EVALUATE THE PERFORMANCE OF WSK-DWDM TRANSMISSION SYSTEM WITH THE COMBINED EFFECT OF CROSS-PHASE MODULATION AND STIMULATED RAMAN SCATTERING

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ABSTRACT

Dense wavelength division multiplexing (DWDM) is a technology that puts data from different sources together on an optical fiber, with each signal carried at the same time on its own separate light wavelength. Due to the feature of constant light intensity, the WSK modulation is used to reduce the unwanted cross gain modulation in a semiconductor optical amplifier and the four-wave mixing in a WDM system . This paper continues the analyses considering the combined influence of Cross Phase Modulation (XPM) and Stimulated Raman Scattering (SRS) with direct detection binary WSK receiver. The performance results are evaluated in terms of Signal to Noise Ratio (SNR) and Bit Error Rate (BER) by changing system parameters considering Single Mode Fiber (SMF) and Dispersion Shifted Fiber (DSF) at a bit rate of 10 Gb/s and above. It is noticed that the system performance degrades with power penalty where we found that the maximum amount of power penalty for 32 channels at 10^{-9} *BER is -36.95 dB for channel spacing 80 GHz and the length of the fiber of 120 Km and for 16 channels power penalty is -40 dB and -50.46 dB is for 8 channels.*

Keywords: *Wavelength Shift Keying (WSK), Dense Wavelength Division Multiplexing (DWDM), Stimulated Raman Scattering (SRS), Fiber nonlinearities.*

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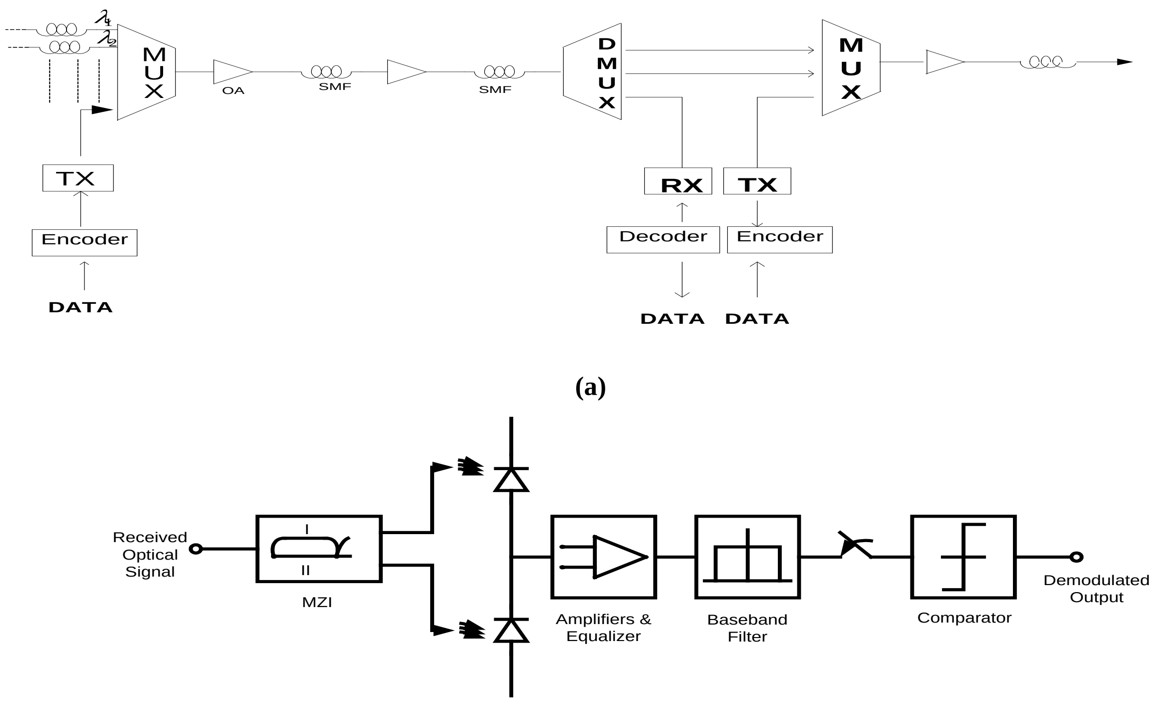
I. INTRODUCTION

In fiber-optic communications, wavelength-division multiplexing (WDM) is a technology which multiplexes a number of optical carrier signals onto a single optical fiber by using different wavelengths (colours) of laser light[1]. This technique enables bidirectional communications over one strand of fiber, as well as multiplication of capacity [2-3]. The WDM is commonly applied to an optical carrier (which is typically described by its wavelength), whereas frequency-division multiplexing typically applies to a radio carrier (which is more often described by frequency). Since wavelength and frequency are tied together through a simple directly inverse relationship, the two terms actually describe the same concept [4]. DWDM is an important technology in nowadays fiber optic network. DWDM and CWDM both use WDM technology to arrange several fiber optic lights to transmit simultaneously via the same single fiber optic cable, but DWDM carry more fiber channel compared with CWDM (Coarse Wavelength Division Multiplexing) [5-7]. DWDM is usually used a multiplexer at the transmitter to join the signals together, and a demultiplexer at the receiver to split them apart. With the right type of fiber it is possible to have a device that does both simultaneously, and can function as an optical add-drop multiplexer. The optical filtering devices used have traditionally been etalons, stable solid-state single-frequency Fabry–Pérot interferometers in the form of thin-film-coated optical glass.

Dense Wavelength Division Multiplexing (DWDM) allows information at various channels to be transmitted in different wavelength with its huge channel capacity and link distance [8]. But the phenomenon like dispersion, self-phase modulation (SPM), cross-phase modulation (XPM) and four wave mixing (FWM) impose limitations on the communication range, number of channels, bit error rate and the performance[9]. Stimulated Raman Scattering (SRS) and Cross-phase modulation (XPM) is a non-linear phase effect due to optical pulses in neighboring channels in WDM systems [10-11]. In a dispersive fiber the input pulses get broaden as it travel across the length causing inter-symbol interference (ISI) at the receiver. The varied power level of the neighboring channels worsens the effects of SRS and XPM. Bit error rate (BER) characteristics of DWDM transmission systems with optical amplifiers in the presence of fiber nonlinearities are calculated and the change of BER by changing system parameters such as no. of channels, area of the fiber and the channel separation.

II. SYSTEM MODEL

The model of WSK-DWDM system is shown in figure 1.



(a)

(b)

Fig1**: (a)** System model of WSK-DWDM system.(b) Block Diagram of a direct detection receiver with Mach-Zehnder Interferometer (MZI)

The transmitted signal is given by

$$S_m(t) = ACos(W_m t + \phi_m), \text{ where, } m = 1, 2, \ldots, M \qquad \textbf{(1)}$$

where $W_m = 2\pi f_m = \dfrac{2\pi C}{\lambda_m}$

ϕ_m = initial phase

A = Signal amplitude

$T_s = KT_b$ = Signaling interval

T_b = bit duration

$E_s = \dfrac{A^2 T_s}{2}$ = Signal Energy = Energy/symbol

In the transmitter, the data of 10 Gbps is used to directly modulate a laser to generate the WSK signal which is transmitted through a single-mode fiber. At the receiving end, the received optical signal is detected by a MZI based direct detection receiver. In the WSK direct detection receiver with MZI, the MZI act as an optical filter and differentially detect the 'mark' and 'space' of received WSK signal which are then directly fed to a pair of photo detectors. The difference of the two photo currents are applied to the amplifier which is followed by an equalizer. The equalizer is required to equalize the pulse shape distortion caused by the photo detector capacitance and due to the input resistance and capacitance of the amplifier. After passing through the baseband filter, the signal is detected at the decision circuit by comparing it with a threshold of zero value.

III. THEORETICAL ANALYSIS

Assume N equally spaced channels with channel separation Δν (Hz).The degradation caused by SRS will be most severe for the shortest wavelength channel (called this the zeroth channel).Assuming scrambled polarization and the Raman gain to be in the linear regime, the power lost, D by the zeroth channel is [1],

$$D = \sum_{i=1}^{N-1} \frac{\lambda_i}{\lambda_0} P_i \gamma_i \, L_e / 2A$$

(2)

Where,

P_i =the injected power (Watts) in the ith channel,

λ_i =the wavelength of the ith channel,

A=the effective core area given by the appropriate overlap integrals,

And L_e =the effective fiber length given by,

$$L_e = \frac{1-e^{-\alpha L}}{\alpha} \qquad \textbf{(3)}$$

Where,

α =the fiber loss coefficient

L=fiber length

the peak Raman gain coefficient γ_p occurs at 0.00005 m^{-1} and assume there is no Raman interaction at larger spacing Consequently then, γ_i=the Raman gain coefficient coupling the ith and zeroth channels,

$$\gamma_i = \frac{i\Delta\nu}{1.5\times10^{13}}\gamma_p$$

For $i\Delta\nu < 1.5\times10^{13}$

$\gamma_i = 0$

For $i\Delta\nu > 1.5\times10^{13}$

A multi-channel system, the nonlinear phase shift of the signal at the center wavelength λ_i is described by [5],

$$\phi_{NL} = \frac{2\pi}{\lambda_i} n_2 z \, [I_i(t) + 2\sum_{i\neq j}^{M} I_j(t)] \qquad \textbf{(4)}$$

where M is the number of co-propagating channels in the fiber.

The total XPM induced of probe channel at fiber output is the sum of the XPM induced at infinitesimal section z along the fiber with length L is given by [1]:

$$P_{XPM} = 2\gamma_1 P_1(0) P_2(\omega) e^{-aL} e^{-\frac{j\omega L}{V_{g1}}}$$

$$\left\{\frac{1}{a^2+(b+q)^2}\left[a.\sin(bL)-(b+q).\cos(bL)+\left[a.\sin(qL)+(b+q).\cos(qL)\right]\exp(-\alpha L)\right]\right.$$

$$\left.\frac{1}{a^2+(b-q)^2}\left[a.\sin(bL)-(b-q).\cos(bL)+\left[-a.\sin(qL)+(b-q)\cos(qL)\right]\exp(-\alpha L)\right]\right\} \qquad \textbf{(5)}$$

Here $a = \alpha - j\omega d_{12}$, $b = \omega^2 D\lambda_1^2/(4\pi c)$ and $q = \omega^2 D\lambda_2^2/(4\pi c)$. α is the attenuation constant, ω is the angular frequency, D is the dispersion of the fiber, λ is the wave length, d_{12} is the walk-off length and c is the velocity of light. In a nonzero dispersion region $d_{12} \approx D_1.\Delta\lambda_{12}$ where $\Delta\lambda_{12} = \lambda_1 - \lambda_2$ is the wavelength separation between channel 1 and 2.

The probability of error or BER is given by-

$$BER(P_e) = 0.5\,erfc[D/SNR] \qquad \textbf{(6)}$$

where,

Signal-to-noise ratio,

$$SNR(r) = \frac{I_s}{\sigma\sqrt{2}}$$

Where, $I_s = R_d P_s(r)$ and

$$\sigma = \sqrt{P_{th} + P_{shot} + P_{XPM} + D}$$

Where,

$$P_{th} = Thermal\ noise = \frac{4kTB}{R_L}$$

And, $P_{shot} = shot\ Noise = 2eI_s B$

Keeping in view the findings of the literature, SRS and XPM have been considered as main nonlinearities in our study at low data rates.

IV. RESULTS AND DISCUSSION

Following the analytical approach presented in section III, we evaluated the BER performance of WSK-DWDM system considering the effect of changing system parameters such as no. of channels, area of the fiber and the channel separation. For the convenience of the readers the parameters used for computation in this paper are shown in table 1.

Table 1: Nominal Parameters of Optical Communication link

Parameter Name	Value
Bit Rate, B_r	10 Gbps
Temperature	300
Fiber attenuation, α	0.24 dB/Km
Responsivity, R	0.85 A/W
Channel Spacing, D_{ch}	20 GHz
Load Resistance, R_l	50 ohm

Plots of fig. 3 show the variation of Power loss vs. Number of channel for channel spacing v1=800GHz, v2=80GHz, v3=8GHz and v4=800MHz, number of channel 32, area of fiber 100 mm^2, input power =0.01W and length of the fiber is 120 km, Centre wavelength = 1.5×10^{-5} m, Raman gain coefficient=0.00005 m^{-1}.

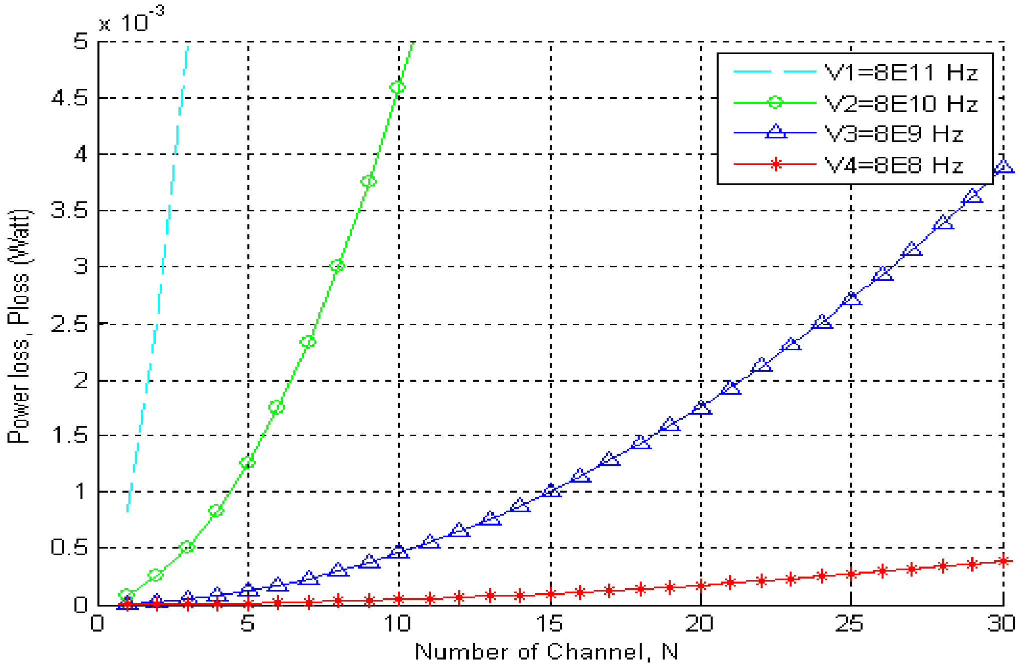


Fig 3: Power loss Vs. No. of channel varying channel spacing.

It has been observed that at 800GHz and above channel spacing the power loss becomes constant and does not depend on the number of channel.

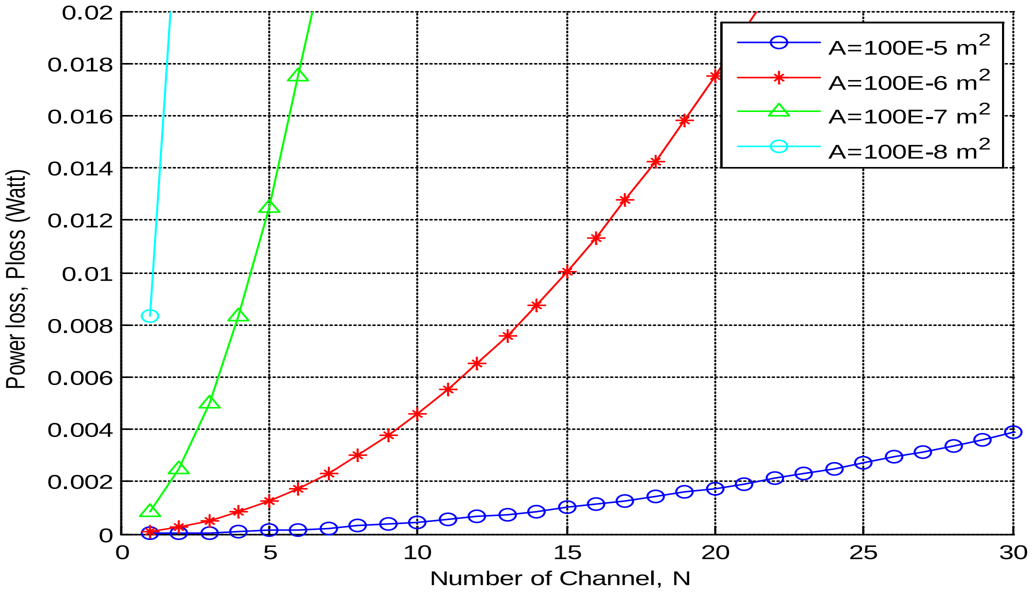


Fig 4: Power loss Vs. No. of channel varying area of the fiber.

Plots of fig. 4 show the variation of Power loss vs. number of channel for area of the fiber A1=1mm^2, A2=10mm^2, A3=100mm^2, A4=10^{3}mm^2 and A5=10^{4}mm^2.It has been observed that if the core area of the fiber is increased the power loss decreases and vice versa.

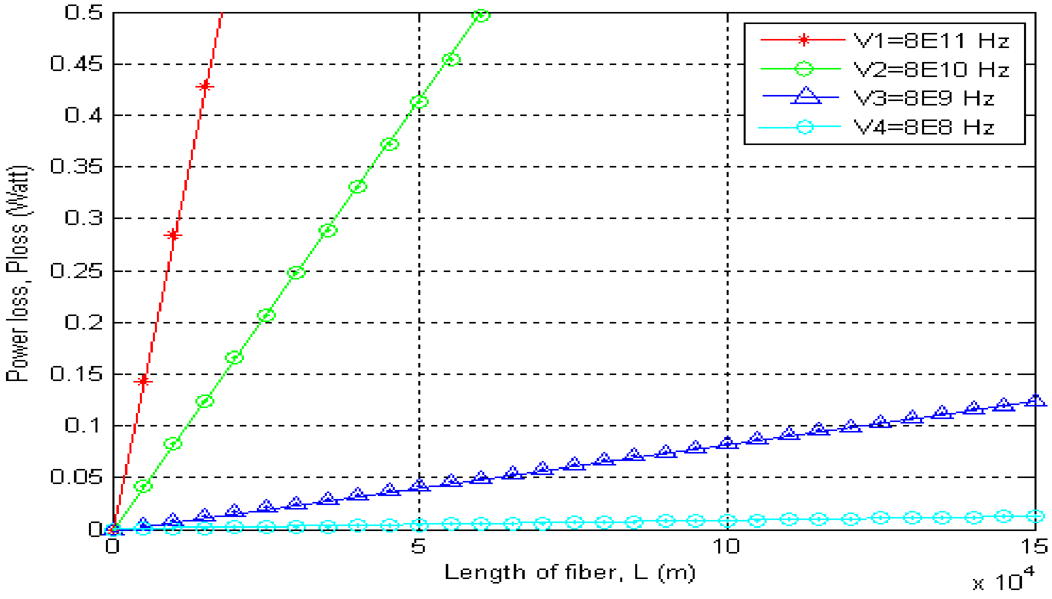


Fig 5: Power loss Vs. Length of fiber varying channel spacing.

Plots of fig. 5 show the variation of Power loss vs. Length of the fiber for channel spacing v1=800GHz, v2=80GHz, v3=8GHz and v4=800MHz. As the channel spacing increases the power loss increases. Table 3 shows the values of power loss in watt for 50 km, 100 km, 120 km and 150 km.

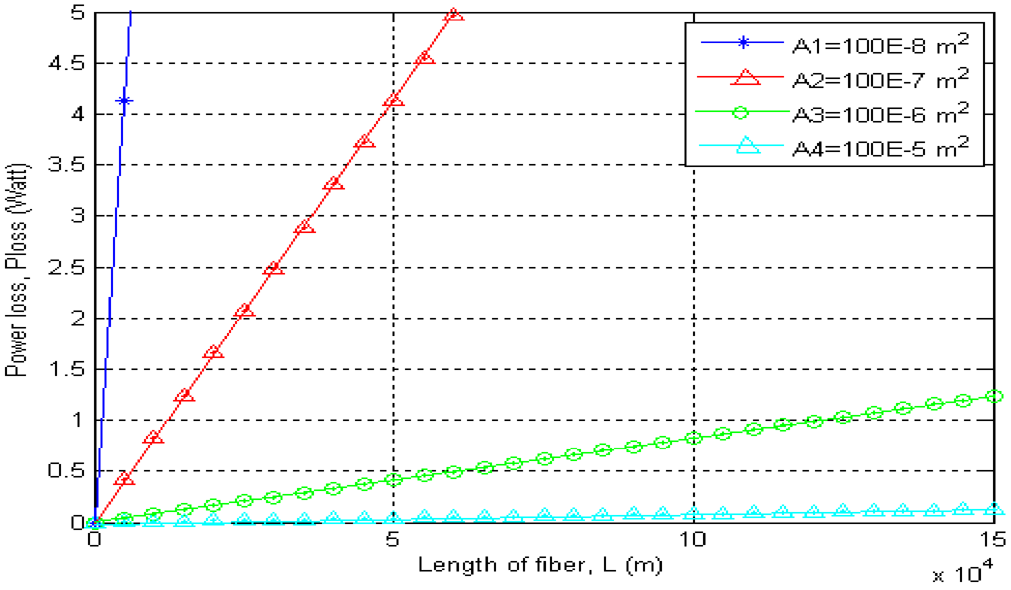


Fig 6: Power loss Vs. Length of fiber varying area of the fiber.

Plots of fig. 6 show the variation of Power loss vs. Length of the fiber for area of the fiber A1=1mm^2, A2=10mm^2, A3=100mm^2 and A4=10^{3}mm^2.As the area of the fiber decreases power penalty increases.

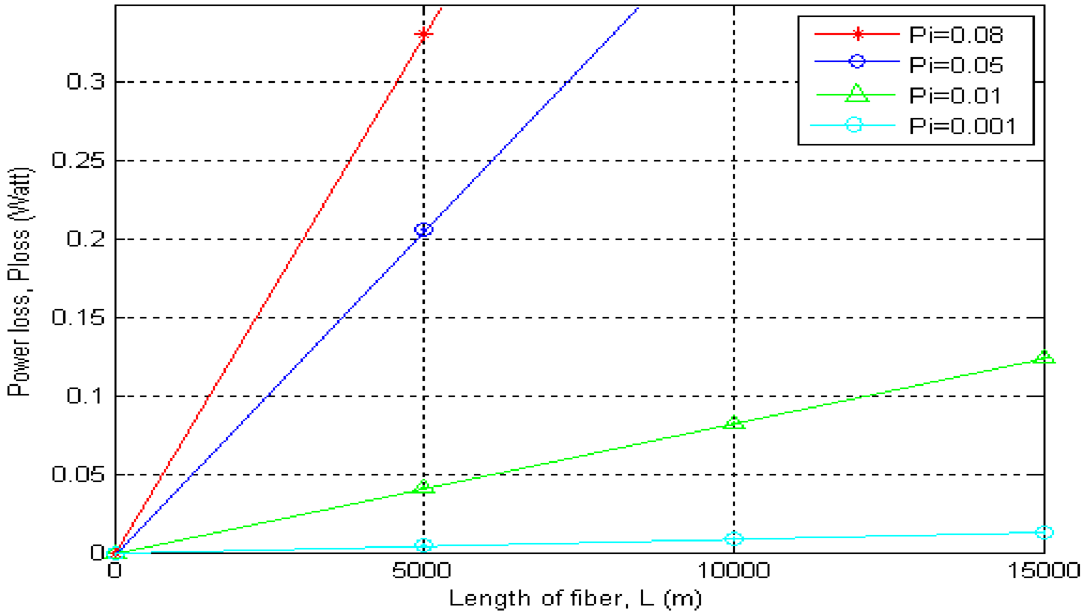


Fig 7: Power loss Vs. Length of fiber varying input power.

Plots of fig. 7 show the variation of power loss vs. Length of the fiber for injected input power P1=1W, P2=0.1W, P3=0.01W and P4=0.001W. If we injected higher Power, power loss increased. This is shown in the table 5 below the figure.

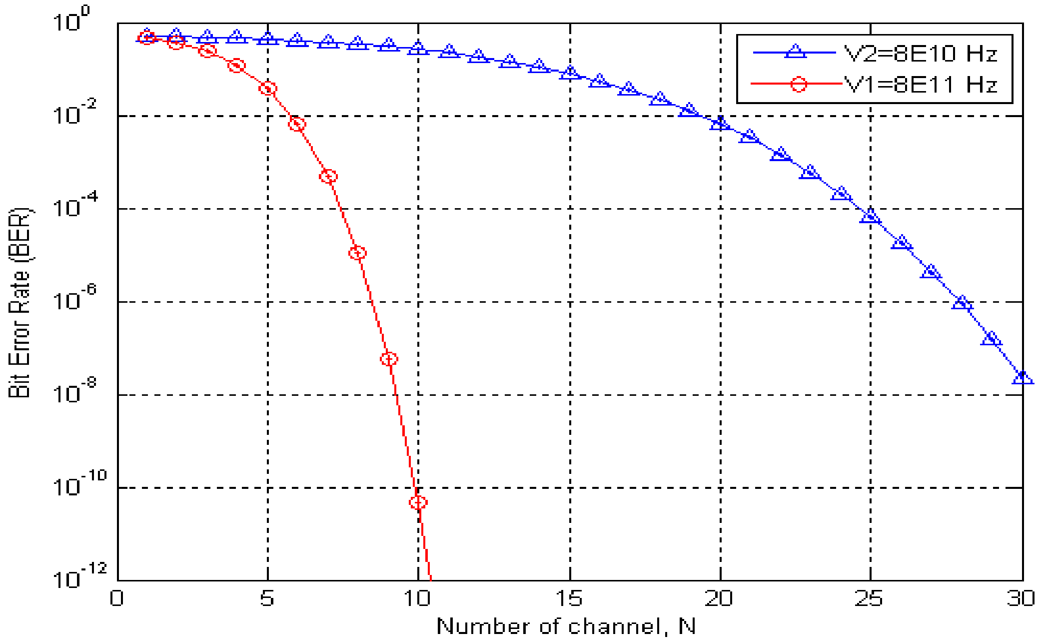


Fig 8: BER Vs. No. of channel varying channel spacing.

Plots of fig. 8 show the variation of Bit Error Rate (BER) vs. Number of channel for channel spacing v1= 80GHz and v2=800GHz. It has been observed that as the channel spacing increases the Bit Error Rate decreases. But At 800 GHz channel spacing after 16 channels Bit Error Rate becomes constant. Similarly for channel spacing larger than 800GHz Bit Error Rate (BER) becomes constant at a specific number of channels. The table 6 shows the values of BER from the figure.

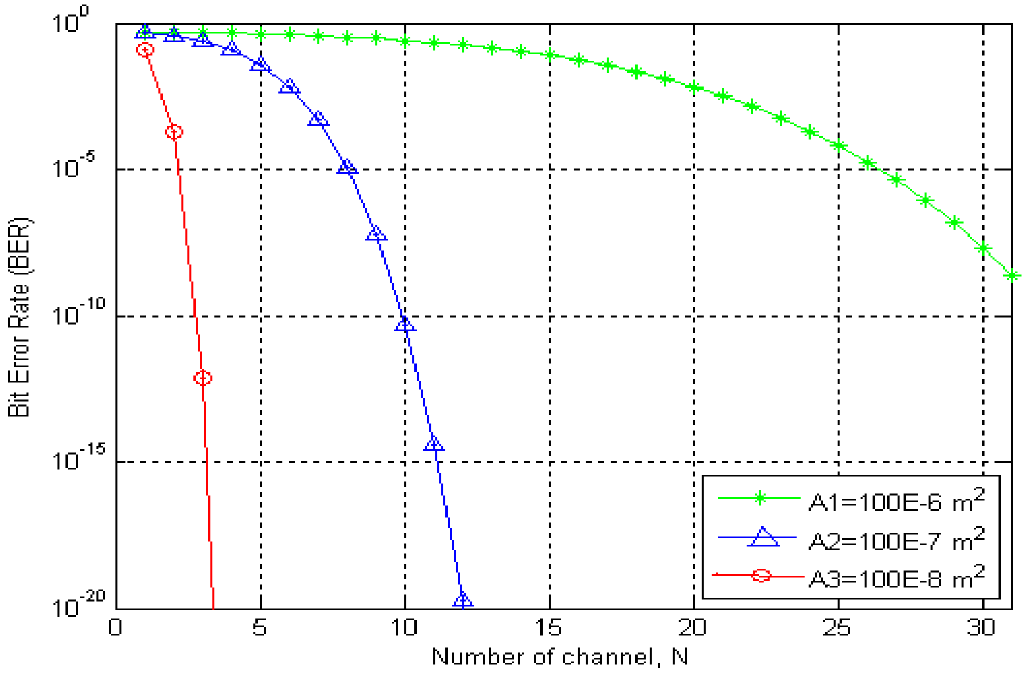


Fig 9: BER Vs. No. of channel varying area of the fiber.

The variation of BER with number of channel has been showed in Fig. 9 for area of the fiber A1=10^3 mm^2, A2=100 mm^2, A3=10 mm^2 and A4=1 mm^2, length of the fiber 120 km and channel spacing 80 GHz. It has been observed that as the core area decreases Bit Error Rate also decreases but this decrement is much higher in comparison with the area decrement. For this reason an optimal area is selected for an optimal Bit Error Rate.

V. Conclusion

Dense wavelength division multiplexing (DWDM) is usually used on fiber optic backbones and long distance data transmission. This paper analyses the combined effect of fiber nonlinearity, Stimulated Raman Scattering (SRS) in DWDM transmission system with direct detection binary WSK receiver. The performance of DWDM transmission system in terms of Bit Error Rate has been evaluated in the presence of SRS, XPM and receiver noise. The calculation of SRS has been done considering walk off effect. Results are evaluated in terms of BER and Power penalty at a BER of 10^{-9}. The results of the analysis are in compliance with the mathematical equations reported in the literature and hence validate this method. From the over all analysis it is found that 80 GHz channel spacing is the optimal channel spacing for BER and power penalty and the power penalty curves that the repeater can be used at an interval of 120 km. The comparison of the figures shows that 32 channels can be used for a Bit Error Rate (BER) of 10^{-9}. It can be concluded from literature that in a multi-channel system, the effect of fiber nonlinearities should be addressed more properly. The two conventional limitation factors in designing optical communication systems, namely, fiber loss and dispersion, are relatively well understood, and can be easily overcome by optical amplifiers and dispersion compensation but fiber nonlinearities have not been fully analyzed and understood despite a rich collection literature dealing with fiber nonlinearities. Therefore, it is crucial to understand fiber nonlinearities and their effects on fiber-optic communication systems.

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