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# Effect of different Modulation Formats on DWDM Optical Transmission Systems in the presence of Four Wave Mixing

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**Abstract: This paper simulates Dense Wavelength Division Multiplexed (DWDM) optical transmission system with different modulation schemes that can help in enhancing the system performance by dampening the nonlinearity effect - Four Wave Mixing (FWM). FWM can have vital deleterious effects in the system where it can cause cross talk between different wavelength channels and/or an imbalance in channel power. Here, the analysis of DWDM has been carried out for Carrier Suppressed Return to Zero (CSRZ), Duobinary and Differential Phase Shift Keying (DPSK) modulation formats. The effect of variation in system length, dispersion and bit rate is observed in terms of Q-value and BER. Variation in output FWM power has also been observed in terms of channel spacing and dispersion. It has been observed that Duobinary is the opposite technique to reduce the effect of FWM.**

**Keywords: DWDM, FWM, CSRZ, DPSK.**

## Introduction

Fiber optic communication systems are light wave systems that employ optical fibers for information transmission. Optical communication systems use high carrier frequencies (~100 THz) in the visible or near-infrared region of the electromagnetic spectrum. Optical fiber systems have many advantages over metallic based communication systems such as interference, attenuation, and bandwidth limitations. Fiber optic characteristics can be classified as linear and nonlinear. The terms linear and nonlinear, in optics, mean intensity-independent and intensity-dependent phenomenon respectively. In linear fiber optics, the propagation constant is a function of fiber and the wavelength only. Linear characteristics include attenuation, chromatic dispersion (CD), polarization mode dispersion (PMD), and optical signal-to-noise ratio (OSNR). Nonlinear effects in optical fibers occur due to a change in the refractive index of the medium with optical intensity and inelastic-scattering phenomenon. This intensity dependence of the refractive index is responsible for the Kerr effect. When the optical fiber becomes nonlinear, the pulse propagation gets modified significantly[1]. Also, new frequencies are generated inside the optical fiber. The spectrum of the output signal is not same as that of the input signal. Nonlinear characteristics are influenced by parameters, such as bit rates, channel spacing, and power levels.

Depending upon the type of the input signal, Kerr nonlinearity manifests itself into three different effects namely self phase modulation (SPM), cross phase modulation (XPM), four wave mixing (FWM) [2].At high power levels, inelastic scattering phenomenon includes stimulated effects such as stimulated Raman scattering (SRS), and stimulated Brillouin scattering (SBS).

Four wave mixing (FWM) is a kind of optical parametric process which is analogous to the inter modulation distortion in standard electrical systems. In fiber-optic communication system, when three wavelengths ($\lambda$1, $\lambda$ 2, and $\lambda$ 3) interact in a nonlinear medium, they give rise to a new wavelength ($\lambda$ 4), which is formed by the scattering of the three incident photons, producing the fourth photon [3]. This effect is known as four photon mixing or FWM which affects Wavelength Division

Multiplexed (WDM) systems.

WDM multiplexes a number of signals onto a single optical fiber using different wavelengths. They are divided into two different wavelength patterns namely Conventional WDM, which provides up to 8 channels in the transmission window of around 1550nm in C-Band and Dense WDM, which utilizes same transmission window with denser channel spacing [4]. Channel plans vary typically 40 channels at 100GHz and 80 channels at 50GHz. Four wave mixing ultimately limits this channel density and capacity of Dense WDM systems.

Kaler et al. [5] compared three Modulation formats such as carrier suppressed return-to-zero (CSRZ), duo-binary return-to-zero (DRZ) and modified duo-binary return-to-zero (MDRZ) for different dispersion compensation schemes namely pre-compensation, post-compensation and symmetrical-compensation using Dispersion Compensating Fiber (DCF) by varying signal input power on 16 x 40Gb/s long haul (500-2000Km) DWDM system. The performance of the system was analyzed in terms of received maximum Q value and eye opening using Split Step Fourier transform method. It was reported that MDRZ format with symmetrical compensation is most resilient against dispersion and nonlinearities and is more suitable for transmission distance beyond 1550Km.

Laxman et al. [6] investigated the effect of four wave mixing on Bit Error Rate(BER) in 2 channel wavelength division multiplexed (WDM) optical communication system for Duobinary and binary modulation like NRZ rectangular at different values of dispersion, core effective area of fiber and channel spacing for 100km long optical communication system. It was reported that Duobinary modulation format dominates over binary modulation formats in reducing BER by varying the values of dispersion, core effective area and channel spacing.

Mohit et al. [7] compared the effect of three dispersion compensation technique namely pre-compensation, post-compensation and symmetrical compensation techniques using PDCF (Pumped Dispersion Compensating Fiber) and PSMF (Pumped Single Mode Fiber) for 64 x 20 Gbps DWDM system on Modified Duobinary Return to Zero (MDRZ) format to achieve high capacity. The performance of system was compared for 200GHz, 100GHz and 50GHz channel spacing in terms of Bit Error Rate (BER) and Q-factor. It was reported that 100 GHz channel spacing using symmetrical compensation technique is used to achieve maximum coverage distance with maximum Q-factor and minimum Bit error rate.

Anju et al. [8] compared Non Return to zero (NRZ), Return to zero (RZ) and Duobinary modulation formats for wavelength division multiplexed system operating at data rate of 10Gb/s in terms of jitter or Per delay performance and Bit error rate (BER) at various value of distances from 5Km to 100km. It was reported that out of the three modulation formats Return to zero format is best for long distance optical communication system due to its low value of jitter and BER at bit rates.

Prabhpreet et al. [9] investigated the effect of four wave mixing on 16 channel wavelength division multiplexing for different modulation formats such as Non Return to zero (NRZ), Return to zero (RZ) and Duobinary at various values of dispersion, core effective area and channel spacing. The performance of system was evaluated in terms of four wave mixing power, BER and Q-factor. It was simulated that the effect of four wave mixing decreases with increase in the channel spacing and core effective area of fiber due to decrease in interference between input signals. It was reported that the Duobinary modulation format dominates over binary modulation formats in reducing four wave mixing power, BER as well as increasing Q-factor by varying dispersion from 0 to 4 ps/nm.km, core effective area and channel spacing.

In this paper, the simulation of 3 channel DWDM is carried out on different optical modulation formats such as Duobinary, Carrier Suppressed Return to zero (CSRZ) and Differential Phase Shift Keying (DPSK) in terms of Bit error rate (BER), Q-factor at different lengths of the fiber varying from 0.1Km to 200Km and at different dispersion values varying from 1 ps/Km-nm to 16 ps/Km-nm. Each virtual channel has data speed of 10Gbps. The paper is organized into 4 sections. In section 1, introduction to FWM is explained. In Section 2, optical simulation set-up is described. In Section 3, simulation analysis and results have been compared and discussed for different modulation formats and finally in Section 4, conclusions are summarized.

## Simulation setup

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Figure.1 shows the schematic of simulation setup of a 3 Channel DWDM optical communication system operating at 10Gb/s with the center emission frequency of the first channel= 193.352 THz, center emission frequency of second channel=193.412 THz and center emission frequency of the third channel=193.472 THz. To ensure separation between channels in the frequency domain for crosstalk suppression, the channel spacing of 60GHz is kept. The other simulation parameters and fiber parameters used in the above model are given in Table 1 and Table 2 respectively.

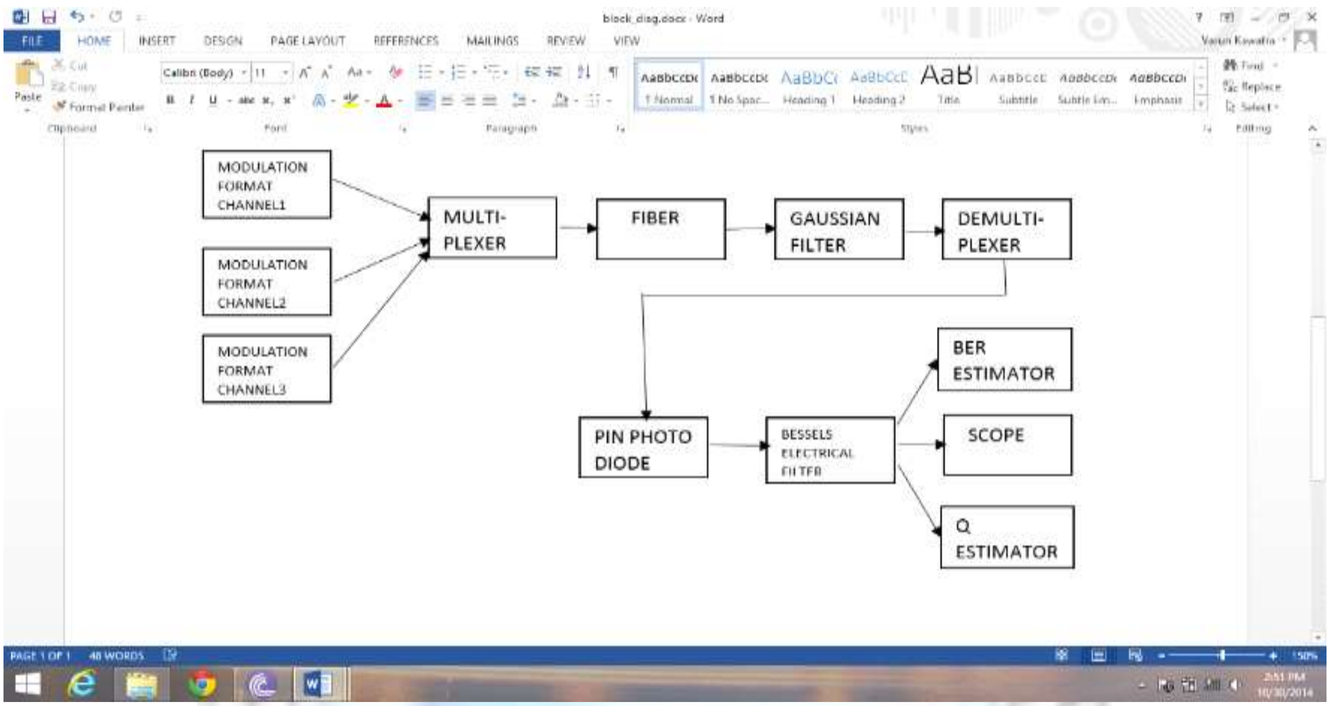


**Fig.1: Simulation setup of 3 Channel DWDM**

**Table 1: Simulation parameters**

| Parameters | Values |
|---|---|
| Frequency operational range | 193.349 – 193.479 THz |
| Bit rate | 10 Gb/s |
| Sample/bit | 13 |
| Input channels used | 3 |
| Channel spacing | 60 GHz |
| Central frequency of first channel | 193.352 THz |
| Capacity | 3 x 10 Gbps |

**Table 2. Fiber parameters**

| Parameter | Values |
|---|---|
| Optical fiber length | 70 Km |
| Attenuation | 0.205 db/Km |
| Dispersion $D$ | 16 ps/Km-nm |
| Dispersion Slope | 0.09 ps/Km-nm$^2$ |
| Effective Core area $A_{eff}$ | 65 μm$^2$ |
| Nonlinear refractive index | 2.5 x $10^{-20}$ m$^2$/w |

This work includes the simulation of 3 channel DWDM system on different modulation formats in terms of system length and dispersion against Q-value and BER. Variation in output power has also been observed in terms of channel spacing and dispersion.

### CSRZ modulation format

Carrier Suppressed Return to zero is an optical modulation format in which the field intensity drops to zero between consecutive bits and the field phase alternates by $\pi$ between neighboring bits, so that if the phase of the signal is 0 in even bits (bit number $2n$), the phase in odd bit slots (bit number $2n+1$) will be $\pi$.

Figure.2 shows the block diagram of CSRZ transmitter. It consists of 3 DWDM channels wherein each channel configuration includes Pseudo-Random Bit sequence (PRBS) generator with bit rate of 10Gbps. The random sequence is then coded by NRZ rectangular driver and modulated with Continuous wave Lorentzian lasers using two Dual-arm Mach-Zehnder modulators. In each channel, the continuous wave lasers with the center emission frequency of the first laser $L_1$ = 193.352 THz, center emission frequency of second laser $L_2$=193.412 THz and center emission frequency of third laser=193.472 is used to create the carrier signal. The output of the modulator goes through the MZ modulator or a phase modulator driven by an analog sine wave generator operating at the frequency equivalent to 5Gbps to obtain carrier suppressed return-to-zero format. As a result of this, a phase shift of $\pi$ is introduced between any two adjacent bits. The output of the 3 channels is then multiplexed using an optical combiner having attenuation on each output = 0.0 dB. The combined optical signal is then fed into a single mode optical fiber. Here, various parameters such as dispersion parameters, attenuation, non-linear refractive index and core area of the fiber are set according to Table 2. The optical signal from the fiber is passed through an optical band pass Gaussian filter with center frequency =193.41449 THz and -3 dB two sided bandwidth of 52GHz. De-multiplexing of the transmitted signals is then carried out using an optical splitter. De-multiplexed optical signals are converted into electrical signals using PIN photodiode with reference wavelength as 1550 nm, quantum efficiency=0.7, -3 dB bandwidth of 40 GHz and dark current of 0.1 nA. After conversion, the electrical signal is fed into an electrical low pass Bessel filter having number of poles =5 and -3 dB bandwidth as 8 GHz and the final output is received. At the output of the receiver, an electrical scope is kept to examine BER and Q-value.

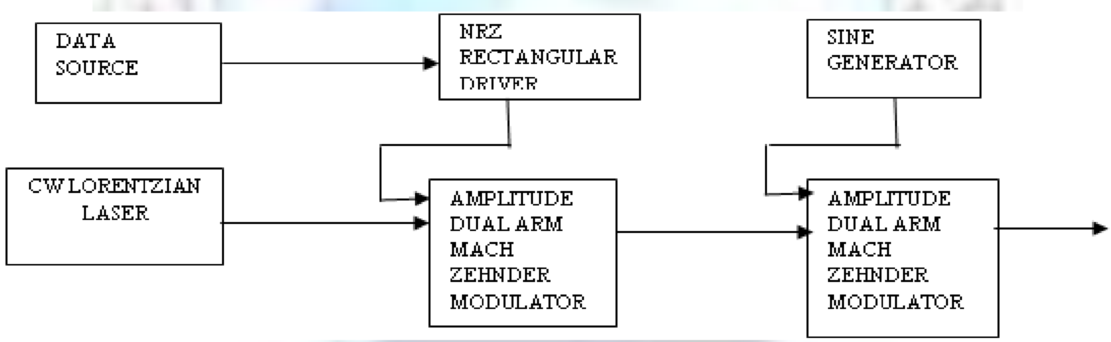


**Fig. 2: Block diagram of CSRZ transmitter**

### Duobinary modulation format

The duobinary format takes advantage of all the three possible amplitude levels: the mark state (represented by the zero level) and the space state (represented by the positive or negative level). Here, the polarities of two successive bits are opposite if the number of in-between bits at the center level is odd; otherwise, no level transition occurs. Duo means doubling the binary capacity by bandwidth compression. This format is intended to increase the data transmission efficiency. Figure.3 shows the schematic of simulation setup for 3 channel DWDM optical communication system using duo-binary modulation format. The transmitter consists of PRBS sequence generator which is fed into two NRZ rectangular drivers, one of them directly and other through a NOT gate. The NOT gate is used to invert the signal. NRZ rectangular driver is the modulator drive. Each of the electrical signals after passing through NRZ rectangular driver is then fed into two separate Bessel filters. Bessel electrical filter is a type of linear filter which preserves the wave shape and has maximally flat group delay. External modulation of three signals, a signal from each filters and a Continuous wave (CW) lorentzian laser is carried out by using amplitude dual arm Mach Zehnder (MZ) modulator. Duo-binary modulation format is hence obtained. The Mach Zehnder modulator has maximum transmissivity, offset voltage of 0.5V & extinction ratio of 20dB. The output of the 3 channels is then multiplexed using an Optical combiner having attenuation on each output = 0.0 dB. The combined optical signal is fed into a single mode optical fiber. Here, various parameters such as dispersion parameters, attenuation, non-linear refractive index and core area of the fiber are set according to Table 2. Optical signal received from fiber is passed through a raised cosine filter, the output of which is then de-multiplexed using splitter. De-multiplexed output is fed into a PIN photodiode for optical to electrical conversion. After conversion, electrical signal obtained is passed through an electrical Bessel filter. The output is received and examined for BER and Q-value using electrical scope.

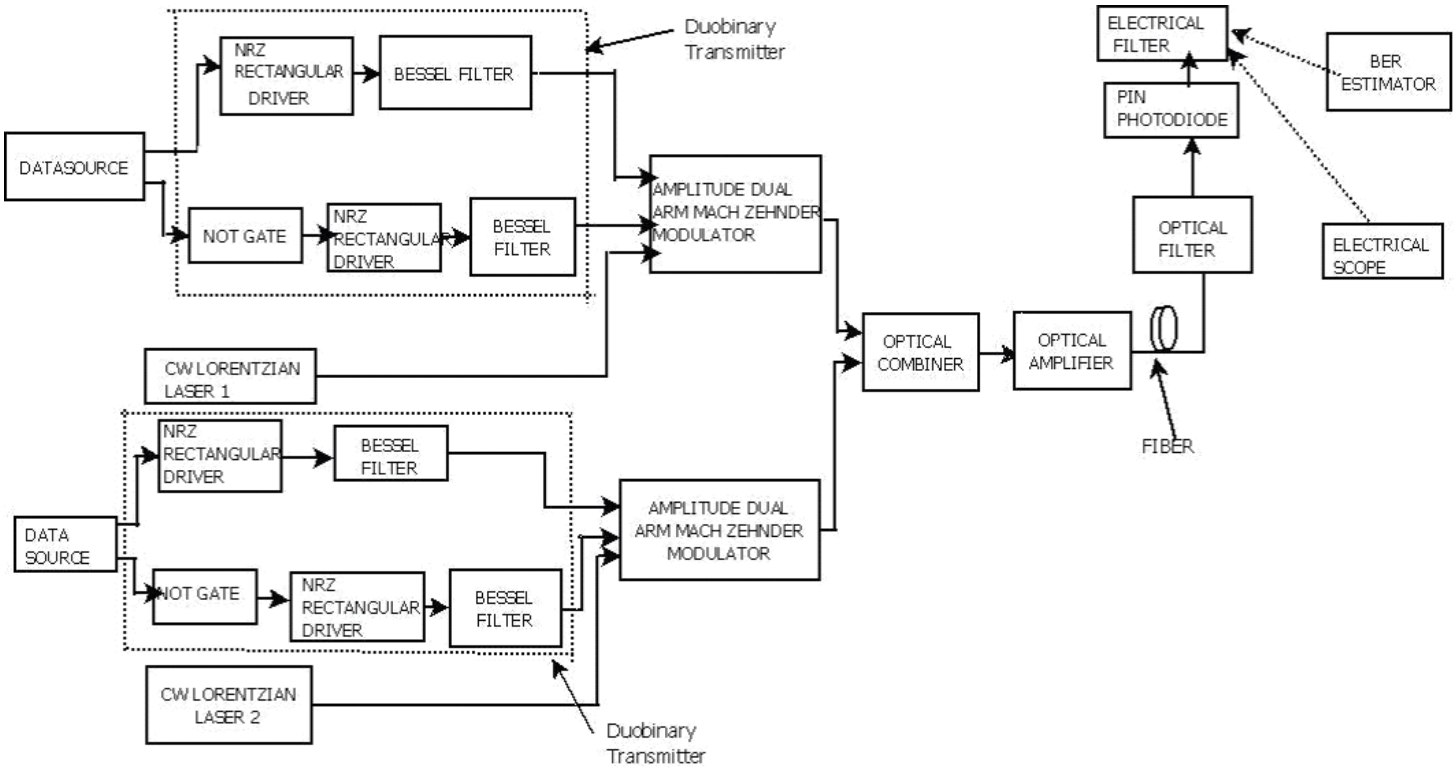


**Fig.3: Block diagram of Duobinary transmitter**

## DPSK Modulation format

Figure.4 shows block diagram of DPSK transmitter for 3 channel DWDM optical communication system The transmitter consists of PRBS sequence generator with bit rate = 10 Gbps. This signal is fed into NRZ Rectangular driver and modulated with CW Lorentzian lasers using unbalanced amplitude modulator. The values for lasers are same as that used in Duo-binary format. The maximum transmissivity voltage of unbalanced modulator is 5V and -3dB bandwidth is 40GHz. The output of the modulator is then multiplexed using an optical combiner having attenuation on each output= 0.0dB. The combined signal is then fed into a single mode optical fiber. Here, various parameters are set according to Table 2. The optical signal from the fiber is then passed through an optical band pass Gaussian filter with center emission frequency = 193.414 THz and -3dB bandwidth of 52GHz. De-multiplexed optical signals are converted into electrical signals using PIN photodiode with reference wavelength as 1550 nm, quantum efficiency= 0.7, 3dB bandwidth of 40GHz and dark current of 0.1nA. After conversion, the electrical signal is fed into an electrical low pass Bessel filter having number of poles= 5 and -3dB bandwidth as 8GHz and the final output is received.

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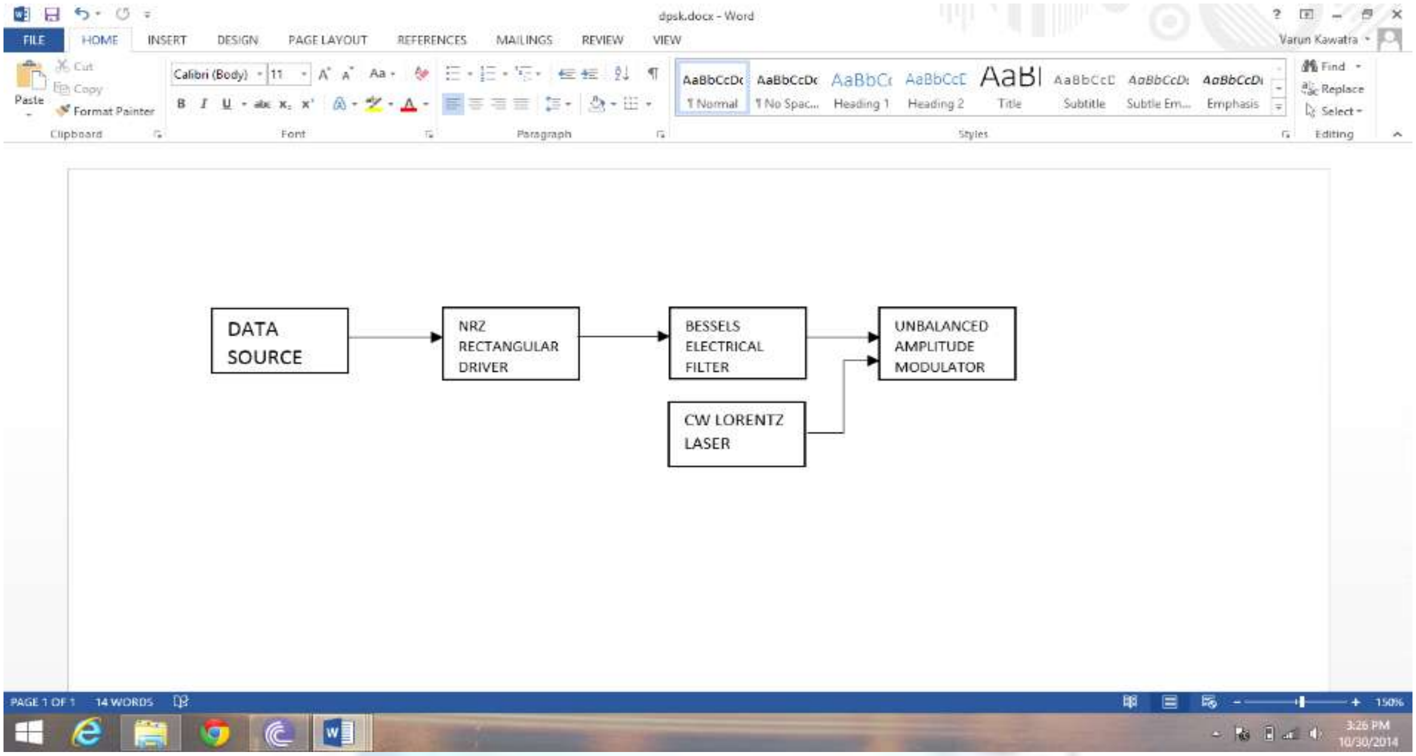


Fig.4: Block diagram of DPSK transmitter

## Results and Discussion

The three modulation formats namely Duobinary, Carrier Suppressed Return to zero (CSRZ) and Differential Phase Shift Keying (DPSK) have been numerically compared in terms of BER, Q-value, channel spacing, power.

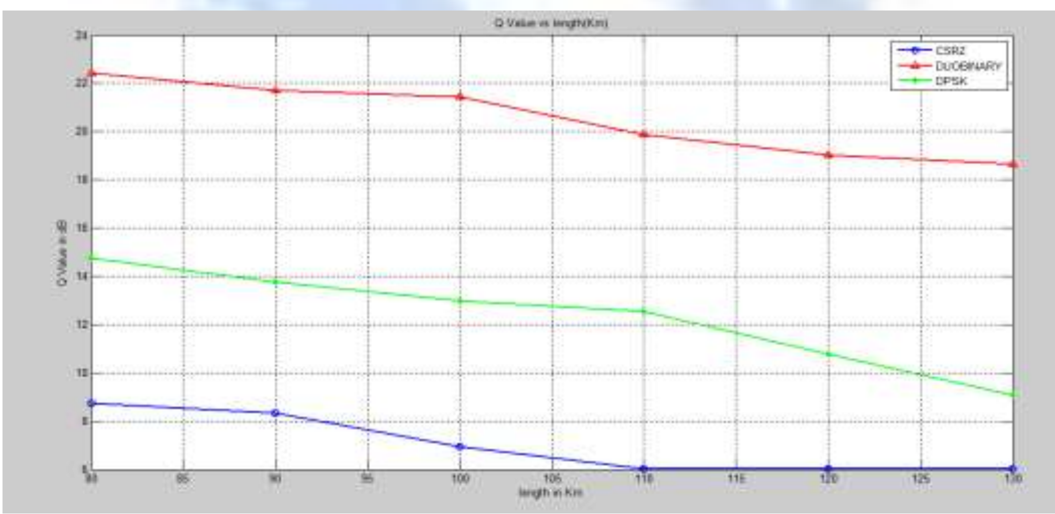


Fig.5: Q-value vs Length for fiber for 3 channel DWDM system

Figure.5 shows the graphical representation of Q-value as a function of length of the fiber which deteriorates as the length of the fiber is varying from 80Km to 130Km for constant dispersion=16ps/Km-nm and core effective area=65 μm$^2$. The variation in Q-value for Duobinary, CSRZ and DPSK are 22.50-18.8dB, 8.7-6.0dB and 14.9-9.2dB respectively. The decrease in Q-value is least for Duobinary modulation format. As the length of the fiber increases, FWM effect also increases, hence Q-value decreases. The Q-value for Duobinary format at 110 Km length is 19.8 dB and that for DPSK and CSRZ is 12.4 dB and 6.2 dB respectively.

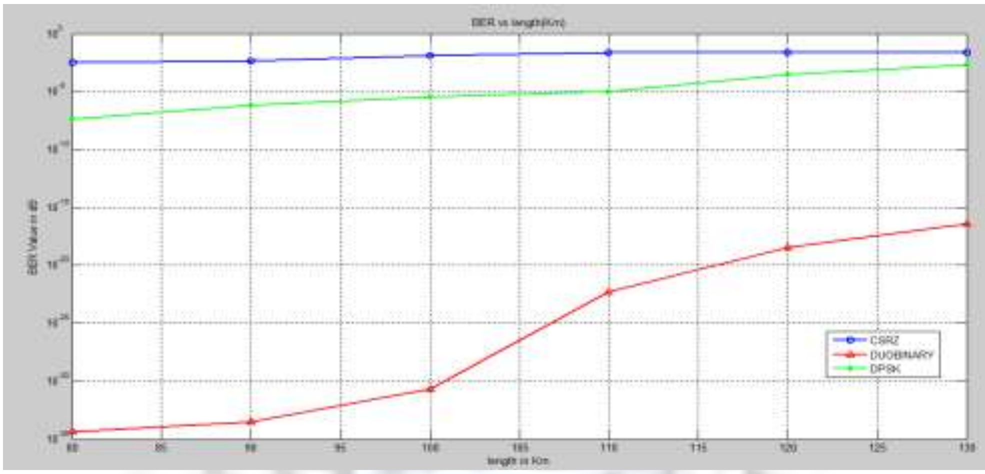


Fig.6: BER vs Length of fiber for 3 channel DWDM system

Figure.6 shows the graphical representation of BER as a function of length of fiber which is varying from 80Km to 130 Km for constant dispersion=16 ps/Km-nm and core effective area=65 $\mu m^2$. When we compare the results, it is concluded that reduction in BER is greater in Duobinary than other modulation formats. As the length of the fiber is increased, so does the FWM effect as it being a nonlinear effect gets accumulated according to the length of the medium. Hence BER increases. The value of BER for Duobinary, DPSK and CSRZ at 110 Km length is $10^{-23}$ dB, $10^{-5}$ dB and $10^{-2}$ dB respectively.

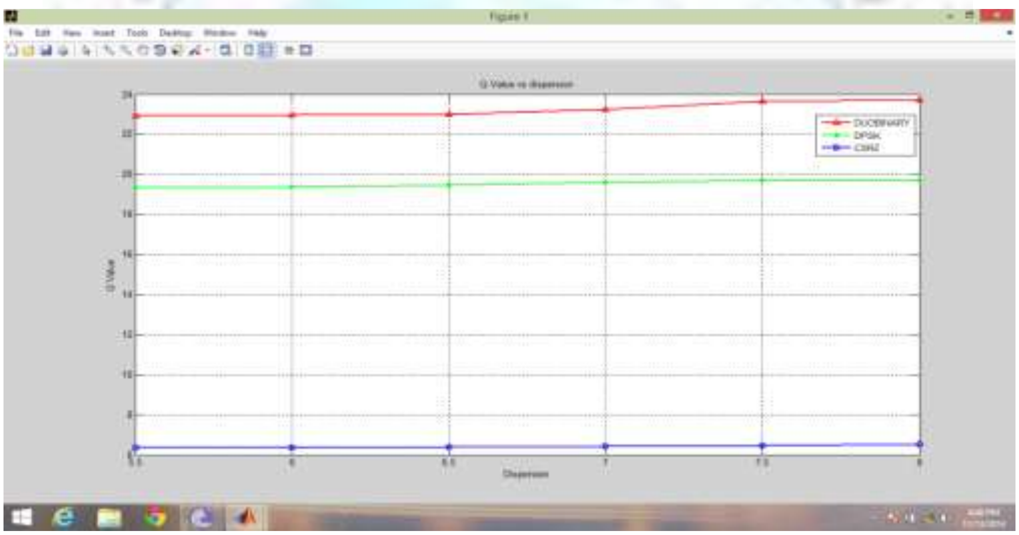


Fig.7. Q-value vs dispersion for 3 channel DWDM system

Figure.7 shows the graphical representation of Q-value as a function of dispersion which is increasing as the dispersion is varying from 5.5ps/Km-nm to 8ps/Km-nm for constant length=0.8Km.The variation in Q-value for Duobinary, CSRZ and DPSK are 23dB to 23.8dB, 6.3dB to 6.8dB and 19.2dB to19.8dB respectively. The increase in Q-value is greatest for Duobinary modulation format. Increasing dispersion leads to spreading of signal in frequency and time domain and hence there will be overlapping of different signal in and out of phase alternatively. This leads to dampening in FWM effects, hence Q-value increases. The Q-value of Duobinary at dispersion =7 ps/Km-nm is 23.4dB and that for DPSK and CSRZ are 19.5dB and 6.4dB respectively.

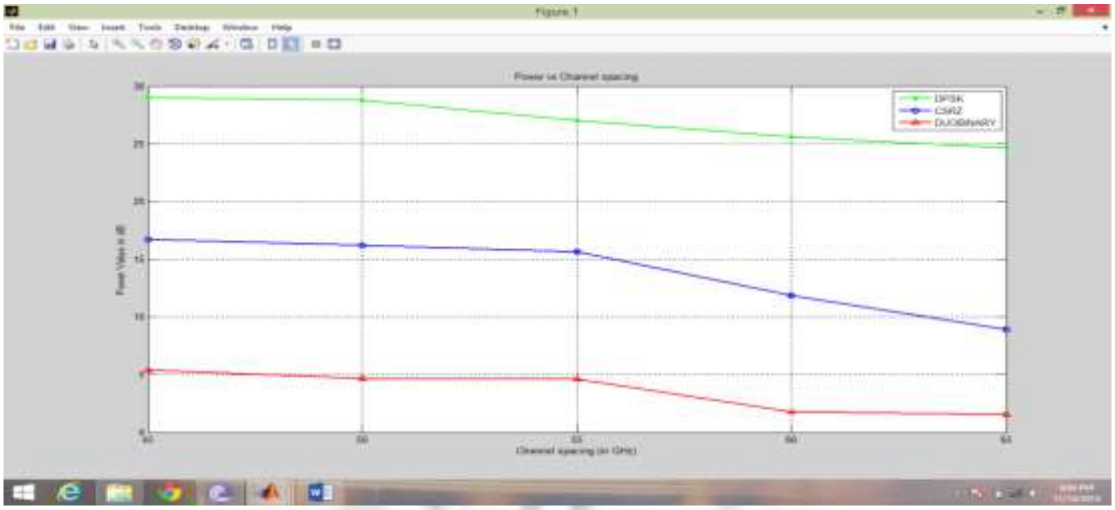


Fig.8. power vs channel spacing for 3 channel DWDM system

Figure.8 shows the graphical representation of variation in output FWM power as a function of channel spacing which is decreasing as the channel spacing is varying from 45-65GHz in uniform spacing of 5GHz. The variation in output power for Duobinary, DPSK and CSRZ are 5.411dBm to 1.583dBm, 28.9dBm to 24.63dBm and 16.70dBm to 8.88dBm respectively. As the channel spacing increases, the interference between the interfering signals will be less. Thus it leads to less FWM output power. Duobinary modulation format provides better output power which is equivalent to 4.8dBm and 2.1dBm at 55GHz and 60GHz channel spacing and that of DPSK and CSRZ are 27.3dBm, 25.9dBm and 16.6dBm, 12.4dBm respectively.

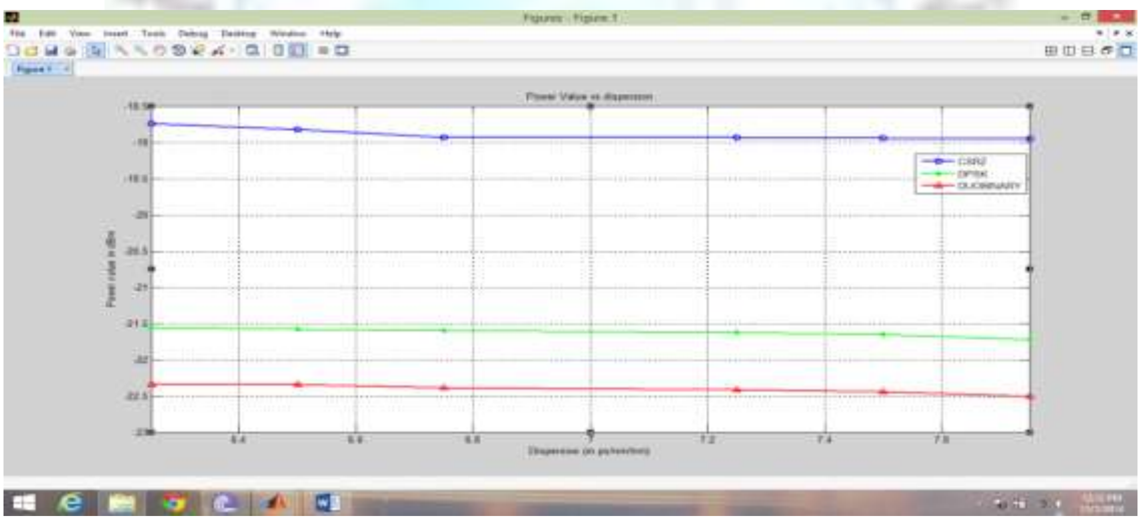


Fig.9. power vs dispersion for 3 channel DWDM system

Figure.9 shows the graphical representation of variation in output FWM power as a function of dispersion which is decreasing as the dispersion is varying from 6.2ps/Km-nm to 7.8ps/Km-nm. The variation in output power is about -22.3dBm to -22.5dBm in case of Duo-binary and that in DPSK and CSRZ are -21.6dBm to -21.55dBm and -18.7 to -18.9dBm respectively. The output FWM power is least in case of Duobinary with increasing dispersion. When dispersion is zero, then all the interfering signal travels with same group velocity so FWM effect is reinforced. On the other hand, when dispersion is present different signals travel with different group velocities, thus the different waves alternatively overlap in and out of phase and the net FWM effect is less. Therefore, it leads to reduction in FWM power when dispersion is increased. The output FWM power in case of Duobinary for dispersion=7ps/Km-nm is -22.4dBm and that of DPSK and CSRZ are -21.6dBm and -18.9 respectively.

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## Conclusions

In this paper, performance of 3 channel DWDM system is investigated for different modulation formats such CSRZ, Duobinary and DPSK. It is concluded that the use of duobinary modulation scheme can significantly reduce the level of FWM. From the obtained results, it has been noticed that the reduction in Q-value is least for Duobinary as a function of the length of fiber which is about 7.4dB and 13.6dB less than that of DPSK and CSRZ respectively. It is concluded that the reduction in Bit error rate as a function of the length of fiber is more for Duobinary which is about $10^{-18}$dB and $10^{-21}$dB times more than that of DPSK and CSRZ respectively. Also, the increase in Q-value is maximum in case of Duobinary which is about 3.9dB and 18.0dB more than that of DPSK and CSRZ respectively at dispersion=7ps/Km-nm. The results also show that with increasing channel spacing, output FWM power decreases. This decrease is more in case of Duobinary which is about 22.5dBm and 11.8dBm as compared to DPSK and CSRZ respectively at channel spacing of 55GHz. Moreover, Duobinary shows less FWM output power which is about -0.8dBm and -3.2dBm less than that of DPSK AND CSRZ respectively at dispersion=7ps/Km-nm.

## References

[1]. S. P. Singh, N. Singh, 2007, Nonlinear effects in optical fibers: origin, management and applications.
[2]. Nazmi A. Mohammad, Mahmoud M.Ragab, Moustafa H.Aly, IJEST 2012, Four-wave mixing based wavelength Conversion using different types of fibers.
[3]. Agarwal GP, 2001, Nonlinear Fiber Optics, 3rd Ed., Academic press, San Diego, CA.
[4]. Aloisio.A, Ameli.F. , D'Amico.A., Giordano, R., Giovanetti, G. Izzo, V.,IEEE 2012, Performance Analysis of a DWDM Optical Transmission System.
[5]. R.S Kaler, Anu sheetal, Ajay K. Sharma,Elsevier Optik 2008,Simulation of high capacity 40Gb/s long haul DWDM system with different modulation formats and dispersion compensation Scheme in the presence of Kerr's effect.
[6]. Laxman Tawade, Shantanu Jagdale, Premanand Kadbe, Shankar Deosarkar, IJDPS 2010, Investigation of FWM on BER in WDM Optical communication system with binary and Duo-binary modulation format.
[7]. Mohit Thakur, Harminder Kaur, IJEST 2014, High capacity DWDM system using PDCF & PSMF and simulation of design for different channel spacing.
[8]. Anju Phogat, Tarun Gulati, Deepak Malik, IJLTET 2013, Q-Factor and Jitter performance in WDMsystems using RZ, NRZ and Duo binary modulation formats at different distances.
[9]. Prabhpreet Kaur, Kulwinder Singh, IJERA 2014, Investigation of four wave mixing effects using different modulation formats in optical communication system.