RESEARCH ARTICLE OPEN ACCESS

Investigation of Fiber Non Linearity for Different Modulation Schemes in DWDM Networks

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ABSTRACT

Nonlinear effects in optical fibers have become an area of academic research and of great importance in the optical fiber based systems. The employment of high bit rate multi wavelength systems together with optical amplifiers creates major nonlinear effects such as SRS, SBS, SPM, XPM and FWM in Dense Wavelength Multiplexing Division (DWDM) systems. Presence of these nonlinear effects in the optical fiber communication adversely effect the communication. Here we have investigated the Stimulated Raman effects (SR) and Stimulated Brillouin effects (SB) and Four Wave Mixing (FWM). We have designed and stimulated and analyzed the results using BER and Q factor for different data rates, distance, modulation formats and for different receivers.

Keywords:- Stimulated Raman effects (SR), Stimulated Brillouin effects (SB), Four Wave Mixing (FWM).

I. INTRODUCTION

In some circumstances, the nonlinearity could counteract with the dispersion. In addition, when multiple channels are considered, the fiber nonlinearity results in interactions among channels. These nonlinear effects can be managed through proper system design. By increasing information spectral efficiency, which can be done by increasing channel bit rate, decreasing channel spacing or the combination of both, the effects of fiber non linearity come to play even more decisive role.

Fundamental investigations have demonstrated the usefulness of Standard Monomode Fiber (SMF) for transmission of bit rate higher than 10 Gb/s over a single channel [1]. In the last few years, both dispersion and optical Kerr's effects [2-4] have been studied together creating path ways to techniques called dispersion management techniques. The combined use of SPM and joint optimization of the bias and modulation voltages to increase the dispersion limited transmission distance at 10Gb/s was reported as high-speed transmission over SMF at

1.55μm suffers severely from the combined interaction of Kerr nonlinearity and dispersion. Several techniques have been developed to overcome these limitations[5]. The use of dispersion compensating fibers (DCF) has emerged as one of the most practical techniques to compensate for the chromatic dispersion in long-haul optically amplified standard fiber transmission systems.[6]

II. FIBER NONLINEARITIES

Even though optical networks are fast, robust, and error free, still nonlinearity exist. The nonlinear effects of the fibers play a detrimental role in the light propagation. Nonlinear Kerr effect is the dependence of the refractive index of the fiber on the power that propagating through it. This effect is responsible for self phase modulation (SPM), cross phase modulation (XPM) and four wave mixing (FWM). The other two important effects are stimulated Brillouin scattering (SBS) and stimulated Raman scattering (SRS).

2.1 Four Wave Mixing

FWM is a phenomenon that occurs in the case of DWDM systems in which the wavelength channel spacing are very close to each other. This effect is generated by the third order distortion that creates third order harmonics. In fact, these spurious signals fall right on the original wavelength which results in difficulty in filtering them out. In case of 3 channel system, there will be 9 cross products, where 3 of them will be on the original wavelength. This is caused by the channel spacing and fiber dispersion. If the channel spacing is too close, then FWM occurs. If the dispersion is lesser, then FWM is higher since dispersion is inversely proportional to mixing efficiency. In general, for N wavelengths input channel there will be M cross mixing products and are given by

$$M = \frac{N^2}{2}(N-1)$$

If the WDM system is considered as a sum of N monochromatic plane waves, it is possible to solve the arising channels angular frequencies. Considering a simple three-wavelength λ_1, λ_2, λ_3 system that is experiencing FWM distortion, nine cross products are generated near λ_1, λ_2, and λ_3 see Fig 1. that involve two or more of the original wavelengths. There are additional products generated, however they fall well away from the original input wavelengths.

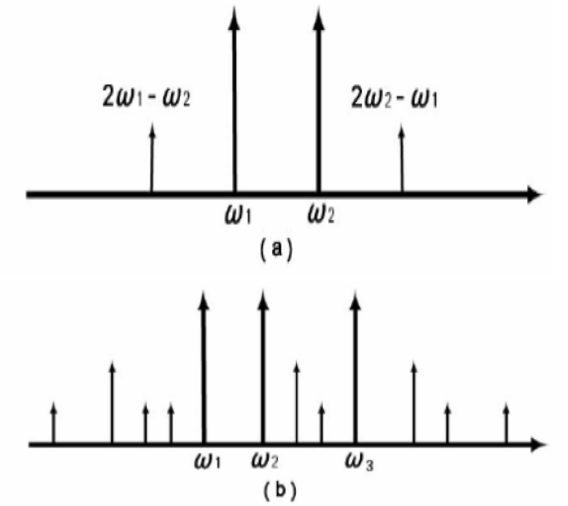


Figure 1 (a) two input signals 1 and 2 (b) three input signals 1, 2 and 3 and the arising new frequency components due to FWM

Assuming that the input wavelengths are λ_1 =1551.72nm, λ_2= 1552.52 nm and λ_3=1553.32nm The interfering wavelengths generated around the original three wavelength system are :

$$\lambda_1 + \lambda_2 - \lambda_3 = 1550.92 \text{ nm}$$

$$\lambda_1 - \lambda_2 + \lambda_3 = 1552.52 \text{ nm}$$

$$\lambda_2 + \lambda_3 \lambda_1 = 1554.12 \text{ nm}$$

$$\lambda_1 - \lambda_2 + \lambda_3 = 1552.52 \text{ nm}$$

$$2\lambda_1 - \lambda_3 = 1550.12 \text{ nm}$$

$$2\lambda_3 - \lambda_1 = 1554.92 \text{ nm}$$

$$\lambda_2 + \lambda_3 - \lambda_1 = 1554.12 \text{ nm}$$

$$2\lambda_2 - \lambda_1 = 1553.32 \text{ nm}$$

$$2\lambda_3 - \lambda_2 = 1554.12 \text{ nm}$$

The Figure 1 also shows the magnitude of FWM mixing efficiency versus fiber dispersion and channel spacing. If a system design uses NDSF with dispersion of 17 ps/nm/km and the minimum recommended International Telecommunication Union (ITU) DWDM spacing of 0.8 nm, then the mixing efficiency is about -48 dB and will have little impact. On the other hand, if a system design uses DSF with a dispersion of 1 ps/nm/km and a non-standard spacing of 0.4 nm, then the mixing efficiency becomes -12 dB and will have a severe impact on the system performance, perhaps, making the recovery of the transmitted signal impossible. The magnitude of the mixing efficiency will vary widely as these parameters vary.

It can be seen that three of the interfering products fall right on top of the original three signals and the remaining six products fall outside of the original three signals. These six wavelengths can be optically filtered out. The three interfering products that fall on top of the original signals are mixed together; and cannot be removed by any means. Figure 3.2 shows the results graphically. The three tall solid bars are the three original signals. The shorter cross-hatched bars represent the nine interfering products.

Therefore two factors strongly influence the magnitude of the FWM products, referred to as the FWM efficiency. The first factor is the channel spacing; where the mixing efficiency increases dramatically as the channel spacing becomes closer. Fiber dispersion is the second factor, and the mixing efficiency is inversely proportional to the fiber dispersion, being strongest at the zero-dispersion point. In all cases, the FWM mixing efficiency is expressed in dB, and more negative values are better since they indicate a lower mixing efficiency.

FWM is independent of the used bit rate; however, it is critically dependent on channel spacing and chromatic dispersion. Therefore, the effects of FWM must be considered even at moderate-bit-rate systems, if the channel spacing is small or the chromatic dispersion of the fiber is low. Thus, it is possible to minimize the effects of FWM by increasing the channel spacing and the chromatic dispersion of the fiber.

2.2 Stimulated Brillouin Scattering (SBS)

SBS falls under the category of inelastic scattering in which the frequency of the scattered light is shifted downward. This results in the loss of the transmitted power along the fiber. At low power levels, this effect will become negligible. SBS sets a threshold on the transmitted power, above which considerable amount of power is reflected. This back reflection will make the light to reverse direction and travel towards the source. This usually happens at the connector interfaces where there is a change in the refractive index. As the power level increases, more light is backscattered since the level would have crossed the SBS threshold. The parameters which decide the threshold are the wavelength and the line width of the transmitter.

Lower line width experiences lesser SBS and the increase in the spectral width of the source will reduce SBS. In the case of bit streams with shorter pulse width, no SBS will occur. The value of the threshold depends on the RZ and NRZ waveforms, which are used to modulate the source. It is typically 5 mW and can be increased to 10 mW by increasing the bandwidth of the carrier greater than 200 MHz by phase modulation.

2.3 Stimulated Raman Scattering (SRS)

SRS occurs when the pump power increases beyond the threshold, however SRS can happen in either direction, forward and backward. The molecular oscillations set in at the beat frequency and the amplitude of the scattering increases with the oscillations. The equations that govern the feedback process are

$$\frac{dI_p}{dz} = -g_R I_p I_s - \alpha_p I_p$$

$$\frac{dI_s}{dz} = -g_R I_p I_s - \alpha_s I_s$$

Where g_R is the SRS gain.I_p and Is are intensities of Pump and stokes field. In case of the threshold power, the P_{th} is given by

$$P_{th} = 16\alpha(\pi w^2)/g_R.$$

Where πw^2 is the effective area of the fiber core and w is the spot size.

Even though there are some detrimental effects posed by these two effects, SBS and SRS can also be used in a positive way. Since both deal with transferring energy to the signal from a pump, they can be used to amplify the optical signal. Raman gain is also used in compensating losses in the fiber transmission.

III. SIMULATION DESIGN

Total transmission capacity can be enhanced by increasing the number of multiplexed WDM channels. This can be carried out by reducing channel spacing. We know that for WDM transmission channel spacing between two adjacent channel for 10Gbps should not be less than 37.5 GHz .

Figure 2a. shows the first simulation is carried out for binary modulation format to determine variation in BER with channel spacing between adjacent channels for constant dispersion=17 ps/nm/km and core effective area =80µm. The variation in BER with channel spacing for binary and duobinary modulation is shown binary modulation format are $0.267e^{-04}$ and $0.539e^{-05}$ respectively. We have taken 0.35 nm as channel spacing between adjacent channels to get better eye diagram and less

BER which plays an important role to improve WDM system performance.

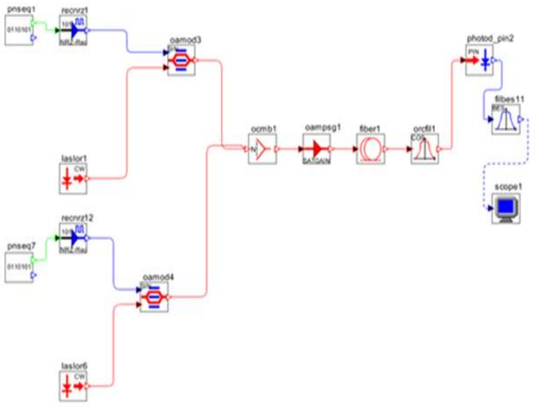


Figure 2a Simulation setup for Binary Modulation

The second simulation is conducted for duobinary modulation format in order to investigate the variation in BER with channel spacing for constant dispersion = 17 ps/nm/km & variable core effective area 80µm variation in BER with channel spacing for different core effective area & for constant dispersion =17ps/nm/km is shown. It is observed that at 0.1nm & 0.2nm channel spacing the BER is constant for all core effective area. There is variation in BER for all core effective area after 0.2nm channel spacing. In figure.2b it is observed that BER reduces with the increase in core effective area. In eye diagrams with BER are shown for all core effective area at 0.35nm channel spacing for duobinary & binary..

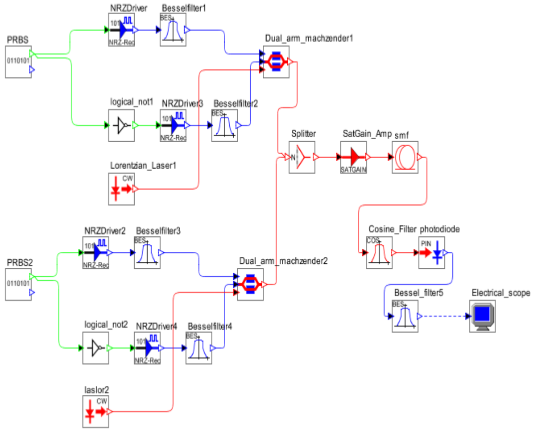


Fig. 2b. Simulation setup for Duobinary Modulation

Of course it is found that the reduction in BER is more in Duobinary modulation than binary modulation. The minimum BER value for duobinary modulation is 1E-40. It is clear that the minimum BER value for binary modulation is maximum BER value for duobinary modulation. I The nature of optical spectrum after 100km fiber for different dispersion value & core effective value & constant channel spacing 0.35nm is shown. In fig 2 it is clear that for minimum dispersion value & minimum core effective area the FWM effect is great & whatever FWM products are formed having large power. When we increase dispersion value and core effective area then there is decrement in power of FWM product. It is also observed that BER is more reduced by using duobinary modulation as compared to binary modulation. Table1 Shows the parameters used for DWDM network

Parameters Used for Design

Component	Parameter Type	Value
PRBS Generator	Up/Down stream Bit Rate (Gbps)	2.5, 5, 10
Electrical Generator	Rise time/Fall time	0.05 bit
Laser Source	Wavelength(nm)	1550
	Power	3dBm
Mach Zehnder Modulator	Modulation Format	NRZ
Optical Fiber	Distance	100 km
	Attenuation Loss	0.2 dB/km
	Dispersion	17ps/nm/km
Amplifier	Power	7 dBm

Table1. Parameters Used for Design

IV. RESULTS AND DISCUSSIONS

Stimulated Raman Scattering(Duobinary modulation) for PIN receivers

Table.2. SRS Duobinary for PIN diode

parameter	Data Rate Gbps/ Distance	25km	50km	100km
BER	2.5	4.665e-09	8.112e-09	1.6019e-9
Q-Factor		19.545	17.425	13.214
BER	5	1.009e-09	8.112e-09	2.345e-09
Q-Factor		17.0482	17.425	8.9338
BER	10	4.678e-09	7.809e-09	2.289e-09
Q-Factor		14.54508	10.3625	6.7742

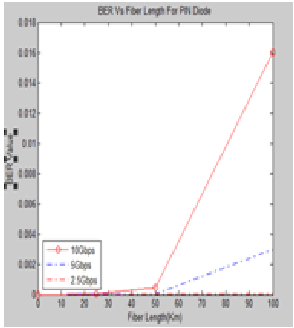


Fig. 3a BER vs Fiber Length

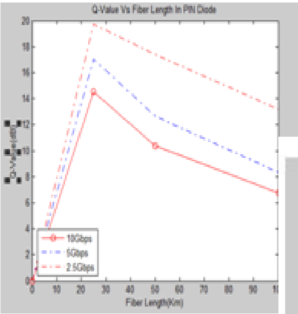


Fig. 3b Q Factor vs Fiber Length

Stimulated Raman Scattering(Duobinary modulation) for APD receivers

Parameter	Data Rate Gbps/ Distance	25km	50km	100km
BER	2.5	2.448e-09	6.708e-09	3.299e-9
Q-Factor		13.193	17.38	19.74
BER	5	1.879e-09	7.279e-09	9.045e-10
Q-Factor		8.9377	12.615	16.981
BER	10	4.678e-09	4.0709e-09	1.889e-09
Q-Factor		6.66007	10.3776	14.523

Table 3 SRS Duobinary for APD diode

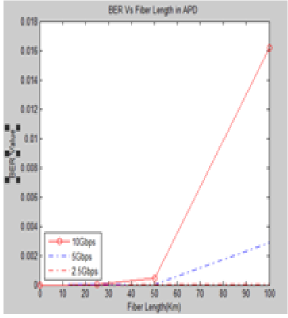


Fig. 4.a BER vs Fiber Length

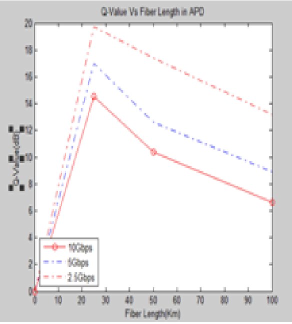


Fig. 4.b Q Factor vs Fiber length

Stimulated Raman Scattering(Binary modulation) for PIN receivers

parameter	Data Rate Gbps/ Distance	25km	50km	100km
BER	2.5	7.548e-09	5.02001e-09	8.3456e-9
Q-Factor		24.91081	17.2943	19.64602
BER	5	3.80067e-09	1.9956e-09	2.6687e-10
Q-Factor		18.8927	15.9165	12.0612
BER	10	1.1875e-09	9.2344e-09	0.00289e-09
Q-Factor		0.00409	16.5453	11.1982

Table 4 SRS Binary for PIN diode

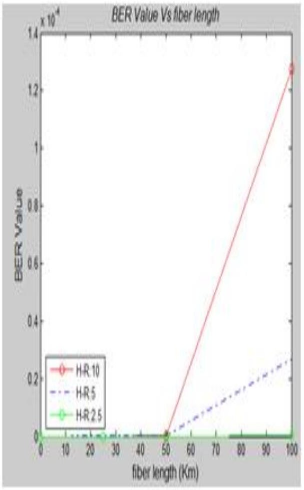


Fig. 5a. BER vs Fiber Length

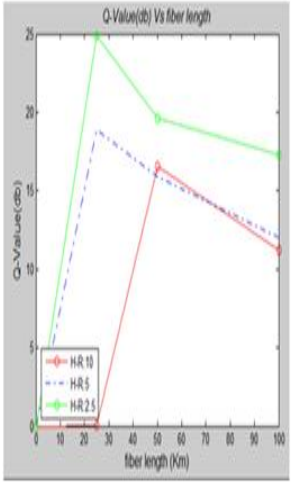
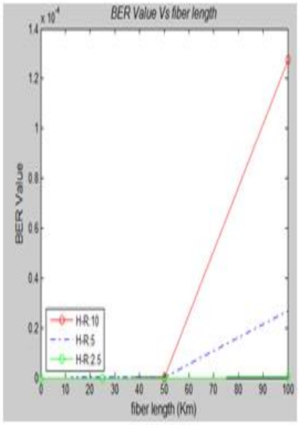


Fig.5b Q Factor vs Fiber Length

Stimulated Raman Scattering(Binary modulation) for APD receivers

parameter	Data Rate Gbps/ Distance	25km	50km	100km
BER	2.5	7.548e-09	5.02001e-09	8.3456e-9
Q-Factor		24.91081	17.2943	19.64602
BER	5	3.80067e-09	1.9956e-09	2.6687e-10
Q-Factor		18.8927	15.9165	12.0612
BER	10	1.1875e-09	9.2344e-09	0.00289e-09
Q-Factor		0.00409	16.5453	11.1982

Table 5 SRS Binary for APD diode



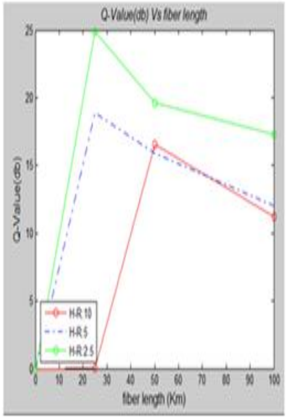
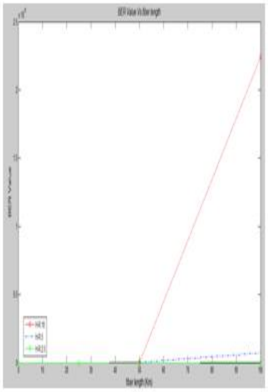


Fig. 6a BER vs Fiber Length   Fig 6 b. Q Factor vs Fiber Length

Stimulated Brillouin Scattering (Duobinary modulation) For PIN Receivers



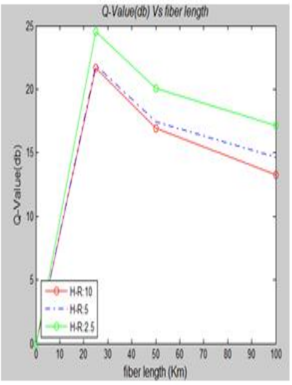
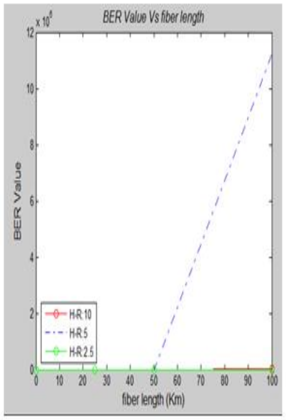


Fig.7a BER vs Fiber Length   Fig.7b Q Factor vs Fiber Length

SBA for APD Receivers (Duobinary modulation)



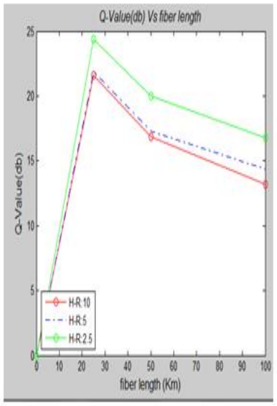
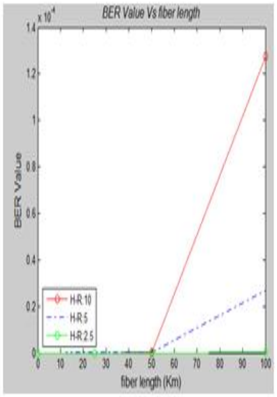


Fig. 8aBER vs Fiber Length   Fig8b Q Factor vs Fiber Length

Stimulated Brillouin Scattering For PIN receivers (Binary modulation)



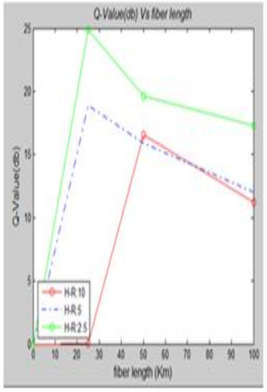
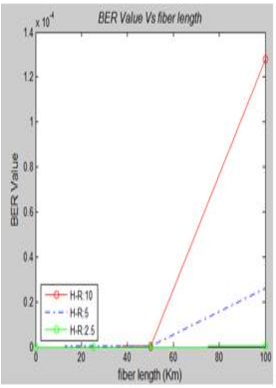


Fig. 9aBER vs Fiber Length Fig.9b Q Factor vs Fiber Length

SBS For APD Diode (Binary modulation):



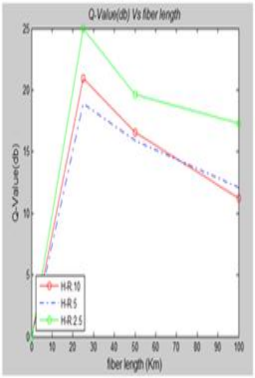
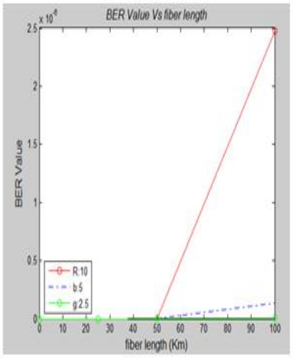


Fig. 10a BER vs Fiber Length   Fig.10b Q Factor vs Fiber Length

V. FOUR WAVE MIXING

FWM For PIN Receivers (Duobinary Modulation):



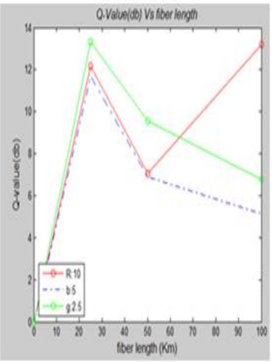
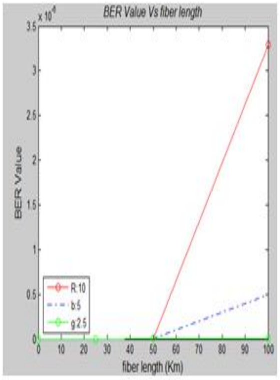


Fig. 11aBER vs Fiber Length Fig.11b BER vs Fiber Length

FWM For APD Receivers (Duobinary Modulation):



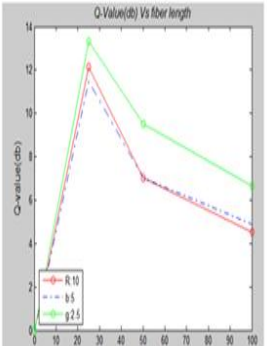
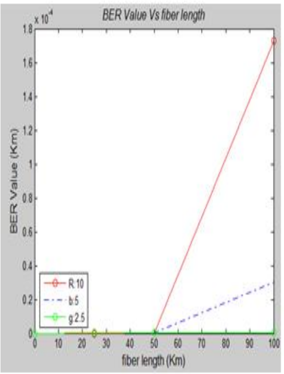


Fig.12a BER vs Fiber Length Fig.12b Q Factor vs Fiber Length

For PIN Diode(Four Wave Mixing)

Four-Wave-Mixing : Binary Modulation(PIN)



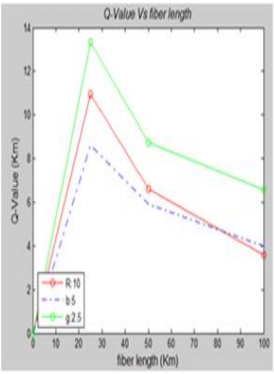
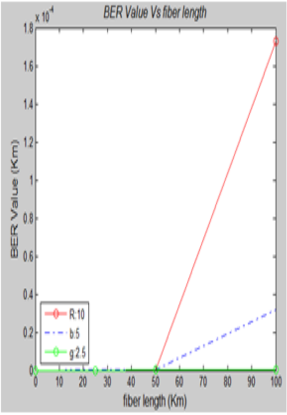


Fig. 13a BER vs Fiber Length Fig.13b BER vs Fiber Length

For APD Diode(Four Wave Mixing)



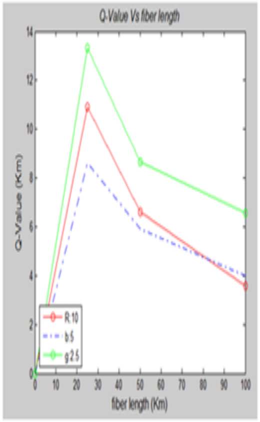


Fig. 14a BER vs Fiber Length Fig.14b BER vs Fiber Length

VI. CONCLUSION

In WDM optical communication system using optsim , this simulation provides verification that the use of a duobinary encoding scheme can reduce significantly of the NON-LINEAR EFFECTS. The reduction in BER is more for Duobinary modulation than binary modulation with channel spacing for constant dispersion value=17ps/nm/km & constant core effective area =80µm.second thing which is observed is that the reduction in BER is more for duobinary modulation for variable core effective area & constant dispersion value=17ps/nm/km. Further BER is reduced by decreasing fiber length. Thus duobinary becomes a very attractive encoding method. Using Optical spectrum analyzer we had shown the different frequencies at different power levels.

VII. FUTURE WORK.

The above project can be extended in future for studying the non linear effects using DWDM networks with reduced cannel spacing.. It can also be extended for coherent detection of receivers using advanced modulation formats. It can also be investigated under long reach WDM networks.

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