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Simulation of single channel optical communication system with different modulation formats in the presence of SPM non linearity

Anmol Bansal[1], Jagjot Singh Sehgal[2], Shweta Kurbet[3], Sagar Taneja[4], Monika Bhutani[5]

[1234] Final year Student, ECE department Bharati Vidyapeeth's College of Engineering , New Delhi, India
[5] Faculty ECE department, Bharati Vidyapeeth's College of Engineering, New Delhi, India

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Abstract: This paper investigates the effect of Self Phase Modulation (SPM) non-linearity on single channel optical communication system. For the analysis, different modulation formats: Differential Phase Shift Keying (DPSK), Duo-binary Return to Zero (DBRZ), Carrier Suppressed Return to Zero (CSRZ) and Differential Quadrature Phase Shift Keying (DQPSK) were simulated and compared. The effect of variation in system length was observed in terms of Q-value and Bit Error Rate. On comparison of the four modulation formats, it was concluded that Duo-Binary modulation format is the best format among the four techniques.

Keywords: CSRZ; DBRZ; DPSK; DQPSK; SPM

Introduction

Optical fiber communication uses light as media to convey the information. The channel used for this mode of communication is optical fiber. Earlier employed coaxial systems and Microwave transmissions had limitations over the bit rate which became the reason for evolution of optical communication, which provided better bit rate, larger bandwidth, low loss and high speed transmission of information [1]. Optical fiber plays an important role in long distance transmission at higher bandwidths than the earlier systems of communication [2]. Nonlinear effects in optical fiber have a great importance in fiber optic communication. Nonlinear effects occur in the optical communication system due to the changes that take place in the refractive index of the optical fiber. This phenomenon is Kerr-effect [3]. Kerr non-linearity is due to the changes in refractive index with power. This is responsible for generation of different effects depending on the shape of induced field in the fiber such as Self Phase Modulation (SPM), Four Wave Mixing (FWM) and Cross Phase Modulation (XPM) in the optical communication system. Four Wave Mixing (FWM) is an inter modulation phenomenon in non-linear optics, whereby interactions between two wavelengths produce two extra wavelengths in the signal. FWM is a fiber optic characteristic that affects Wavelength Division Multiplexing (WDM) systems, where multiple optical wavelengths are spaced at equal intervals or channel spacing. Cross Phase Modulation (XPM) is a non-linear optical effect where one wavelength of light can affect the phase of another wavelength of light through the optical Kerr Effect. XPM leads to inter channel cross talk in WDM systems and can produce amplitude and timing jitter. SPM is due to the changes in refractive index that occurs due to the intensity dependant changes [4]. SPM results in to non-linear phase-shifts that are inflected in magnitude with the fiber length.

The Kerr non-linearity gives rise to the Self Phase Modulation (SPM). SPM is observed when an intensity modulated signal is propagated through an optical medium. SPM affects a single light pulse propagating through the medium. Thus, it is seen on single channel optical fiber communication [8]. It causes a frequency chirp on optical pulse which causes pulse broadening. SPM caused by group velocity dispersion causes distortions in the waveform that restricts the transmission capacity and the distance over which signal is propagated. It does not alter the spectrum in time domain.

Jawla et al [5] compared the modulation formats (Non-Return to Zero ON-OFF Keying, Return to Zero ON-OFF Keying, Carrier Suppressed Return to Zero and Duo-Binary) and their performance in optical communication system. These modulation formats result in variation of spectral bandwidth, noise and dispersion tolerance. CSRZ provides high dispersion tolerance for a system with high bit rate. Duo-binary is another modulation format that provides high forbearance to dispersion.

Kashyap et al [6] studied the effect of Self Phase Modulation on Optical fiber. The Quality Factor was analyzed at different values of optical dispersion for a fiber length of 100kms with the optical dispersion varying from -

10ps/nm/km to 10ps/nm/km and the effect of self phase modulation was studied. The simulation was performed at 10 Giga bits per second (Gbps) transmission system. It was concluded that due to Self Phase Modulation (SPM) the quality factor became non linear which was earlier constant.

Khanna et al [7] analyzed the Two Channel Optical WDM System using Binary and Duo Binary modulation formats. The analysis involved the comparison of Bit Error Rate (BER) and Quality Factor (Q factor) with different bit rates for the two modulation formats. It was concluded that BER improves with duo binary modulation format than due to the binary scheme. The duo binary format offered higher Q factor than Binary modulation scheme for bit rates of 5Gbps and 2.5Gbps.

In this paper, the simulation with different modulation formats is carried out on single channel. Modulation formats used are Differential Phase Shift Keying (DPSK), Differential Quadrature Phase Shift Keying (DQPSK), Duo-Binary Return to Zero (DBRZ) and Carrier Suppressed Return to Zero (CSRZ). Simulations are performed in terms of BER and Q-factor, varying the length of the fiber (L) and keeping the bit rate constant at 10Gbps. In Section 2 the simulations of above mentioned modulation formats is done and parameters are defined. Section 3 of this paper covers the comparison results. Finally in Section 4, conclusion is summarized.

Simulation

The simulation setup consists of a single channel optical communication system with reference frequency as 193.41THz and the corresponding reference wavelength as 1550nm.
Figure 1 shows simulation block diagram where the transmitter section consists of a binary sequence generator, continuous wave laser, modulator and an optical signal booster. At the receiving section the PIN photodiode is used for optical to electrical conversion along with a low pass electrical Gaussian filter, which is used for proper filtering. Q-estimator and BER estimator are connected to the transmitter in order to observe the results of the simulation.

Table 1 gives the details of simulation parameters. It specifies the values of important parameters such as operational frequency, bit rate and number of channels used. Table 2 specifies the fiber parameters such as fibre length, dispersion attenuation and effective core area.

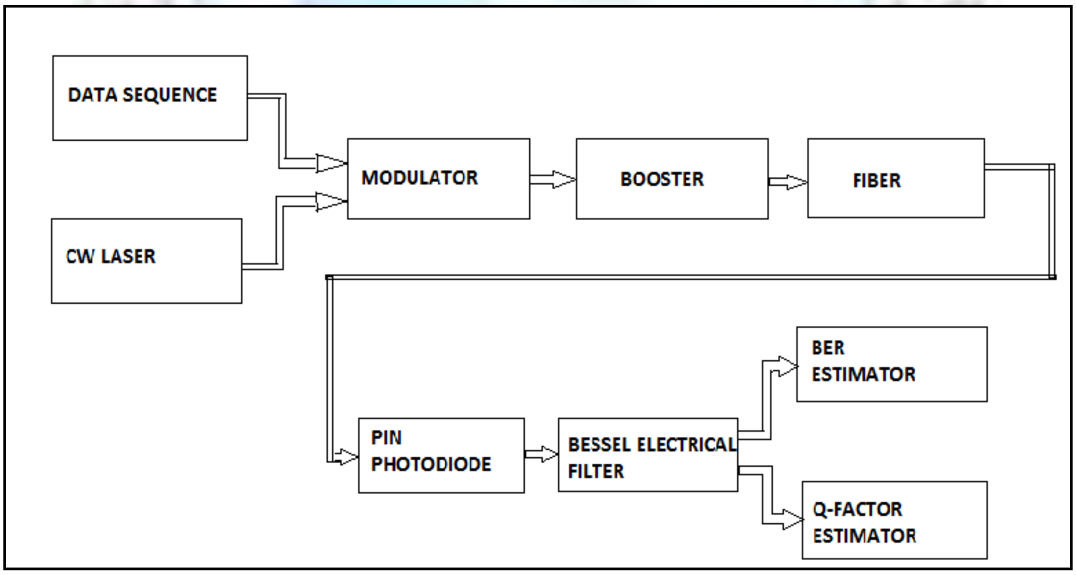

Fig.1: Block diagram of the simulation setup.

TABLE 1: Simulation Parameters

PARAMETER	VALUES
Operational Frequency	193THz
Bit Rate	10Gbps
Samples per bit	13

TABLE 2: Fibre Parameter

PARAMETER	VALUES
Attenuation	0.205db/km
Dispersion	16ps/km-nm
Core effective area	80 x $10^{-12}m^2$

DPSK Modulation Format

Differential Phase Shift Keying (DPSK) is an optical modulation format in which occurrence of π phase change between successive bits represents logic ‘1’ and when there is no phase change then it represents logic ‘0’. The signal optical power remains fixed in DPSK scheme. It is one of the often used modulation scheme in optical communication.
Figure 2 shows the block diagram of single channel DPSK transmitter. This includes an unbalanced sine square modulator, NRZ driver, optical fiber and an electrical Bessel filter (low-pass). 10 Gbps data source is provided as an input to the NRZ driver. The NRZ coded output is applied to the electrical Bessel low pass filter with 30 GHz centre frequency. This along with 1 mw continuous wave laser is applied to an unbalanced sine square modulator. The fiber length is varied with the parametric run and has 0.07ps/nm^2/km dispersion derivative, 193.41449 THz frequency and 1550 nm wavelength at reference frequency. The core effective area of the fiber is taken as 80 x $10^{-12}m^2$.

DQPSK modulation format

Differential Quadrature Phase Shift Keying (DQPSK) modulation format transmits multiple bits in each symbol and 0, +π/2, -π/2 and π phase changes are transmitted. This transmission has a symbol rate as half of bit rate [9]. This modulation scheme has higher frequency tolerance than DPSK.

Figure 3 shows the block diagram for single channel DQPSK transmitter. Two 5 Gbps data sources are applied as an input to the DQPSK pre-coder. The two outputs from the pre-coder are then applied to the NRZ driver and then to low pass electrical Bessel filter. These signals, along with 1mW CW laser and phase shift, are collectively applied to the DQPSK modulator. The fiber length is varied with the parametric run and has 0.07ps/nm^2/km dispersion derivative, frequency as 193.41449 THz and wavelength as 1550nm. The core effective area of the fiber is taken as 80 x 10^{-12} m^2.

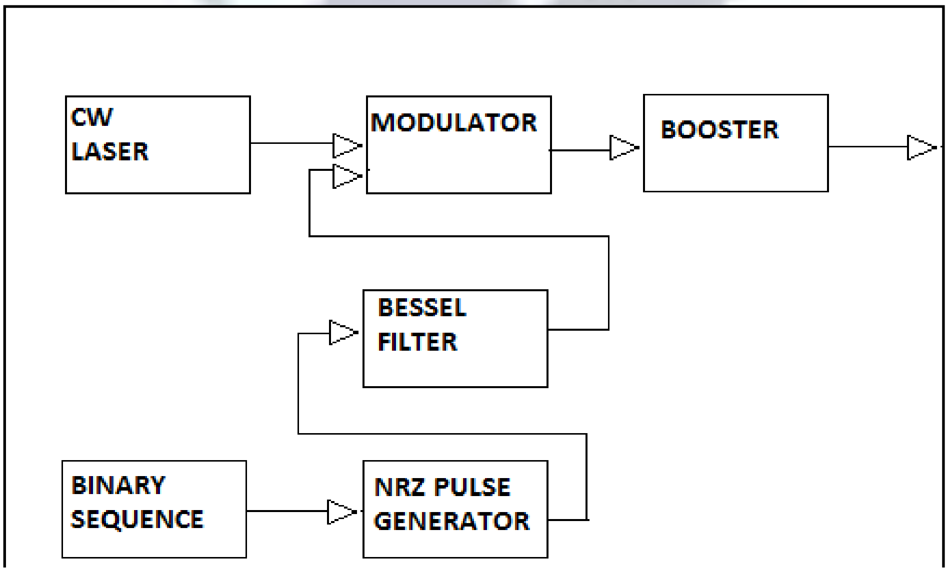

Fig. 2: Block diagram for DPSK Transmitter

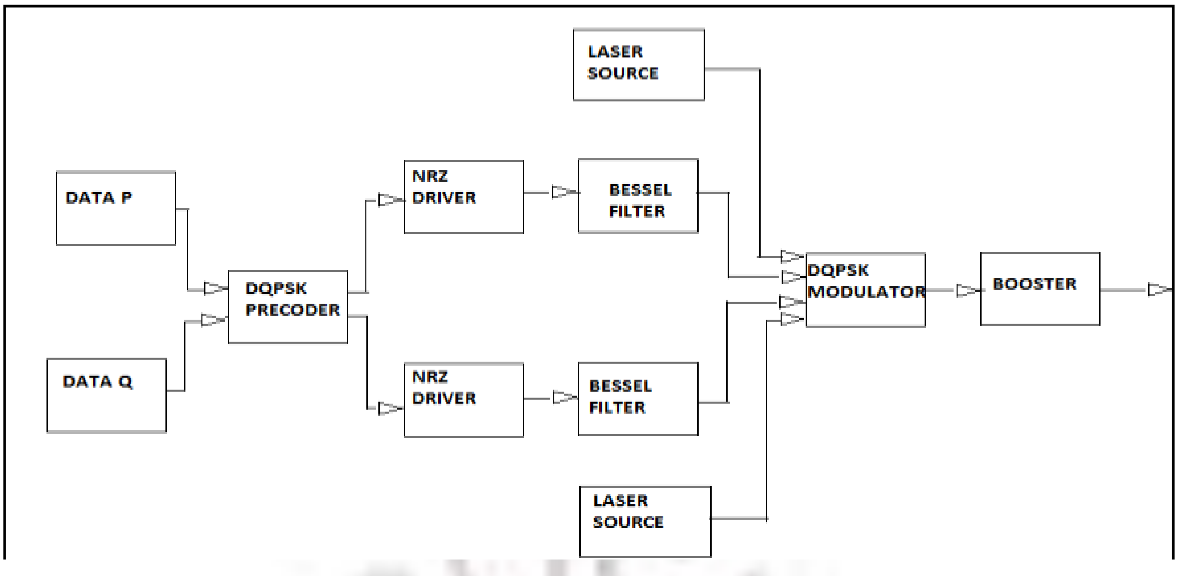

Fig. 3: Block diagram for DQPSK Transmitter

Duo-binary modulation format

Under Duo-Binary modulation scheme B bits are transmitted per second using bandwidth for less than B/2 Hz. However inter symbol interface is present in duo-binary pulses [10]. In this format, the successive bits have opposite polarities. The level transition occurs only when the in between bits at centre level is odd. Here the bandwidth is reduced by a factor of two but the system complexity becomes slightly higher. Duo–Binary modulation scheme also enhances the transmission efficiency of the optical communication.
Figure 4 shows the block diagram of single channel duo-binary transmitter. It includes a logical NOT gate, Mach-Zehnder Modulator and an electrical Bessel filter (low pass). A 10 Gbps data source is provided as an input to NRZ driver and also to a NOT gate. Output of this NOT gate is provided to another NRZ driver. The NRZ coded outputs are applied to electrical Bessel low pass filter with 30 GHz centre frequency. Along with this 1 Mw continuous wave laser is applied to a Dual Arm Mach-Zehnder Modulator. The fiber length is varied with the parametric run and has $0.07 ps/nm^2/km$ dispersion derivative, 193.41 THz frequency and 1550nm wavelength. The core effective area of the fiber is $80 \times 10^{-12} m^2$.

CSRZ modulation format

In Carrier Suppressed Return to Zero (CSRZ) modulation scheme, optical signals have a π phase shift between successive bits. In this modulation scheme, the carrier frequency is suppressed and sidebands are created half data rate away from the carrier [11]. CZRZ has high tolerance effect of Self Phase Modulation.
Figure 5 shows block diagram of single channel CSRZ transmitter. For simulation, a 10 Gbps data source is provided to NRZ driver. Output of the driver is provided as input to unbalanced Mach-Zehnder Modulator. Another input to this modulator is provided through CW laser. Output of this modulator is provided as input to another modulator block with sine wave generator.

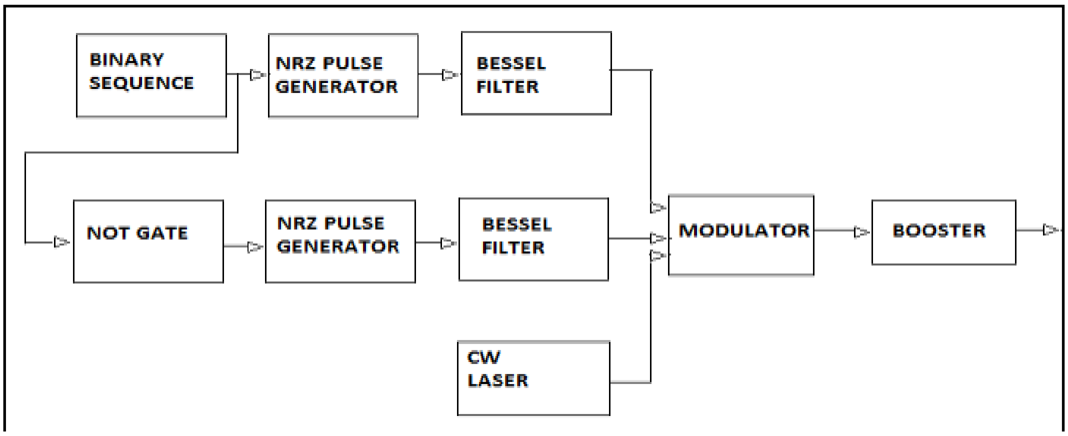

Fig. 4. Block diagram for Duo-binary Transmitter

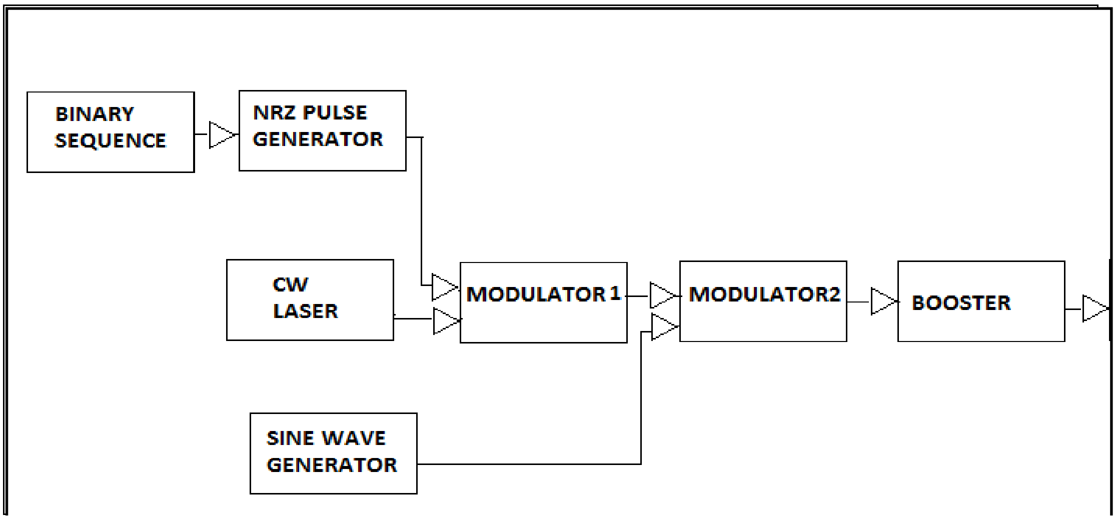

Fig.5. Block diagram for CSRZ Transmitter

Results and Discussions

Here in this paper, the input and output power spectrum of the system was observed. Fig.6. shows the input optical power spectrum which has only one peak and Fig.7 shows the output optical power spectrum which has 2 peaks due to the spectral broadening effect of Self Phase Modulation.

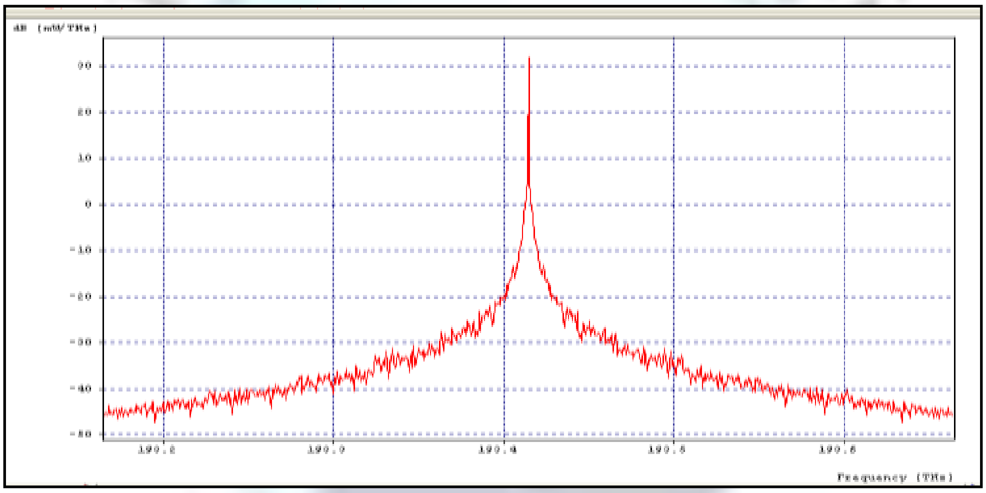

Fig.6. Input optical power spectrum

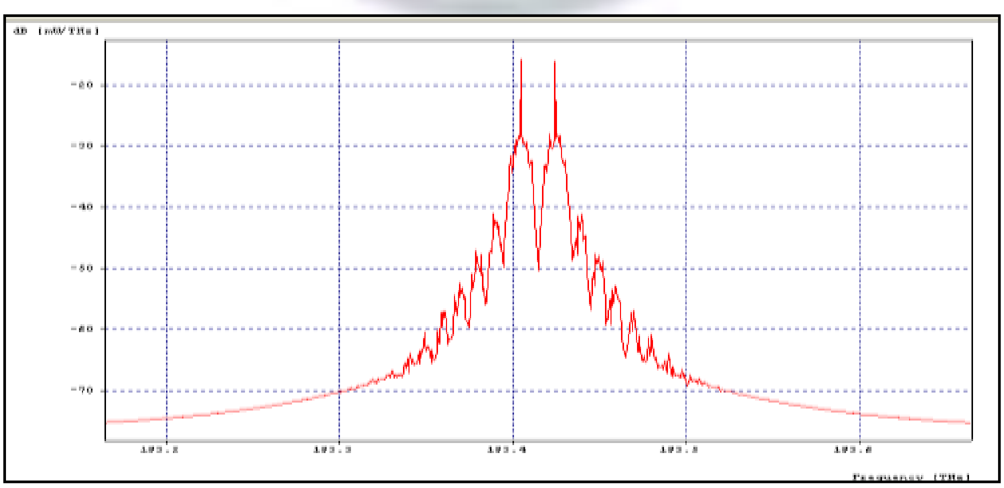

Fig.7. Output optical power spectrum

The four modulation formats have been graphically compared for different fiber lengths against Bit Error Rate and Q-factor. Figure 8 represents the comparison of DPSK, DQPSK, CSRZ and Duo-Binary modulation formats in terms of Q-factor at varying optical fiber lengths. This analysis shows that as we increase the fiber length the non-linearity increases and thus the Q-factor decreases. Duo-Binary modulation scheme gives Q-factor as 31.58 at the 30km fiber length whereas DPSK and DQPSK give smaller Q-factor for this length as 15.08 and 16.15 respectively. At fiber length 100 km the Duo-Binary modulation scheme gives Q-factor value 20.45 which is much larger than what is obtained for DPSK and DQPSK for which values obtained are 7.80 and 12.48 respectively. The result shows that among all the modulation formats studied, the Duo-Binary modulation scheme shows the highest Q-factor value for optical fiber length ranging from 30 to 140km. Clearly, Duo-Binary modulation format shows best results for Q-factor for varying optical fiber length.

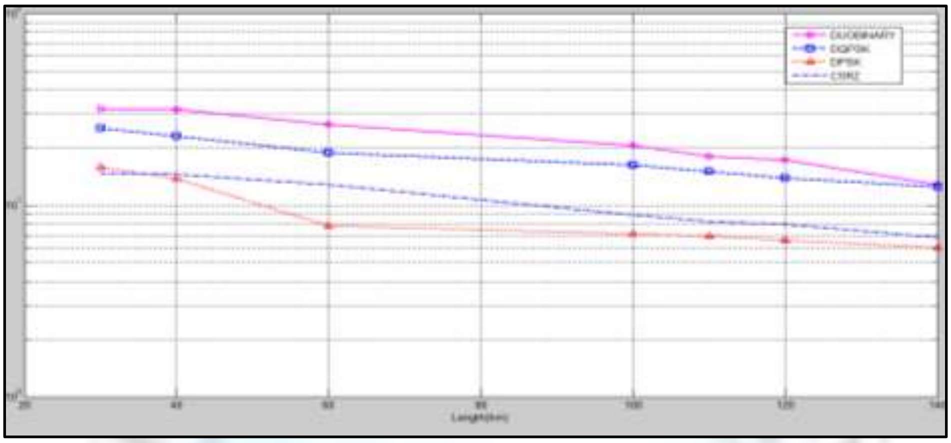

Fig.8. Comparison of different modulation formats in terms of Quality factor at varying optical fiber lengths

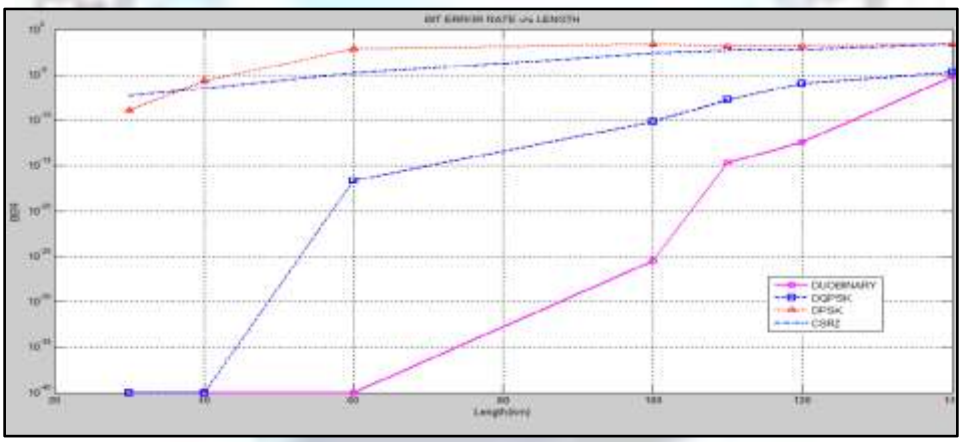

Fig.9. Comparison of different modulation formats in terms of Bit Error Rate at varying optical fiber lengths

Figure 9 represents the comparison of DPSK, DQPSK, CSRZ and Duo-Binary modulation formats in terms of Bit Error Rate at varying optical fiber lengths. The study shows as we increase the fiber length the Bit Error Rate increases. At fiber length 30km the Duo-Binary modulation format gives BER as 0.99 x 10^{-40} whereas in DPSK and DQPSK this value is much larger. In DPSK and DQPSK the values obtained for BER is 0.13 x 10^{-8} and 0.7 x 10^{-10} respectively. Taking a length of 100 km, the Dou-Binary modulation format still gives smallest BER value among all as 0.315 x 10^{-14}. Among all the modulation formats it is found that Duo-Binary modulation scheme has the least BER at all the lengths in the range considered, thus clearly the performance of Duo-Binary modulation format is better in terms of BER on varying optical fiber length.

Conclusion/Results

In this paper the performance of DPSK, DQPSK, CSRZ and Duo-Binary modulation scheme was studied. By investigating the Q-factor and BER on varying lengths it was observed that Duo-Binary modulation scheme provides the best results amongst the four modulation formats. Thus, Duo-Binary modulation scheme enhances the transmission efficiency of the optical communication system. It gives higher values for Q-factor when length is varied and increased up to 140 km. The BER values are also better for Duo-Binary as it shows comparatively smaller value on increased fiber length. Apart from this it was also seen that self phase modulation causes spectral broadening in the output optical power spectrum.

Since the Duo-Binary modulation scheme is concluded to be the best among the four modulation schemes, it can be used for suppressing the Four Wave Mixing (FWM) and Cross Phase Modulation (XPM) non-linearity in the future.

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