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A Review on Different DispersionCompensation Techniques in WDM System

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***Abstract*—With the development in communication technology for internet, theuser's needof bandwidth and data rate also enhances. To increase the capacity, optical fiber communicationsystem introduced Wavelength Division Multiplexing (WDM) concept, in which multiplesignals are combined to form single inputto increase the capacity.The discrepancy in the frequency of the signals and modes of the light pulsecauses dispersion which means broadening of pulses that can affect the signal's quality to an extent causing IntersymbolInterference (ISI). In this review article, advancement in the field of WDM, Fiber Bragg Grating, and dispersion compensating techniquesare described.**

***Index Terms* —Chromatic Dispersion, Dispersion Compensation,Dispersion Compensating Fiber(DCF), Fiber Bragg Gratin(FBG),Wavelength Division Multiplexing (WDM).**

I. INTRODUCTION

In today's era as the network and communication applications is increased so the researchers are more interested in this field to work on. With the enhancement in the field of networks, the number of users is also increased. The performance of the applications which are related to the network or internet depends upon the bandwidth of the network. Solution to increase the bandwidth of the network is WDM which uses the concept of Fiber optic network which also provides the better data transmission range and the facility to transfer the multiple wavelengths at a given period of time over the same fiber[1]. Due to its features the use of WDM system along with optic fiber is increased day by day. Therefore there is a requirement to find out the parameters or factors that affect the quality of the fiber optics network. To design the WDM system, various factors should be considered such as power transmit, bit rate, length of fiber and dispersion effects[2] . Attenuation, losses and dispersion are the major factors that leave an impact on the performance of fiber optics network

II. EFFECT OF DISPERSION ON TRANSMISSION

Dispersion is definedas thepulse or signal gets scattered or distorted due to the inconsistency in the frequency of the signals and modes of the light pulse which can affect the signal'squality to an extent causing ISI. Single Mode Fiber (SMF) WDMsystem is mainly affected byChromatic Dispersion (CD), the index of the glass is based on the wavelength of the light and the lights from real optical transmitter possess the non-zero spectral width.Polarization mode dispersion is another dispersion which affects the quality of the signals in SMF. The reason behind the occurrence of the polarization dispersion is that even though the SMF supports one transverse mode, but handles this mode in two different polarizations. The distortion in fiber can leads to the alterationsin the propagation velocity for both of these polarizations. Thisprocess is known as birefringence. It is defined as follows:

$$B_m = \frac{|B_x - B_y|}{k_0} = n_x - n_y \qquad (1)$$

where,B_m defines the term birefringence, and

n_x , $n_y$defines the refractive of two orthogonal polarizations.

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III. TYPES OF DISPERSION

Intermodal Dispersion

The reason of occurrence of intermodal dispersion is that the different beams of light passing from multimode fiber have different speeds and different propagation angles.The beam which travels through various propagations reaches at the output at different times. Hence it leads to the scattered output and finally dispersion occurs at receiver or output end.

PolarizationMode Dispersion

The polarization mode dispersion takes place when the fiber optic cable has two linearly polarized waves simultaneously and these waves mutually propagate at perpendicular planes.But the perpendicular planes are not same because of asymmetry in fiber cable, splicing process, refractive index and this cause polarization mode dispersion.

Intramodalor Chromatic Dispersion

The intramodal dispersion is caused because of the variation in the phase delay of various frequency components of the single signal itself. It leads to the broadening of the pulses at the receiver. The signals are dispersed because the signal that carries the information contains multiple wavelengths. This process gives rise to group velocity dispersion.

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IV. DISPERSION COMPENSATION TECHNIQUES

There are many techniques that can be used for dispersion compensation in WDM are as follows:

DISPERSION SHIFTED FIBER(DSF)

These are the type of SMF with the tailored index profile of core-cladding to shift the zero dispersion wavelength at 1300nm to 1500nm.This is done by varying the refractive index profile of the core byconstructing a SMFwith triangular shaped refractive index variation. But these fibers have the good performance for single channel transmission but not for multiple channel transmission. So DSF is not suitable compensation scheme for WDM systems due to four wave mixing(FWH).

DISPERSION COMPENSATING FIBER(DCF)

DCF supports the negative dispersion value ranging from -70 to -90 ps/nm/km. It is used as a technique for updating the installed links which are created by using SMF for operations at 1550 nm.Smaller length of DCF will be required if DCF has large dispersion coefficient. Spans of

SMF and DCF are used for the better compensation. The net dispersion will be zero if we place one DCF with negative dispersion after a SMF with positive dispersion. The equation is as follows:

$$D_{SMF} \times L_{SMF} = -D_{DCF} \times L_{DCF} \quad (2)$$

In equation (2), the variable D defines the dispersion and the variable L defines the Length of each fiber. Basically, there are three configurations of DCF as follows:

Pre-Compensation defines when the DCF is placed at the starting of optical link and before amplifier as shown in figure 1.

Post Compensation defines the situation when DCF is placed at the end of optical link as shown in figure 2.

Mix compensation refers to placing of DCF before as well as after the SMF to achieve the dispersion compensation. It is also called symmetrical compensation as shown in figure 3.

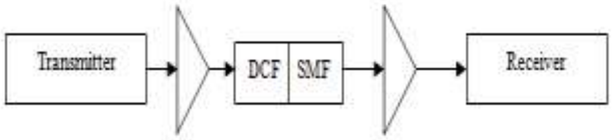

Figure 1.Pre Compensation

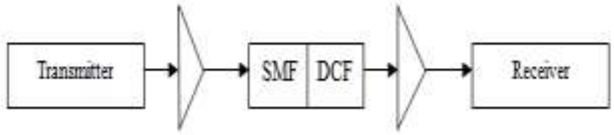

Figure2.Post Compensation

Figure3.Mix Compensation

FIBER BRAGGGRATING(FBG)

FBG is atechnique used for dispersion compensation in WDM system. It is a distributed Bragg reflector whichreflects a specific pulse or wavelength. After reflection of the light or wavelength is transferred to all other channels.The refractive index varies with respect to the propagating medium. The working of FBG relies on the principle of Fresnel reflection which describes that the beam of light that is passing through the media cab reflect or refract at the interface. The value of the refractive index will vary over a specific length. At the time of refraction an amount of light is reflected back. These reflected light signals are grouped into a single large reflection corresponding to a particular wavelength.This particular wavelength possesses the value of grating period equal to the half of the input light wavelength. This situation or point leads to the Bragg condition on the wavelength and the wavelength will be considered as Bragg wavelength.

The equation used for Bragg wavelength is as follow:

$$\lambda_B \equiv 2\bar{n}\wedge$$

Where $\bar{n}$ = average mode index,

$\wedge$= grating period

V. LITERATURE REVIEW

Soniet al. [1]analyzed an 8 channel WDM system operating at data rate of 3Gbps at different wavelengths i.e. 980nm, 1300nm and 1550 nm. They showed that the system has better performance at 1550 nm wavelength in terms of Q-factor and BER as compared to other wavelengths i.e. 980nm and 1300nm. In order to increase the quality of the signals while data transmission the chromatic dispersion rate should be decreased or compensated as discussed in [2].Further Nakajima et al. [3] demonstrated that the optimal performance of DWDM system varies with the type of the transmission line. The performance of 40 Gbps DWDM network has been compared with two types of transmission lines.One transmission fiber was combination of Main Transmission Fiber (MTF) which was 80 km long having the CD of D_+ and a DCFM(DCF Module). Other was the hybrid connection of MTF and IDF (Inverse Dispersion Fiber) with different chromatic dispersion characteristics.It was found that the hybrid transmission line has greater potential to resist any change in the dispersion slope compensations as compared to type 1 that employed DCFM.

Singh et al.[4]analyzed the performance of 120 Gbps8 channel WDM systems with two different compensation techniques i.e.FBG and DCF. Different configurations i.e.

pre, post, mix compensation were compared. It was found that FBG post compensation has better performance than the other compensation techniques as FBG post compensation has highest Q-factor and the least BER than all other schemes.Further it was compared by [5], DCF and FBG techniques for chromatic dispersion compensation and described that DCF will generate the non linear effects at low optical power levels, but FBG doesnot show these losses even at higher optical power levels.FBGrequires fewer compensation points and lesser number of amplifiers as compared to DCF.

Xie et al.[6], proposed a 40 Gbps Fiber Optics system with a grating equalization technique to mitigate the effects of CD in SMF. Theyemployed DCB (Dispersion Compensation Bank) that consisted of three dispersion compensation components,i.e. Ideal Dispersion Compensation Grating (IDCG),FBG, Gaussian optical filter (GOF).It was observedthat dispersion effects were mitigated more effectively with DCB. Spolitis et al.[7]proposed that the CD compensation is the important premise to achieve the higher performance of long reach DWDM-PON network. They investigated the pre and post CD methods for improvement of the link length of 16 channel DWDM-PON system and simulation has been carried on OPTSIM 5.2 software. Ng et al.[8], proposed a CD equalisation technique which employed a cascaded parallel optical all-pass filter (Cp-OAPF). The phase response of proposed Cp-OAPF was designed such that it cancels the phase shift in the SMF. Significant improvement was also observed in BER and SNR performance.Patel et al.[9] presented the hybrid approach that combines the electrical and optical compensationtechniques for dispersion compensation in 10Gbps WDM system. In optical compensation scheme; DCF in pre, post and symmetrical configuration was modelled and it was found that hybrid compensation techniqueyielded better performance in terms of Q value and BER using Eye diagram. Singh et al.[10], have compared the performance of 10 Gb/s WDM system using different optical amplifiers by taking the two cases i.e. with and without nonlinearities at different transmission distances.The performance was compared in terms of output power, BER, Q-factor using eye- diagram. It was observed that when 2ps/nm/km dispersion was there and few channels were used, better results have been pprovidedby SOA but performance was degraded due to gain saturation problem of SOA when number of channels was increased butEDFA gave better results with large number of channels.

VI. INFERENCES DRAWN FROM LITERATURE REVIEW

The following graph shows the reach improvement in percentage of WDM system using various dispersion compensation techniques[5].

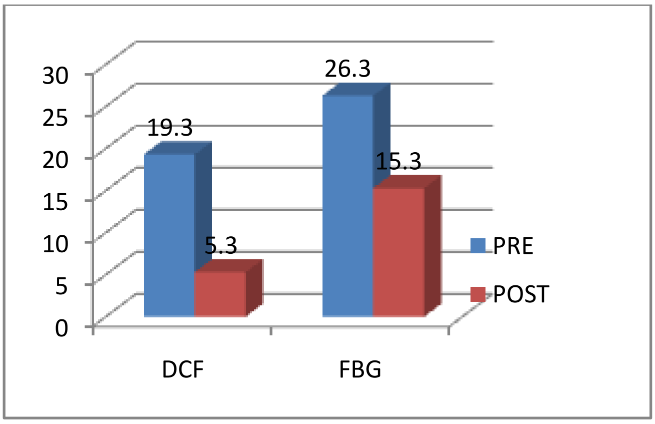

Figure 4: Reach Improvement in 16 channel WDM System

The following table shows the important findings, parameters of different compensation techniques reviewed above in literature review section.

Table1: Findings of the paper reviewed

Ref No.	Technique	Parameters	Findings
1.	DCF (17km) + SMF(105km) [Pr-C]	• Bit Rate(BR):3Gbps • Wavelength(λ): 980,1300,1550nm • Input power(P_{in}): 9dBm	980nm: Q-factor:11.5794; BER:2.458e-031
			1300nm: Q-factor:12.8167; BER:6.4018e-035
			1550nm (best results for WDM): Q-factor:16.2516; BER:1.0849e-059
2.	DCF + SMF [Pr-C]	• BR:5Gbps • Distances:	As the transmission distance increased, BER increased.

	SMF + DCF [Po-C]	40,80,100km • Modulation formats: NRZ and RZ	RZ exhibits better performance at all distances with DCF pre compensation.
3.	Transmission fibers were analysed as: 1. MTF + DCFM 2. MTF + IDF	• Bit rate: 40 Gbps • Distance: 240km (80× 3) • Modulation Format: NRZ	In hybrid transmission line, CD of 12 ps/nm/km was optimum to resist any change in the dispersion slope compensation as compared to DCFM type transmission fiber.
4.	DCF + SMF [Pr-C] SMF + DCF [Po-C] DCF + SMF + SMF + DCF [Mix-C] FBG + SMF [Pr-C] SMF + FBG [Po-C]	• BR:120 Gbps • P_{in}: 0-9 dBm • Modulation format: NRZ • CW Laser power: 0dBm • Frequency(f): 193.1 to 193.8 THz • DCF:24km • SMF:120km	In DCF compensation schemes, mix compensation gave the good performance than pre and post with Q-factor: 15.9 and BER: 1.263e-58. Out of all compensation schemes, FBG pre has the highest Q-factor of 16.3 and lowest BER of 2.478e-60.
5.	Different FBG, DCF Compensation techniques for DWDM PON system	• BR:10Gbps • Spacing:100GHz • CW laser power:2dBm • Fixed BER: 10^{-9} • D_{SMF} =-80 ps/nm/km • λ = 1550nm	Pre DCF improved the distance by 19.3% i.e. 57 to 68km further post DCF improved by 5.3% i.e. 57 to 60km and post FBG improvement was 15.8% i.e. 57-66km Pre FBG improved by 26.3% i.e. 57 to 72 km (best compensation technique)
6.	SMF + DCB (i.e.FBG +IDCG + GOF) + EDFA	• BR:40 Gbps • Distance : 50-200km • P_{in}:5-20dBm • SMF α: 0.2 dB/km • BW of GOF:10GHz	FBG +SMF yielded decrease in pulse spread from 400 to 300ps Efficient results were obtained when signal was passed through DCB as the pulse spread was decreased to 36 ps.
7.	Cp-OAPF using two EDFAs in cascade.	• BR:10Gbps • Modulation format: NRZ • Gain:20dB • BER: 10^{-9}	SNR improvement :19.2 dB (rectangular pulses) and 23.2 dB (Gaussian pulses). Maximum error free distance without and with compensationis 34km and 214km (which is 7times), respectively.
8.	Hybrid Compensation i.e.DCF mix compensation +Electronic Equaliser	• BR:10 Gbps • λ:1550nm • P_{in}:0dBm • SMF length:50km • D_{SMF} :17ps/nm/km • SMF α: 0.2 dB/km • DCF length:10km • D_{DCF}: -85ps/nm/km	Symmetrical (mix) compensation has BER of 1.61e-16 which was better than DCF pre & post at around 2000km. Symmetrical compensation showed improvement of 47% in Q-factor as compared to pre and post.

		• DCF α: 0.5 dB/km	Hybrid compensation scheme yielded BER of 2.77e-24(best) showed 23% improvement over mix compensation
9.	One common ASE light source+ DCF/FBG for 16 channels WDM system	• BR:2.5 Gbps, • P_{in} :23dBm • Spacing:100GHz • λ= 1550 nm • SMF: 10 and 20km α = 0.2dB/km , D=16ps/nm/km • DCF : 2 and 4.5 km α = 0.55dB/km D= -80ps/nm/km	For optimal CD compensation using DCF: • DCF(2km) + SMF(10km) • DCF(4.5km) +SMF(20km) For FBG, compensated amount for 10 and 20 km was 125 and 280ps/nm, respectively. Maximum reach can be extended atleast twice from 10 to 20 km using CD compensation and proposed light source.
10.	EDFA, RAMAN, SOA amplifiers for dispersion compensation in WDM system	• BR:10 Gbps • f: 193.414 THz • α : 0.2 dB/km • EDFA- O/P power: 12dBm • SOA- L:300×10^{-6}m Biased current:100mA • RAMAN: Fiber Length:10km Pump λ: 1480nm Pump Power:300mW	Better O/P power is provided by EDFA in the absence of non linearities i.e. 12.043dBm Better Q-factor was provided by RAMAN amplifier i.e. 26.19dB In the absence of non-linearities, SOA provided lowest BER i.e. 10^{-17}. For D= 2 ps/nm/km, SOA has better performance but as no. of channels increased, it degraded performance whether EDFA has better performance.

Pr-C= Pre Compensation, Po-C= Post Compensation, α= Attenuation Factor.

VII. CONCLUSION

As studied in the section of literature review, it is observed that the WDM is widely used in various fields of networking in order to provide fast data transmission and higher bandwidth. There is a problem that occurs in WDM i.e. Chromatic Dispersion. This leads to the dispersion and scattering of the signals. There are various techniques that have been developed which can be used for reducing the dispersion of the beam or signals. FBG, DCF, OAPF are one of these techniques. Among these techniques, FBG compensation is preferred because of low insertion losses and low non-linearities.But these techniques do not compensate the dispersion of the signals to the 100%. Hence in future a lot of work can be done in order to make these compensating techniques more reliable and efficient.

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