</td>
<td>+2000 ps/nm/km</td>
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<tr>
<td>positive dispersion</td>
<td>−80 to −120 ps/nm/km</td>
<td>−2000 ps/nm/km</td>
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<tr>
<td>dispersion</td>
<td>16 pm/km/nm</td>
<td>17 pm/km/nm</td>
</tr>
<tr>
<td>Bending loss</td>
<td>0.4-0.6 dB/km</td>
<td>0.14 dB/km</td>
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<tr>
<td>Reflectance ratio</td>
<td>99.99%</td>
<td>10-95%</td>
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<tr>
<td>attenuation</td>
<td>0.8 dB/km</td>
<td>0.2 dB/km</td>
</tr>
<tr>
<td>Non linear effects</td>
<td>Some limitations</td>
<td>no</td>
</tr>
<tr>
<td>Insertion loss</td>
<td>high</td>
<td>low</td>
</tr>
<tr>
<td>Overall Cost of system</td>
<td>high</td>
<td>low</td>
</tr>
</tbody>
</table>

IV. CONCLUSION

In conclusion, it is found that dispersion compensation is necessary to reduce losses and cost of the system. Dispersion compensation can be done through two different methods i.e dispersion compensation fiber and fiber Bragg gratings. By comparing the two methods, we can see that using DCF techniques increases the total losses, nonlinear effects, and costs of optical transmission system. FBG helps in decreasing the cost of the system and also have low insertion loss. Table 1 shows the comparison between DCF and FBG.

REFERENCE