Polarization Mode Dispersion compensation in WDM system using dispersion compensating fibre

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Abstract: In this paper, the polarization mode dispersion in eight channel WDM system is evaluated by considering one even channel and one odd channel performance parameters like BER and Q-factor. As PMD effects transmission at high bit rates so it is compensated with the help of dispersion compensating fibre at different distances by controlling the polarising angle with the help of polarization controller at ellipticity =+45/-45, azimuth=0 corresponding to right hand/left hand circular polarization technique and analyse BER,Q-factor and eye diagram of WDM system. The overall results shows some improvements in performance of WDM system .

Keywords--- *Bit error rate (BER), Eye diagram, Polarization controller, Polarization mode dispersion (PMD), Polarization schemes, Wavelength division multiplexing (WDM),Dispersion compensating fibre (DCF).*

I. INTRODUCTION

PMD is an important linear phenomenon occurring inside optical fibers, which can cause the optical receiver to be unable to interpret the signal correctly, and results in high bit error rates. Due to the rapid increase in the demand for bandwidth, wavelength divison multiplexed (WDM) systems have been widely deployed in trans-oceanic links as well as continental and metropoliton networks[1]. There are three polarization effects that lead to impairments in the long-haul optical fiber transmission systems: polarization mode dispersion (PMD), polarization dependent loss (PDL), and polarization dependent gain (PDG) [2]–[3]. There exist special orthogonal pairs of polarization at the input and the output of the fiber called the PSPs. Light launched in a PSP does not change polarization at the output to first order in ω . These PSPs have group delays, tg, which are the maximum and minimum mean time delays of the time domain view. The difference between these two delays is called the DGD. The DGD grows roughly as the square root of the length of fibre, as is characteristic of a random walk problem**.** One commonly accepted parameter used to characterize the PMD delay is the mean DGD across a certain wavelength range (Δτ), and is expressed in [ps].

$$PMD=\langle\Delta\tau\rangle$$

The mean DGD is proportional to the square root of the length of the fiber. The PMD coefficient, $\Delta\tau c$ [ps/√km], is used to express the PMD delay as a function of the fiber length. $\Delta\tau = \Delta\tau c \times \sqrt{L}$; where L is length of the fiber[4]. EDFA in a WDM system are often required to have equalized gain spectra in order to achieve uniform output powers and similar signal-noise ratios [5]. There are several methods in designing a flat spectral gain EDFA such as by controlling the doped fiber length and the pump power , proper choosing of optical notch filter's characteristic, by using an acousto-optic tuneable filter and by employing an inhomogeneously broadened gain medium [6]. PMD can be compensated by using DCF. The system can be either pre-compensated post compensated or dual-compensated (using a combination of pre- and post-compensation) in total accumulated dispersion [7]. The DCF introduces a negative dispersion coefficient. Post compensation is achieved by adding the DCF onto an existing fibre. The fibre'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[8]. When this type of DCF is used for dispersion compensation, the dispersion slope for the whole transmission system including the DCF becomes larger than that for the transmission fiber alone and a wavelength region where the dispersion is well compensated is restricted to a narrow range[9]. In a WDM system, multiple wavelengths are used to transmit information. DCF provides an "un-tunable" fixed negative dispersion for all the different channels in the WDM system[10]. DCF is a good compensating device for its reference wavelength but it will leave residual dispersion at other wavelengths in a multi-channel transmission [11].

II. DESIGN TOPOLOGIES

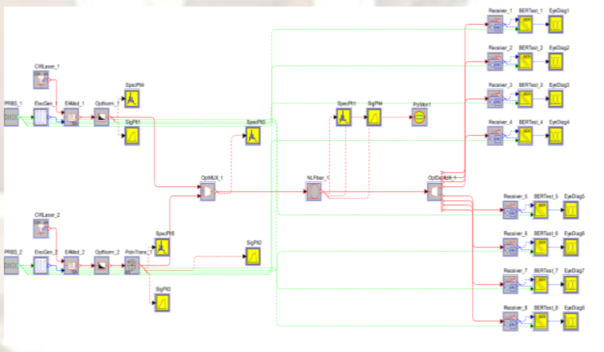


Fig (1). Polarization mode dispersion measurement in WDM system .

The system configuration consists of eight channels, which are originated with the help of PRBS generator, continue wavelength laser and electrical signal generator. In the WDM system, each channel is transmitted at the data rate of 10Gbps. So the capacity of the system becomes (10x8) 80Gbps. Polarisation Transform is used to control the polarising angle at ellipticity +45/-45^0 and azimuth 0^0. After multiplexing the signal is transmitted through non linear fibre. The differential group delay, which occurs due to the polarization mode dispersion in the fibre is measured by using polarimeter. In this model we measure the PMD in terms of differential group delay at various distances and the system parameters such as Q- factor, bit error rate etc. are analysed after being demultiplexing. Optical multiplexers and demultiplexers are used here.

2.1 PMD compensation using Dispersion ompensating Fibre

We use dispersion compensating fibre to compensate polarization mode dispersion in the WDM system. There are various methods to use DCF in the system. Dispersion compensating fiber (DCF) provides an optical medium with a relatively large negative chromatic dispersion factor D(λ) at the operating wavelength. If a transmission fiber of length LTF is connected in series with a DCF of length LDCF, then the total chromatic dispersion is given by

$$\Delta t = L_{TF} D_{TF}(\lambda)\,\Delta\lambda + L_{DCF} D_{DCF}(\lambda)\Delta\lambda$$

Where $\Delta t = \Delta t_{chrom} + \Delta t_{comp}$, *DTF(λ)* is the chromatic dispersion factor for the transmission fiber, *DDCF(λ)* is the chromatic dispersion factor for the DCF and *Δλ* is the transmitter spectral width. We have to make $\Delta t = \Delta t_{chrom} + \Delta t_{comp} = 0$, so it gives simple relationship:

$$\Delta t_{chrom} = -\Delta t_{comp}$$

$$L_{TF} D_{TF}(\lambda)\,\Delta\lambda = -\,L_{DCF} D_{DCF}(\lambda)\Delta\lambda$$

So that $-\,D_{DCF}(\lambda) = D_{TF}(\lambda)\,L_{TF} / L_{DCF}$

Similarly,
the total attenuation loss of the two-fibre combination is given by

$$\text{Loss} = L_{TF} A_{TF} + L_{DCF} A_{DCF}$$

Therefore, given target values for chromatic dispersion and attenuation loss plus specifications of the transmitter, fiber and receiver, one can determine the lengths of the transmission fiber and the DCF by solving the above two equations simultaneously.

In this technique, the designed WDM system is compensated with dispersion compensating post compensation method in which DCF is used after the non linear fibre. The length of non linear fibre is 75km with dispersion of $0.09e^3$ s/m^3 and PMD coefficient of $0.315e^{-15}$ s/√m. To compensate this positive value dispersion the dispersion compensating fibre of 10km is used with negative dispersion of $-0.675e^3$ s/m^3 is chosen as per the following equation;

$$-L_{dcf} \times D_{dcf} = L_{nl} \times D_{nl}$$

$$-D_{dcf} = L_{nl}/L_{dcf} \times D_{nl}$$

To improve the system performance an EDFA of 10db power gain and power saturation of 8db is used in the system. In the same way to do the compensation at 100km in the eight channel WDM system the dispersion compensating fibre of 20km long is selected which compensate the positive dispersion of non linear fibre with negative dispersion of $-0.45e^3$ s/m^3. In this system again post compensation is done and an EDFA is used for pre and post amplification of the signal. The EDFA used for pre amplification has power gain of 2db and saturation power of 1db. The power gain is 30db and saturation power of 18db is chosen for post amplification EDFA. At 125km the length of dispersion compensating fibre is 30km with negative dispersion value of $-0.375\ e^3$ s/m^3 to compensate the dispersion of non linear fibre so as to reduce the PMD in the WDM system. An EDFA is used for pre and post amplification purpose so that the system performance is improved by choosing the 15db and 12db power gain and saturation power respectively.

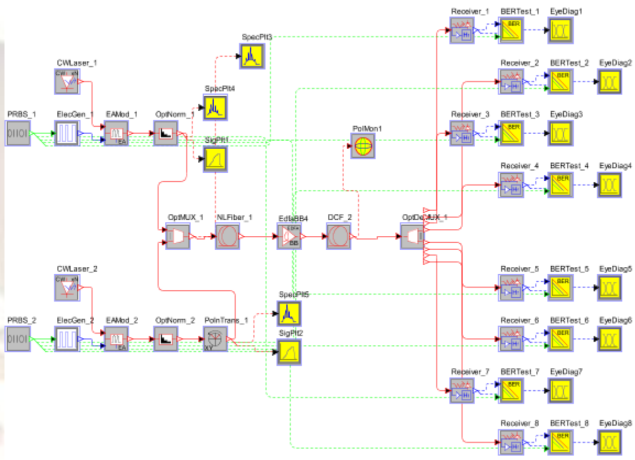


Fig (2) Compensation of WDM system with dispersion compensating fibre at 75km

III. SIMULATION RESULTS

3.1 PMD at 75km in polarization controller mode.

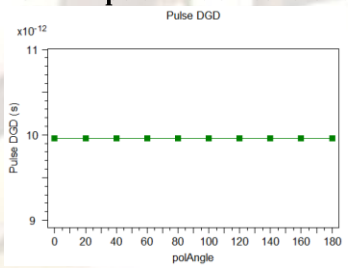
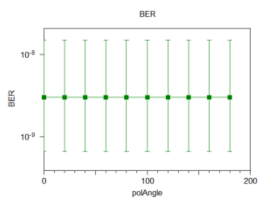


Fig (3a). PMD in polarization controller with ellipticity +45 and azimuth 0.0



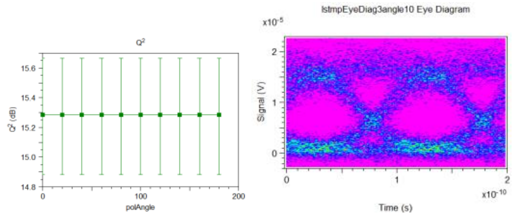


Fig (3b). BER, Q-factor and Eye diagram of odd channel

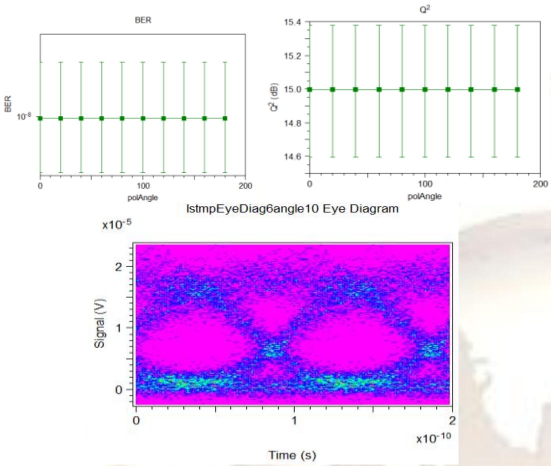
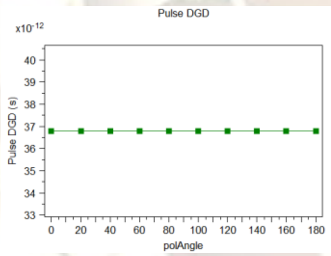


Fig (3c). BER, Q-factor and Eye diagram of even channel

3.2 PMD at 100km using EDFA gain of 8db and saturation power of 6db in polarization controller mode.



Fig(3.2a). PMD in Polarization controller mode

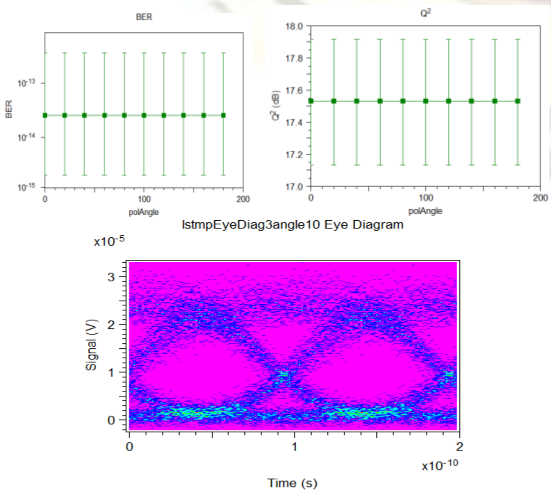


Fig (3.2b). BER, Q-factor and Eye diagram of odd channel

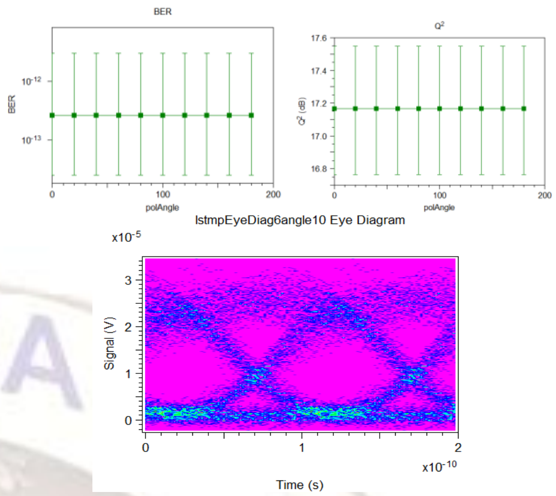


Fig (3.2c). BER, Q-factor and Eye diagram of even channel

3.3 PMD at 125km using EDFA in polarization controller mode.

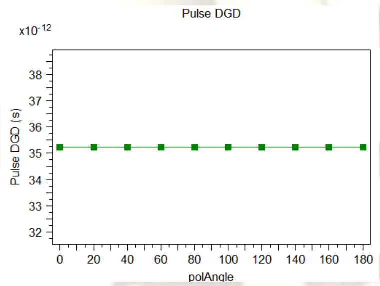


Fig (3.3a). PMD in polarization controller mode with Ellipticity 0, azimuth +45.

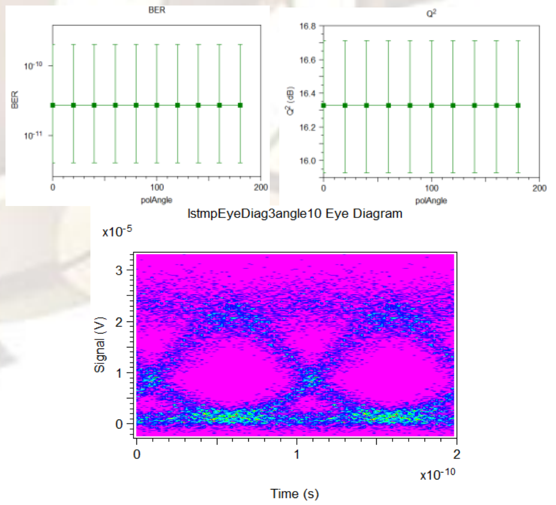


Fig (3.3b). BER, Q-factor and Eye diagram of odd channel

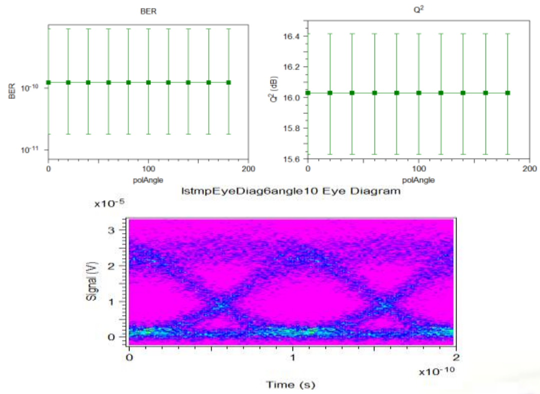


Fig (3.3c). BER, Q-factor and Eye diagram of even channel

3.4 Compensation of WDM system with dispersion compensating fibre at 75km in polarization controller mode:

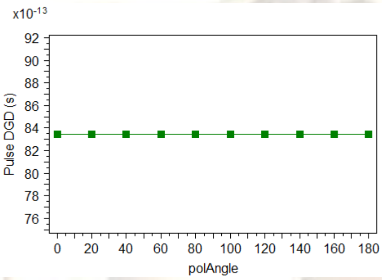


Figure 3.4(a) PMD in Polarization controller mode after DCF compensation at 75km

(a). Odd channel:

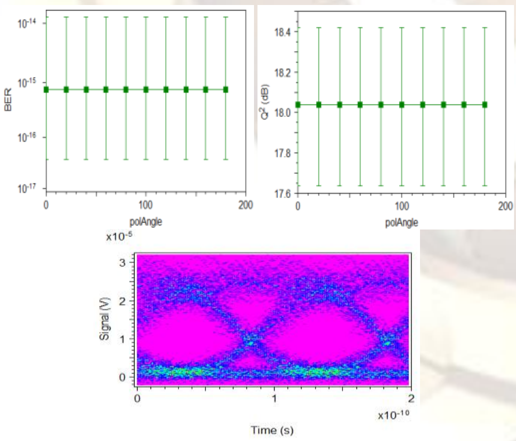


Figure 3.4(b) (i) BER (ii) Q-factor and (iii) Eye diagram of odd channel after DCF compensation at 75km

(b). Even channel:

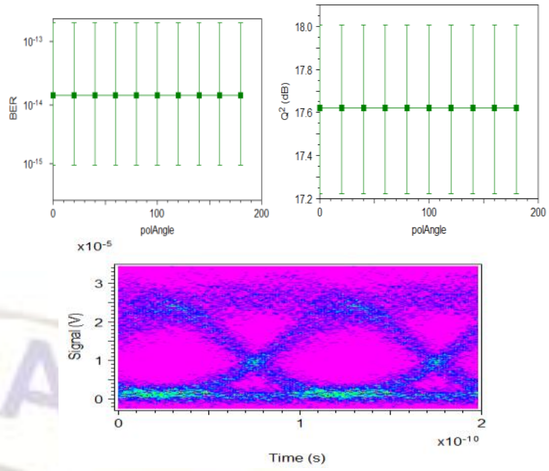


Fig 3.4(c) (i) BER (ii) Q-factor and (iii) Eye diagram of even channel after DCF compensation at 75km

3.5 Compensation of WDM system with dispersion compensating fibre at 100km in polarization controller mode.

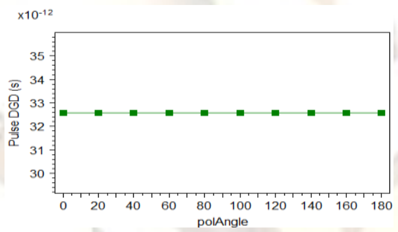


Fig 3.5(a). PMD in Polarization controller mode after DCF compensation at 100km

(a). Odd channel:

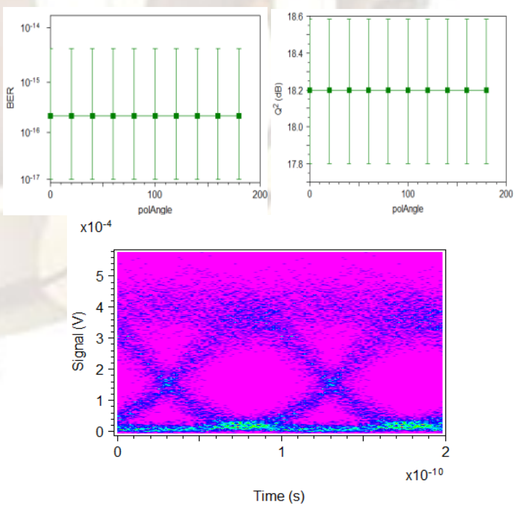


Fig 3.5(b) (i) BER (ii) Q-factor and (iii) Eye diagram of odd channel after DCF compensation at 100km

(b). Even channel:

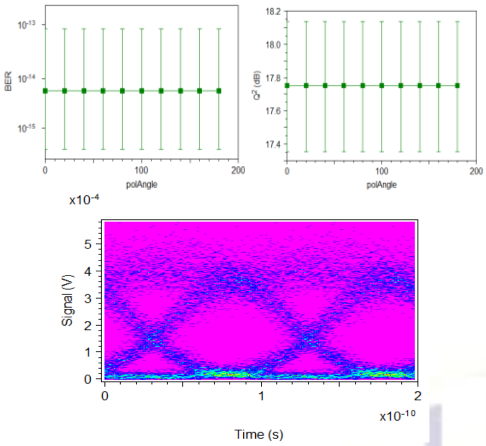


Fig 3.5(c) (i) BER (ii) Q-factor and (iii) Eye diagram after DCF compensation at 100km

3.6 Compensation of WDM system with dispersion compensating fibre at 125km in polarization controller mode.

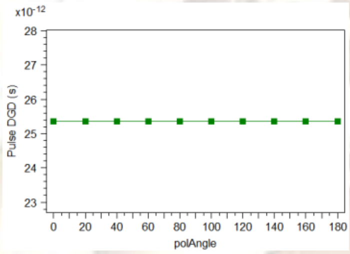


Fig 3.6(a). PMD in Polarization controller mode after DCF compensation at 125km

(a). Odd channel:

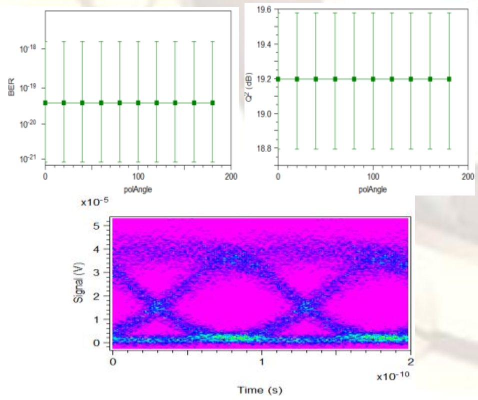


Fig 3.6 (b) (i) BER (ii) Q-factor and (iii) Eye diagram of odd channel at 125km

(b). Even channel:

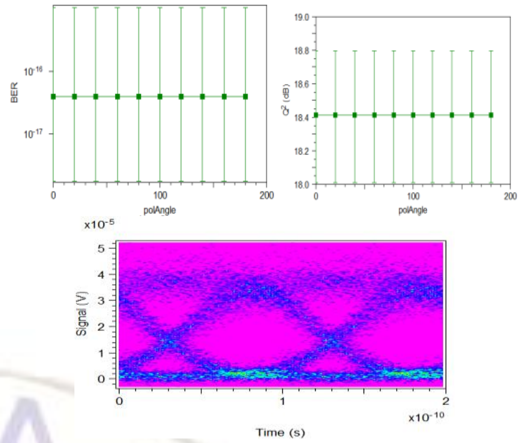


Fig 3.6(c) (i) BER (ii) Q-factor and (iii) Eye diagram of even channel after DCF compensation at 125km

Table I Shows the PMD with and without compensation

DISTANCE (KM)	PMD WITHOUT COMPENSATION (ps)	PMD AFTER DCF COMPENSATION (ps)
75	5	4.1
100	18.5	16
125	17.7	12.2

Table II Shows the BER of odd and even channels of WDM system before and after compensation

DISTANCE (KM)	BER			
	Without compensation		After compensation	
	ODD CHANNEL	EVEN CHANNEL	ODD CHANNEL	EVEN CHANNEL
75	10^{-9}	10^{-8}	10^{-15}	10^{-14}
100	10^{-14}	10^{-13}	10^{-16}	10^{-14}
125	10^{-11}	10^{-10}	10^{-19}	10^{-16}

Table III Shows the Q-factor of odd and even channel of WDM system before and after compensation

DISTANCE (KM)	Q-FACTOR(dB)			
	Without compensation		After compensation	
	ODD CHANNEL	EVEN CHANNEL	ODD CHANNEL	EVEN CHANNEL
75	15.3	15	18.0	17.6
100	17.6	17.2	18.2	17.8
125	16.3	16	19.2	18.1

IV. RESULTS DISCUSSION

The above results show the PMD in WDM system in polarization controller mode. The BER and Q-factor is constant for all the polarization angles. BER is 10^{-9} and 10^{-8} in case of odd and even channel where Q-factor is 15.3dB and 15dB at 75km. The BER at 100km is 10^{-14} and 10^{-13} for odd and even channels which show a small difference, it means BER of all the channels is approachable to acceptable limit where the Q-factor also improves with values 17.6dB and 17.2dB of odd and even channels. At 125km, PMD is 17.7ps and BER is 10^{-11} and 10^{-10} for odd and even channel . The Q-factor of odd channel is 16.3dB and 16dB in the case of even channel.

Table I shows the simulations results of PMD compensation in WDM system with dispersion compensating fibre of various even and odd channels. At 75km the PMD is 5ps in the WDM system. This dispersion is reduced to 4.1ps with the usage of DCF as a post compensation device. At 100km distance, PMD reduced to 16ps which provides compensation of 2.5ps. The PMD at 125km is 17.7ps. After compensated with DCF its value is 12.2ps. From these results it is observed that PMD is compensated with DCF to some extent. Table II shows the BER of various odd and even channels of eight channel WDM system. It is observed that in polarization controller mode its value is constant at all polarization angles. So one odd channel and one even channel is selected to analyse the BER before and after doing the compensation of the designed link with DCF. The resultant table shows that at 75km BER is 10^{-9} and 10^{-8} without compensation and it is 10^{-15} and 10^{-20} when these channels are compensated with DCF. As the distance increases to 100km, BER is 10^{-14} and 10^{-13} without compensation and it is improved by 10^{-16} in case of odd channel and 10^{-14} in the even channel after the system is compensated with DCF. At 125km, the BER of odd and even channel is 10^{-11} and 10^{-10} without compensation and becomes 10^{-19} and 10^{-16} in case of odd and even channel after compensation. nIn the table III the Q factor of WDM system is shown before and after compensation in the polarization controller mode. At 75Km, Q-factor is 15.3db and 15db for various odd and even channels and when the system is compensated with DCF the Q-factor is 18.0db and 17.6db. The various values of Q- factor of odd channel and even channel are18.2db and 17.8db at 100km after compensation. At distance of 125Km, Q-factor for odd and even channel is 16.3db and 16db when it is not compensated where as the Q-factor becomes 19.2db when WDM system is compensated using DCF in case of odd channel where as its value is 18.4db in even channel.So overall results shows improvement in BER and Q-factor of WDM system.

V. CONCLUSION AND FUTURESCOPE

In the WDM system PMD limits the long distance transmission of optical fibre and if the polarization angle is controlled with the help of polarization controller at ellipticity= +45/-45 and azimuth = 0, which is corresponding to right/left circular polarization then the overall results shows improvement in BER, Q-factor and Eye diagrams of various channels. The value of BER varies from 10^{-8} to 10^{-16} for different odd end even channels at various distances, which is acceptable and Q-factor of 17.6 to 19.2 also provide better system performance when it gets compensated with DCF. In future this topology can be enhanced to calculate PMD at bit rates higher than 10Gbps, at larger distances and for more number of channels using different methods. Different optical compensation methods can be discussed.

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