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Chromatic Dispersion Compensation using Optical All Pass Filters

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Abstract—The purpose of this paper is to experimentally study Optical All Pass Filters (OAPF) and optimize the value of distance of origin from poles (r). Using the value of transfer function of optical all pass filter which is of 2nd order we found the factor of numerator and denominator. In this work, we took the value of 'r' as 0.660 and the angular position (w_0) as 0.390. The power taken as 18dBm. When the power of laser is increased beyond 18dBm, poor results of BER and Q-factor were obtained, because non linearity's are added. The phase response of OAPF is designed to cancel the phase delay of single mode fiber (SMF) which is the main cause of Chromatic Dispersion (CD). The simulation of the mathematical model of the optical communication system at 10 Gb/s employing the proposed OAPF is presented. The different values of optical fiber lengths starting from 100km to 180 km. At operating wavelength of 1.55 μm, the CD is 17ps/nm-km which is the amount of broadening in picoseconds that would occur in a pulse with a spectral width of optical source as one nanometer, while propagating through one kilometer of fiber. There is an improvement in BER with equalizer up to 10^{-19} in 1st channel, up to 10^{-9} in 2nd channel and up to 10^{-21} in 3rd channel as compared without equalizer. The improvement in Q-factor for the fiber length of 180 km is up to 4 times in 1st channel, up to 5 times in 2nd channel and up to 3 times in 3rd channel.

***Keywords*—**single mode fibre, chromatic dispersion, four wave mixing, dispersion compensation, optical communication.

I. INTRODUCTION

Dispersion in a Single Mode Optical Fiber (SMF) is the bottleneck of long haul Optical communication systems. Dispersion, attenuation and nonlinear effects are the key problems associated with the Optical fiber communication systems. Attenuation is no longer a main problem due to the invention of the Erbium Doped Fiber Amplifier (EDFA). Nonlinear effects such as Four Wave Mixing (FWM) can also be reduced by introducing dispersion effects [1]. Dispersion then becomes the main limitation on the bit rate and the length of optical links. Most SMF's that have been installed have zero dispersion at the operating wavelength of 1.31 μm.

When Wavelength Division Multiplexing (WDM) system was introduced to increase the fiber bandwidth, the operating wavelength moved to 1.55 μm. At operating wavelength of 1.55 μm, the dispersion in a SMF is known as Chromatic Dispersion (CD) and it will result in pulse spreading and can cause Intersymbol Interference (ISI). CD is made up of Material Dispersion (MD) and Waveguide Dispersion (WD) [2]. The phenomenon of different wavelengths travelling at different speeds due to the variation of refractive index of the SMF is known as Material Dispersion. Furthermore, a proportion of the light will also travel in the cladding of the SMF, which has a different refractive index compared to the core and introduces an effect known as Waveguide Dispersion. Dispersion compensation is desirable for a high speed Optical communication system using SMF operating at the wavelength other than 1.31 μm. At 1.31 μm, the Chromatic Dispersion of a SMF is zero because the negative Waveguide Dispersion cancels out the positive Material Dispersion. However at operating wavelength of 1.55 μm, the Chromatic Dispersion is 17 ps/nm-km which is the amount of broadening in picoseconds that would occur in a pulse when the spectral width of optical source is one nanometer, while propagating through one kilometer of fiber [3]. For example in the case of a single frequency laser and assuming that the spectral width due to modulation is much larger than the inherent source spectral width, the bit rate length product can be obtained as

$$B^2L = \frac{c}{4D\lambda_0}$$

Where B is the bit rate, L is the SMF length, c is the velocity of light, D is the dispersion coefficient and λ_0 is the

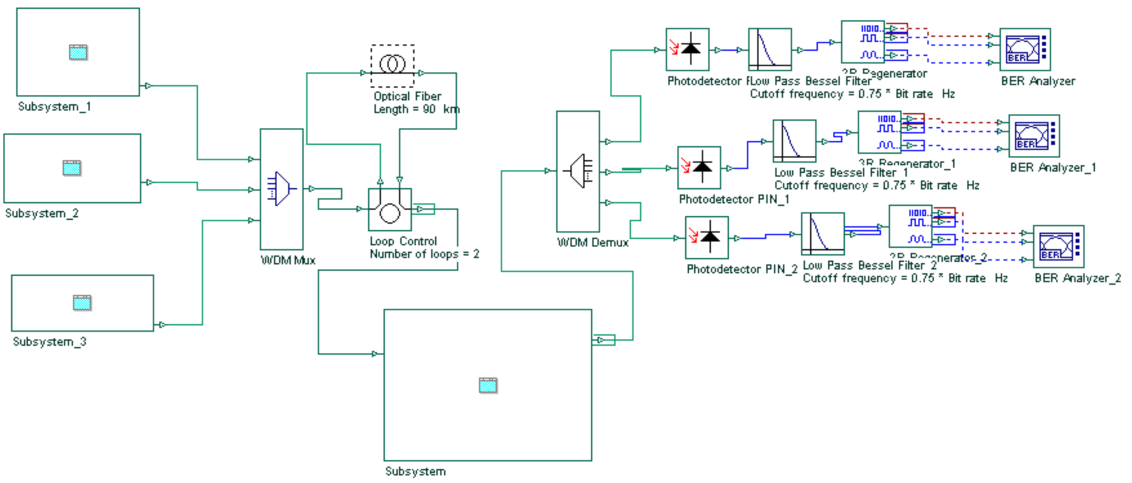

Figure 1. Simulation setup for compensation of chromatic dispersion

operating wavelength. Doubling the bit rate (*B*) would reduce the length (*L*) of optical link by a factor of 4 and at the operating wavelength of 1.55 µm the dispersion is the limit to the repeater-less span length of an optical communication system. The Optical Communication System using SMF is shown in fig. 1.

Chromatic dispersion is the broadening of the input signal as it travels down the length of the fiber. Before explaining the concept of Chromatic Dispersion (CD), one should know about the group delay and optical phase. Group delay is defined as the first derivative of optical phase with respect to optical frequency given in Eq. 1. Chromatic dispersion is the second derivative of optical phase with respect to optical frequency as given in Eq. 2. These quantities are represented as follows:

$$\text{Group delay}=\frac{\partial\theta}{\partial\omega} \qquad (1)$$

$$\text{Chromatic dispersion }=\frac{\partial^2\theta}{\partial\omega^2} \qquad (2)$$

Where θ = optical phase and ω = optical frequency.

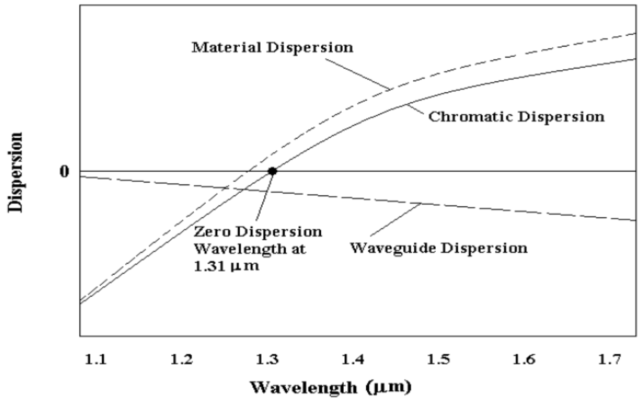

Figure 2. Chromatic dispersion consisting of both material dispersion and waveguide dispersion.

II. RELATED WORK

Chromatic dispersion effects in optical fibres have become an area of academic research due to its great importance in the optical based system. The literature review reveals that many researchers have used chromatic dispersion compensation such as Dispersion Shifted Fiber (DSF), Dispersion Compensating Fiber (DCF), Chirp Fiber Bragg Grating (FBG), Mach-Zehnder Interferometer (MZI), and Optical Phase Conjugation (OPC) for different applications in various fields [4]. Limitations of above mentioned chromatic dispersion compensation techniques have been reported which are mentioned below and to overcome the limitations of existing research works, present work is being carried out.

DSF has the zero dispersion point shifted to a wavelength of 1.55 µm. However, FWM occurs in DSF and causes the optical equivalent of near end crosstalk or interference between the optical channels.

DCF is a specially designed fiber with negative dispersion, employed to compensate for positive dispersion over large lengths of SMF. DCF typically has a much narrower core than a SMF, causing the optical signal to be more tightly confined and accentuating the problem caused by non linear high power effects which results in higher attenuation compared to the SMF.

1) Chirp FBG can compensate CD of a SMF by using the varying distance of grating to delay the faster wavelengths in relation to the slower wavelengths of an optical pulse. By recombining all the wavelengths of an optical pulse, the original optical pulse can be restored. The chirp FBG is limited by its narrow bandwidth and ripple in the opposite group velocity delay (GVD).

2) MZI has been proposed to compensate for CD by providing wavelength dependent paths of different lengths for different spectral components of the signal. In the MZI, the light is split into two paths of different length and then recombined by a 2×2 combiner. The distribution of light in the two output ports will depend on the relative phase delay provided by the two arms. The main limitations of the MZI are its relatively narrow bandwidth and sensitivity to input polarization [5].

OPC is employed to compensate CD by installing a device in the middle of the link to invert the spectrum. If the spectrum of optical pulse is inverted in the middle of the SMF link, the second half of the link acts in the opposite direction. The OPC cannot compensate for the third order dispersion and it is difficult to be implemented in all situations [6].

III. RESULTS & DISCUSSIONS

Table 1. shows the performance analysis parameters values for channel 1 i.e. BER and Q-Factor both with compensation and without compensation for the different fiber lengths. It is seen that as the length of fiber increases, the BER increases and Q-factor decreases. It indicates that at greater length of system, the performance of the system decreases. The value of BER and Q-Factor at fiber length 180 km is 0.0082 and 2.33 respectively without equalizer. However there is much improvement in BER and Q-Factor using equalizer and the values are equal to $1.1*10^{-19}$ and 8.9 respectively. This improvement indicates that by using equalizer in the optical system the effect of chromatic dispersion is compensated and therefore performance of the system increases.

TABLE I. BER & Q-FACTOR FOR CHANNEL 1

Sr. No	**Fiber length**	**Channel 1 without equalizer**		**Channel 1 with equalizer**	
		BER	**QFactor**	**BER**	**QFactor**
1	100km	0	44.11	0	49.72
2	120km	$4.7*10^{-195}$	29.76	0	39.67
3	140km	$5.8*10^{-54}$	15.42	$7.4*10^{-142}$	25.32
4	160km	$6.7*10^{-10}$	6.06	$1.5*10^{-52}$	15.21
5	180km	0.0082	2.33	$1.1*10^{-19}$	8.9

The plots between fiber length and Q-Factor for channel 1, both with compensation and without compensation chromatic dispersion are shown in fig. 3.

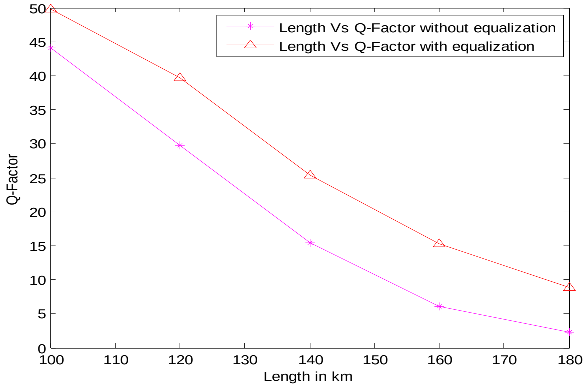

Figure 3. Graphical representation of Q-factor Vs length for Channel 1

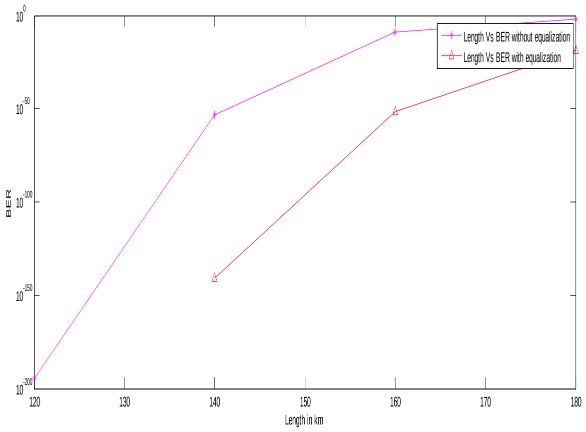

Figure 4. Graphical Representation of BER Vs length for Channel 1

The plots between fiber length and BER for channel1both with compensation and without compensation chromatic dispersion are shown in figure 4.

TABLE II. BER & Q-FACTOR FOR CHANNEL 2

Sr. No	**Fiber length**	**Channel 2 without equalizer**		**Channel 2 with equalizer**	
		BER	**Q-Factor**	**BER**	**Q-Factor**
1	100km	$1.8*10^{-215}$	32.10	$3.8*10^{-221}$	31.72
2	120km	$6.9*10^{-125}$	23.7	$5.8*10^{-137}$	24.88
3	140km	$7.4*10^{-37}$	12.62	$4.7*10^{-62}$	16.57
4	160km	$5.3*10^{-10}$	6.09	$2.7*10^{-27}$	10.74
5	180km	Not measurable	0	$1.2*10^{-9}$	5.53

Table 2. shows the performance analysis parameters values for channel 2 i.e. BER and Q-Factor both with compensation and without compensation for the different fiber lengths. The value of BER and Q-Factor at fiber length 180 km is much noisy without equalizer and there is much improvement in BER and Q-Factor using equalizer and the values are equal to $1.2*10^{-9}$ and 5.53 respectively. Therefore it can be deduced that there is significant improvement in the performance of the system by using an equalizer.

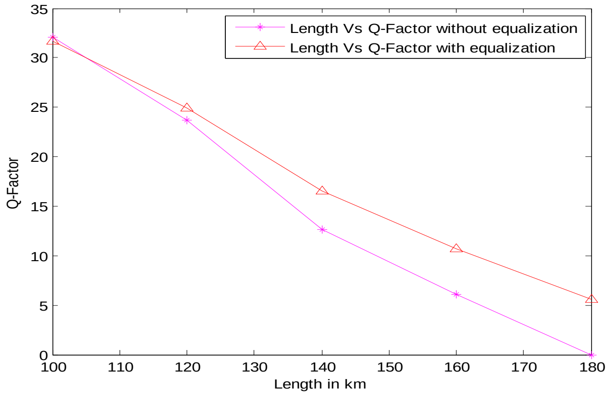

Figure 5. Graphical representation of Q-factor Vs length for Channel 2

The plots between fiber length and Q-Factor both with compensation and without compensation are shown in fig. 5. The 2nd channel is much noisy as compared with other two channels.

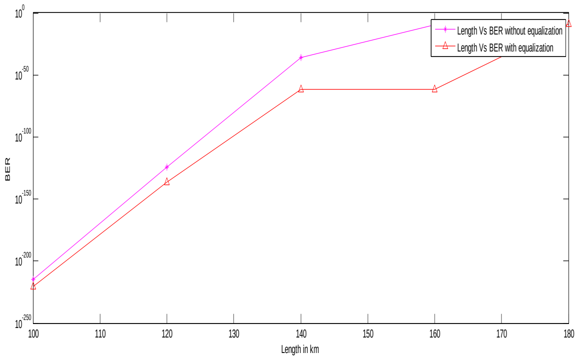

Figure 6. Graphical representation of BER Vs Length for Channel 2

The plots between fiber length and BER both with compensation and without compensation of chromatic dispersion are shown in fig. 6.

TABLE III. BER & Q-FACTOR FOR CHANNEL 3

Sr. No	**Fiber length**	**Channel 3 without equalizer**		**Channel 3 with equalizer**	
		BER	**Q-Factor**	**BER**	**Q-Factor**
1	100km	0	46.38	0	46.38
2	120km	$3.6*10^{-260}$	30.16	0	39.56
3	140km	$2.3*10^{-61}$	16.48	$4.5*10^{-156}$	26.58
4	160km	$8.1*10^{-14}$	7.3	$6.5*10^{-59}$	16.13
5	180km	.00498	2.5	$7.5*10^{-21}$	9.2

Table 3. shows the performance analysis parameters values for channel 3 i.e. BER and Q-Factor both with compensation and without compensation for the different fiber lengths. The value of BER and Q-Factor at fiber length 180 km is 0.00498 and 2.5 respectively without equalizer and there is much improvement in BER and Q-Factor using equalizer up to $7.5*10^{-21}$ and 9.2 respectively. Again the improvement indicates the effect of reduction in chromatic dispersion with the use of an equalizer.

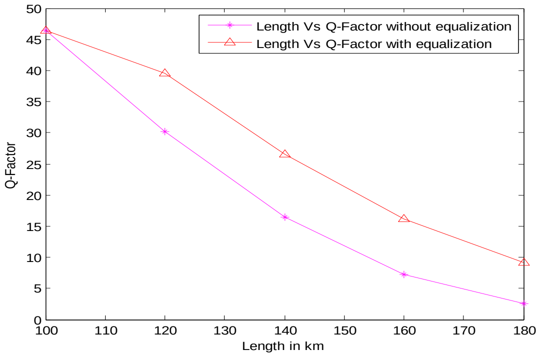

Figure 7. Graphical representation of Q-factor Vs Length for Channel 3

The plots between fiber length and Q-Factor both with compensation and without compensation of chromatic dispersion are shown in fig. 7.

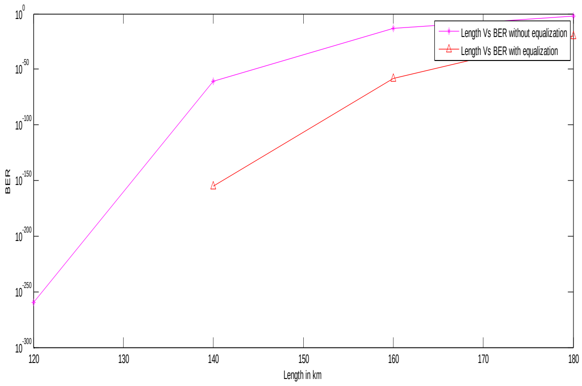

Figure 8. Graphical representation of BER Vs Length for Channel 3

The plots between fiber length and BER both with compensation and without compensation of chromatic dispersion are shown in fig. 8.

IV. CONCLUSIONS

There are number of techniques to compensate the chromatic dispersion of an optical signal travelling along the optical fiber. The dispersion compensation using digital filters is the most effective way of compensating it. It is a new class of digital filters implemented in the optical domain called all pass filters. All pass filters are lossless filters which offer the flexibility to tune a desired phase response arbitrarily close by increasing the number of stages keeping magnitude response of a system unchanged. The work carried shows the basic necessity of using an equalizer to improve gain of the system. Results are shown for BER and Q-Factor both with compensation and without compensation for the different fiber lengths. Results reveal that by using an equalizer chromatic dispersion can be reduced to much extent.

REFERENCES

[1]. *Aggarwal G.P.*, "Applications of Non-linear Fiber Optics," San Francisco, Academic Press, 2001.

[2]. *Loedhammacakra W, Ng W. P., Cryan R.A., and Ghassemlooy Z.*, "Chromatic Dispersion Compensation Employing Cascaded Parallel Optical All-pass Filter," Proceeding of 7th international Symposium on Communication Systems Networks and Digital Signal Processing (CSNDSP), pp 682 – 687, 2010.

[3]. *Loedhammacakra W., Ng W.P., and Cryan R.A* , "Chromatic Dispersion Compensation using an Optical All Pass Filter for a 10 Gb/s Optical Communication System at 160 km," International Journal of Northumbria University , pp 105-108, 2005.

[4]. *Madsen C. K. and Lenz G.*, "Optical All-Pass Filters for Phase Response Design with Applications for Dispersion Compensation," IEEE Photonics Technology Letters, Vol. 10, pp. 7, 1998.

[5]. *Mynbev, Scheiner D.*, "Fiber Optic Communication Technology," Pearson Education, 2001.

[6]. *Devra Shivinder and Kaur Gurmeet*, "Dispersion Compensation using All Pass Filters in Optical Fibers" Proceeding of International Conference on Information and Electronics Engineering, Singapore, Vol.6,2011.