# A simulation Approach for Dispersion Compensation in Optical System with a Fiber Bragg Grating Extending the Reach of DWDM-PON Access Network

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***Abstract-*** **Now a day's optical communication is a popular technique to transmit the data. In daily life we share our useful data by using optical network. We face a common problem that is dispersion. Fiber Bragg Grating (FBG) is one of the most applicable components to compensate dispersion losses in optical communication system.**

**In proposed work we have provided a FBG system to transmit lossless data up to 80 kilometer. We have used coupled mode equations to evaluate appropriate FBG profile for long distances. Various parameters were identified and simulated to get appropriate results.**

***Index Terms-*** Optical Communication, FBG, Chromatic Dispersion, Non-linear effects.

## Objectives-

1. To access need of FBG technology for lossless data transmission in optical communication.
2. To provide appropriate FBG profile (Apodization factor, Tanh function, Chirp parameter, Grading length)
3. To extend the reach of WDM network using proposed technology
4. To provide comparison with existing technologies for judgement of effectiveness of proposed work.

## Literature Review

S. O. Mohammadi, Saeed Mozaffari and M. Mahdi Shahidi, 2011[1] have simulated the optical communication systeme and observed the dispersion and emphasized the need to compensate it in order to receive lossless data. To this purpose described the idea of implementing FBG and simulated the system with it. It is found that the grating length is dependent on the broadening of the pulse as well as to its power. Apodization function is not very effective in FBG reflected spectrum, although the best shape is Tanh function because of its grating length.

Sujith, Gopchandran [2], in this work the performance of WDM communication system is evaluated in terms of non linear effect SPM. A DCF compensating technique is investigated for a 10 Gb/s transmission system over various lengths. The system is simulated using optisim and it is found that the good performance of the system is obtained at the combination of SMF length 85 km with DCF length 15 km to minimize the SPM effect.

Gnanagurunathan, F.A Rahman[3], used the simulation approach for the analysis of the long haul communication network using both the techniques alternatively. The models are investigated in terms of BER, eye diagram and Q factor. On evaluating the simulation results it is observed that the FBG model outperformed the DCF model in terms of insertion losses, traffic load variations and modulation schemes. FBG has smaller dimension and have lesser insertion loss as in DCF as well as FBG is able to sustain the variation in modulation techniques that is RZ or NRZ.

P. X. Zumba, P. T. Cabrera, and E. J. Coronel , June 2016[4] described WDM as a solution to future on optical transmission considering the variations in performance but keeping the WDM principle. However WDM-PON network greatly affected by chromatic dispersion. In this proposed work provided the solution by implementing the FBG topology to be simulated on optisystem and analyzed the different parameters of link distance and fiber type and described that the distance of the link plays an important role due to the amount of dispersion and losses in fiber optic. On investigation it is found that the effects of dispersion can be reduced with the use of post FBG compensator. It was verified that the distance affects the quality of the transmission to the greater the chromatic dispersion and the dispersion value gets a plus for each increase in kilometer and different for each type of fiber, where depending on needs, should be governed by ITU standards to choose the most suitable fibre type.

## Methodology

1. Theoretical analysis for selective coupling profile for FBG
2. Simulation Tool (Optisystem simulator)
3. Transmission system without FBG
4. Transmission system Using FBG

### *A. Theoretical analysis*

Coupled mode theory can be easily evaluated for uniform FBG grating and for non uniform grating we have to use some evaluation methods. One of them is transfer matrix method. The coupled mode equations are the main basis of analyzing the FBG and are solved using transfer matrix method.

$$\frac{dB}{dz} + i\left[\kappa_{dc+}\, {}^{1}\!/_{2}\left(\Delta\beta - \frac{d\varphi(z)}{dz}\right)\right]B = -i\kappa_{ac}^{*}F \qquad \ldots(1)$$

$$\frac{dF}{dz} - i\left[\kappa_{dc+}\, {}^{1}\!/_{2}\left(\Delta\beta - \frac{d\varphi(z)}{dz}\right)\right]F \models i\kappa_{ac}B$$

..(2)

Where,

$$B = A_1(z)e^{-(i/_2)[\Delta\beta z-\varphi(z)]}$$

……(3)

And,

$$F = A_2(z)e^{(i/_2)[\Delta\beta z-\varphi(z)]}$$

……(4)

In these equations, F is a forward and B is backward travelling waves, $A_1$ and $A_2$ are amplitudes of forward and backward travelling waves, respectively z is the transmission distance, $k_{ac}$ is the ac coupling coefficient. Δβ is defined as the detuning which is independent of z,

$$\Delta\beta \equiv \beta - \frac{\pi}{\Lambda}$$

$$\Delta\beta = 2\pi\eta_{eff}\left({}^{1}/_{\lambda} - {}^{1}/_{\lambda_D}\right)$$

……(5)

Here $1/2\,\frac{d\varphi}{dz}$ is the phase term for a linear chirp and is defined as,

$${}^{1}/_{2}\,\frac{d\varphi}{dz} = -\frac{4\pi\eta_{eff}z}{\lambda_D^2}\;\frac{d\lambda_D}{dz}$$

….(6)

Λ is the period of the grating and β is the wave number

The z dependent refractive index of the fiber becomes,

$$\delta n(z) = \Delta n\left\{1 + {}^{\nu}/_{2}\left(e^{i\left[\left(\frac{2\pi N}{\Lambda}\right)z+\varphi(z)\right]}\right)\right\}$$

…..(7)

Where Δn is the averaged refractive index change and N is an integer which signifies harmonic order.

The grating phase φ (z) is defined by,

$$\varphi(z) = Fz^2/2L_g^2$$

…..(8)

Where $L_g$ is the grating length and F is chirp parameter defined by

$$F = 8\pi\eta_{eff}^2L_g^2/\lambda_D^2cD_fL_f$$

…(9)

Where $D_f$ is dispersion parameter of the fiber and $L_f$ is the fiber link length.

Transfer matrix provides a fast and highly accurate modeling in frequency domain.

The transfer function of the whole grating is

$$\begin{bmatrix} B\left(-\frac{L}{2}\right) \\ F\left(-\frac{L}{2}\right) \end{bmatrix} = [M]\begin{bmatrix} B\left(\frac{L}{2}\right) \\ F\left(\frac{L}{2}\right) \end{bmatrix}$$

…..(10)

Here matrix [M] is defined below

$$[M] = \begin{bmatrix} \cosh(\gamma\delta l_j) - (i\delta\sinh(\gamma\delta lj))\,/\,\gamma & (-\kappa_{ac}\sinh(\gamma\delta lj))/\gamma \\ \kappa_{ac}\sinh\,(\gamma\delta lj))/\gamma & \cosh(\gamma\delta l_j) + (i\delta\sinh(\gamma\delta lj))\,/\,\gamma \end{bmatrix}$$

Where, $\delta l_j$ is the length between two consecutive values of z and γ is defined by

The grating length is defined by,

$$L_g = \frac{L_g^{min}}{\alpha_{eff}}$$

…(11)

Where, $L_g^{min}$ = Minimum grating length and $\alpha_{eff}$ = Apodization parameter, which determines whether the profile is tighter or weak, $\alpha_{eff}$ is defined as,

$$\alpha_{eff} = \frac{\int_0^{L_g}|z|K(z)dz}{\int_0^{L_g}|z|\,dz}$$

…..(12)

K(z) is coupling coefficient of the coupled mode equations. We will vary this parameter and observe the reflectivity, group delay and dispersion characteristics of FBG which are expressed as follows, reflectivity, r(z) = $\frac{B(z)}{F(z)}$ delay τ = $\frac{\lambda^2}{2\pi c}\,\frac{d\theta r}{d\lambda}$ and dispersion , D = $\frac{d\tau}{d\lambda}$, where $\theta_r$ is phase angle of reflection coefficient r(z). our proposed equation for K(z) is

$$K(z) = i + \tanh\left[\tau\left(1 - 4\left(\frac{z}{L_g}\right)^{\alpha}\right)\right]$$

…(13)

Where, i is an integer and i = 0,1,2,3 etc.. For our model, τ = 4, and α = 3 are taken in order to attain broader bandwidth of reflectivity.

We have varied i and have optimized the value to realize the desired dispersion. Our proposed profile is given by,

$$K(z) = 4 + \tanh\left[4\left(1 - 4\left(\frac{z}{L_g}\right)^{3}\right)\right]$$

….(14)

This profile has the highest negative dispersion value at 1550nm. After choosing the profile the spectral characteristics of FBG is investigated and for this we have selected eight different variations for hyperbolic tangent profile and checked them to find best profile.

In fig. 1 group delay is decreasing as we are increasing the i of K(z). at 1550nm wavelength the group delay values are tabulated in table 1.

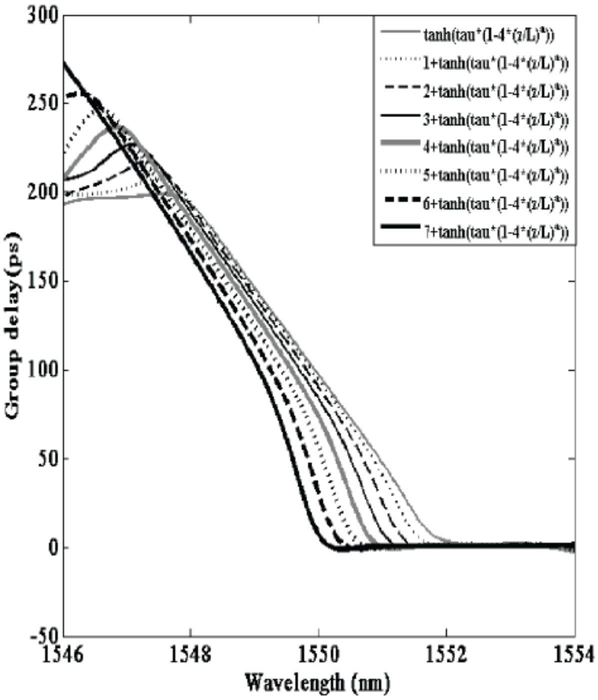


Fig.1: Group delay Vs wavelength for hyperbolic tangent

$$K(z) = i + \tanh\left[4\left(1 - 4\left(\frac{z}{L_g}\right)^3\right)\right]$$

| *i* | *Group delay (ps)* | *Dispersion (ps/nm)* |
|---|---|---|
| 0 | 96.94 | -748.7 |
| 1 | 94.36 | -1226 |
| 2 | 90 | -1739 |
| 3 | 83.47 | -2106 |
| 4 | 73.32 | -2237 |
| 5 | 56.24 | -2031 |
| 6 | 30.26 | -1471 |
| 7 | 7.14 | -632.6 |

Table 1: Group delay and Dispersion for various values of integer i

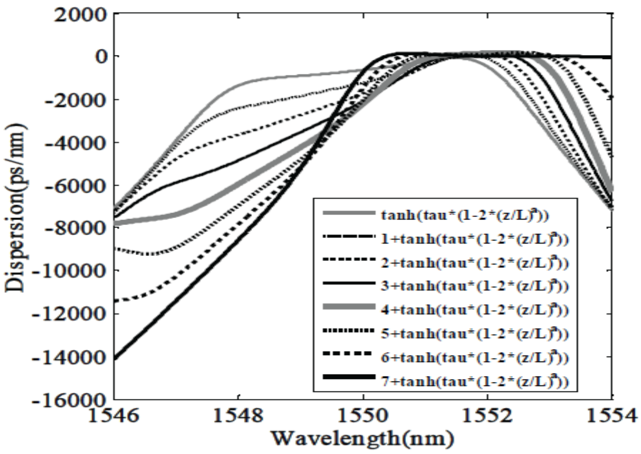


Fig 1.2: Dispersion Vs wavelength for hyperbolic tangent.

According to table 2 it can be seen that when the value of i is 4 we get maximum dispersion of -2237ps/nm at 1550nm and the group delay is also fairly acceptable of 73.32 ps. And when the value of i is 2 the profile is suitable for dense WDM systems, as it has a moderate range of wavelength band and with -3660 ps/nm to -482 ps/nm dispersion. We can adjust the profile to achieve desired characteristics from FBG. We can show the FBG with the proposed profile can be utilized to extend the link length. But longer grating can increase the cost so we need to choose the Apodization factor wisely which depends on τ and α.

### *B. System simulation without FBG*

In this simulation, we use a continuous wave (CW) laser with frequency of 193.1 THz and the output power is 1 MW which is modulated with a return to zero (RZ) pulse generator at a 10 Giga bits/s user defined bit sequence generator in an Amplitude modulator. In this model employed EDFA has the gain amount of 6dB, independent of wavelength and ignorable noise which is only used to compensate dispersion and nonlinear effects of transmission system.

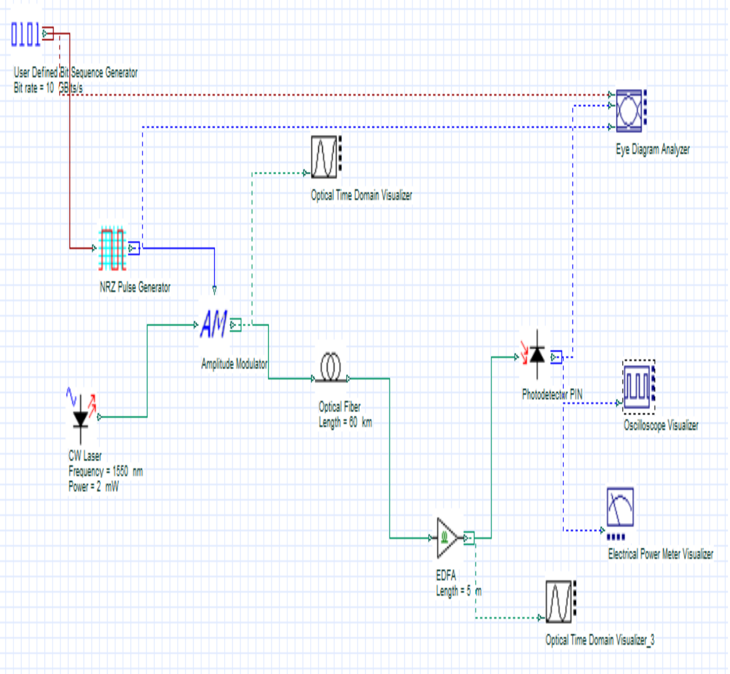


Fig 1.3: System without FBG

| **Model Parameter** | **Proposed Design Value** |
|---|---|
| Data bit rate | 10Gbps |
| Length of SMF | 80 km |
| Length of FBG | 27 mm |
| Frequency | 193.1 THz |
| Dispersion coefficient | 16.75ps/nm/km |
| Dispersion slope | 0.075ps/nm^2/km |
| Attenuation index | 0.20 |
| Effective refractive index | 1.45 |
| Apodization function | Tanh |
| Tanh parameter | 5 |
| Chirp function | Linear |

*C. System simulation with FBG*

The transmission system model includes a user defined bit sequence generator, return-zero (RZ), a continuous wave (CW) laser with frequency 193.1 and output power 1MW and an AM modulator. The modulation of signal done with a return-zero user defined sequence in AM modulator. The output of system1 is fed into optical fiber whose length is 80km, dispersion is 16.75ps/km/nm, dispersion slope is 0.050pm/nm2/km, and attenuation index is 0.20km. Now to get a better result or to achieve a better signal the dispersed wave goes into the chirp fiber Bragg grating. The parameters involved in chirp FBG are frequency, effective refractive index, length of grating, apodization function, Tanh parameter, chirp function. Linear parameter and their values are 193.1THz, 1.45, 27, Tanh, 5, linear and 0.0001 respectively. The amplification of signal done through EDFA amplifier which has a gain amount of 6dB. The receiver side consists of a photo detector (PIN) and eye diagram analyzer.

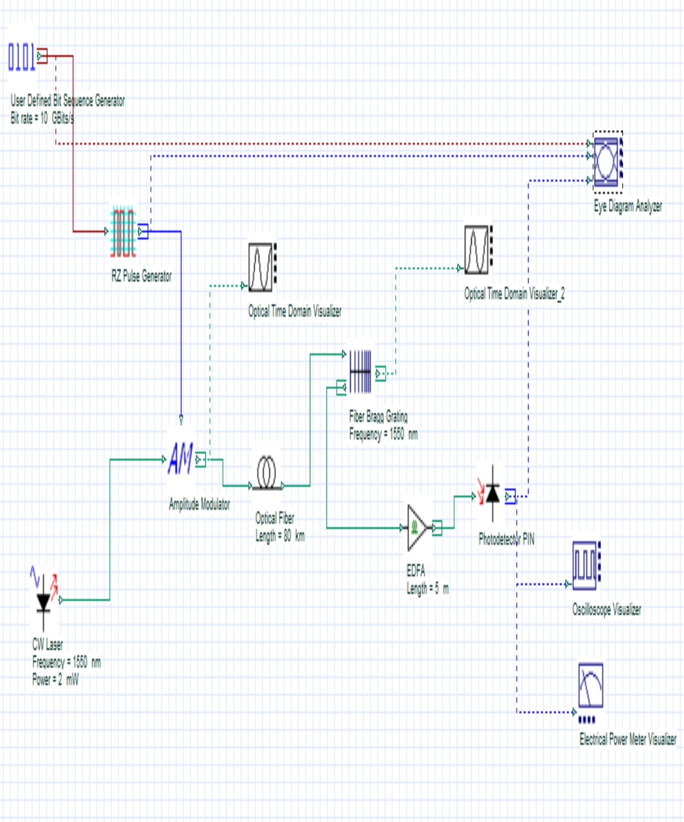


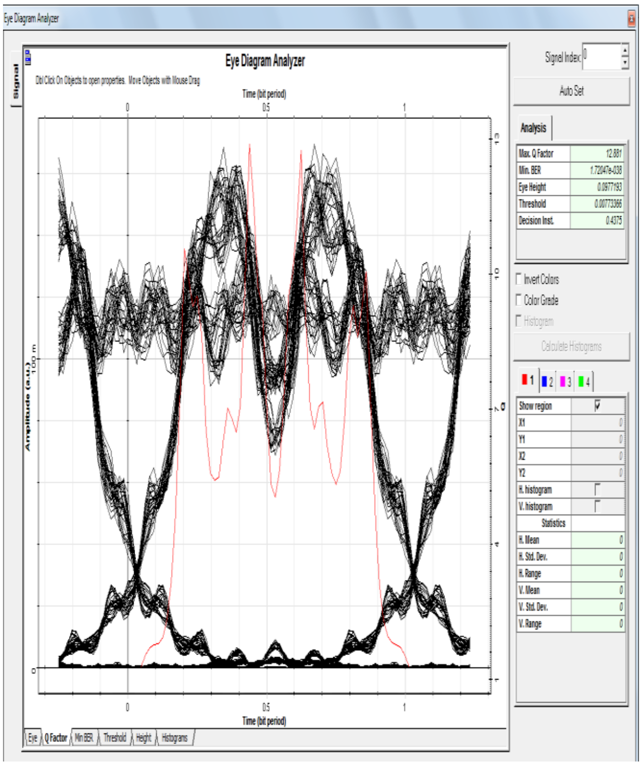
Fig 1.4 System with FBG

Table 1.2: Parameter used in simulation

**Result Analysis**

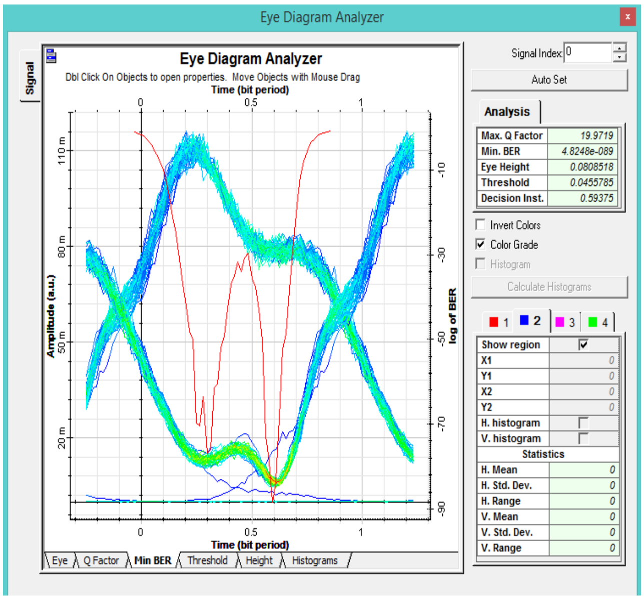
We designed the transmission system to achieve best output of optical system each system has best result. We designed firstly without FBG system which can provide communication only up to 60km without dispersion and then we used FBG and varied length of optical fiber with proposed profile and we successfully achieved length of 80km with no more losses.

Simulation of transmission system is done by using Chirped Fiber Bragg grating for compensation of dispersion.10Gbps data is transmitted for long distance of 80 km. The behavior of the system is defined by Q-factor and bit error rate (BER).By the proposed system the length is increased from 10 km to 80 km along with the increase in the q-factor from 15.61 to 19.97 and BER is reduced from 1.85 $e^{-55}$ to 4.81 $e^{-89}$.



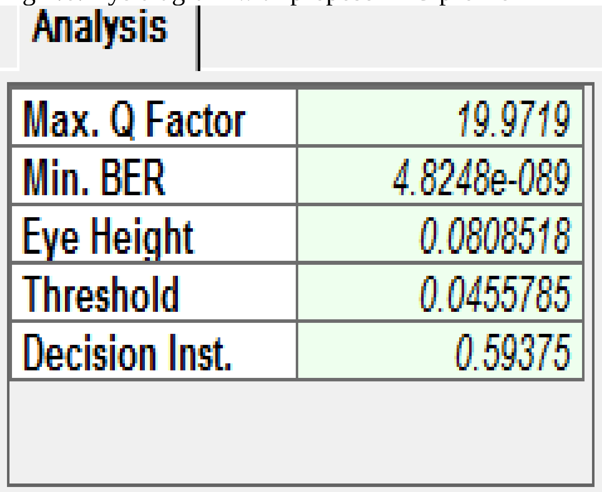
| Analysis | |
|---|---|
| Max. Q Factor | 12.881 |
| Min. BER | 1.72047e-038 |
| Eye Height | 0.0977193 |
| Threshold | 0.00773366 |
| Decision Inst. | 0.4375 |

Fig1.5 Eye diagram of system without FBG



| Analysis | |
|---|---|
| Max. Q Factor | 19.9719 |
| Min. BER | 4.8248e-089 |
| Eye Height | 0.0808518 |
| Threshold | 0.0455785 |
| Decision Inst. | 0.59375 |

Fig 1.6: Eye diagram with propose FBG profile



| Analysis | |
|---|---|
| Max. Q Factor | 19.9719 |
| Min. BER | 4.8248e-089 |
| Eye Height | 0.0808518 |
| Threshold | 0.0455785 |
| Decision Inst. | 0.59375 |

Fig 1.7 Simulation output of the system

| **Parameters** | **Proposed Design** |
|---|---|
| SMF Length | 80 KM |
| FBG Length | 27 mm |
| Q-Factor | 19.97 |
| Bit Error Rate | $4.82\ e^{-89}$ |
| Eye Height | 0.0712 |

Table 1.3: Output of the proposed system

| **CHARACTERIS-TICS** | **DCF** | **FBG** |
|---|---|---|
| Bandwidth | Wide band, 20 nm | Narrow band, 0.1-5 nm |
| Fiber length | 17-20 km | 10-15 cm |
| Construction | Complex | simple |
| Negative dispersion | +15 to +25 ps/nm/km | +2000 ps/nm/km |
| Positive dispersion | −80 to −120 ps/nm/km | -2000 ps/nm/km |
| Dispersion | 16pm/km/nm | 17pm/km/nm |
| Bending loss | 0.4-0.6dB/km | 0.14 dB/km |
| Reflectance ratio | 99.99% | 10-95% |
| attenuation | 0.8 dB/km | 0.2 dB/km |
| Non linear effects | Some limitations | no |
| Insertion loss | high | low |
| Overall Cost | high | low |

### Comparison of Different Dispersion Compensating Techniques

Chromatic dispersion affects the signal very badly when signal travels a long distance. Different techniques are available to compensate dispersion. Not all of them are the same in performance. Though there is different kind of dispersions in OFC, they can be compensated using different techniques. Fiber Brag Grating (FBG) and Dispersion Compensating Fiber (DCF) are two mostly used techniques in long haul communication.

### A. Dispersion Compensating Fiber (DCF)

The DCF introduces a negative dispersion coefficient. Post compensation is achieved by adding the DCF onto an existing fiber. The fiber's dispersion can be manipulated by varying the refractive index profile and the relative index value. Very high negative dispersion is achieved by methods like depressed cladding or decreasing the core radius. However these could induce other penalties such as non-linear effects and insertion loss.

### B. Advantage of FBG as dispersion compensator

For high speed communications, FBG has prospectively more advantageous than DCF, as it almost lossless, compact easily tunable and negligible non linearity. FBG's are found to be better negative response to dispersion as compared to DCF.

Table 1.4: Comparison between DCF and FBG

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.

By comparing the two methods we can see that Using DCF techniques increase 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 1.4 shows the comparison between DCF and FBG.

## Conclusion

In proposed work we have successfully received the lossless data by implementing selective FBG profile. We have applied the concept of FBG to compensate chromatic dispersion losses in optical fiber as well as we have achieved the extension in link length up to 80 km. Results were found after implementing proposed work in OptiSystem software Present study shows the acceptable quality of results.

On the other hand we also studied the existing technologies and compared them with the proposed system. It is found that the proposed technique outnumbered the DCF over number of issues like insertion losses, attenuation, complexity and economy.

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