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ANALYSIS OF THE CROSSTALK IN OPTICAL AMPLIFIERS

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Abstract
In this work, we tried to analyze the crosstalk in optical amplifiers. For mathematical analysis, we have considered the Gain (G) for different amplifiers as 35 dB, 18 dB and 26 dB, respectively.

Keywords:
Bit Error Rate, Crosstalk, Optical Amplifiers, Power Penalty

1. INTRODUCTION

In recent years, Optical amplifiers increased the transmission distance in the field of optical fiber communication [1]. Current repeater spacing and speed of EDFA is in the range of 80-100 Km and 40 Gb/s while those for Raman Amplifier (RA) is in the range of 100-160 Km and 160-320 Gb/s [1]. Optical amplifiers are typically used in three different places in a fiber transmission link [2]: Power Amplifiers, Line Amplifiers, and Preamplifiers. One such proposed approach is shown in Fig.1.

Various Characteristics of different types of Optical amplifiers are shown in Table.1 [3].

Table.1. Typical Characteristics of Optical amplifiers

Characteristics	EDFA	RA	SOA
Small signal gain	30-45 dB	15 dB	20-25 dB
Wavelength region	S,C and L bands	S,C and L bands	800 nm – 1600 nm
Bandwidth	30 nm – 40 nm	70 nm – 80 nm	30 nm – 40 nm
Output Power	20 – 25 dBm	N/A	10 – 15 dBm
Crosstalk	No	Yes	Yes

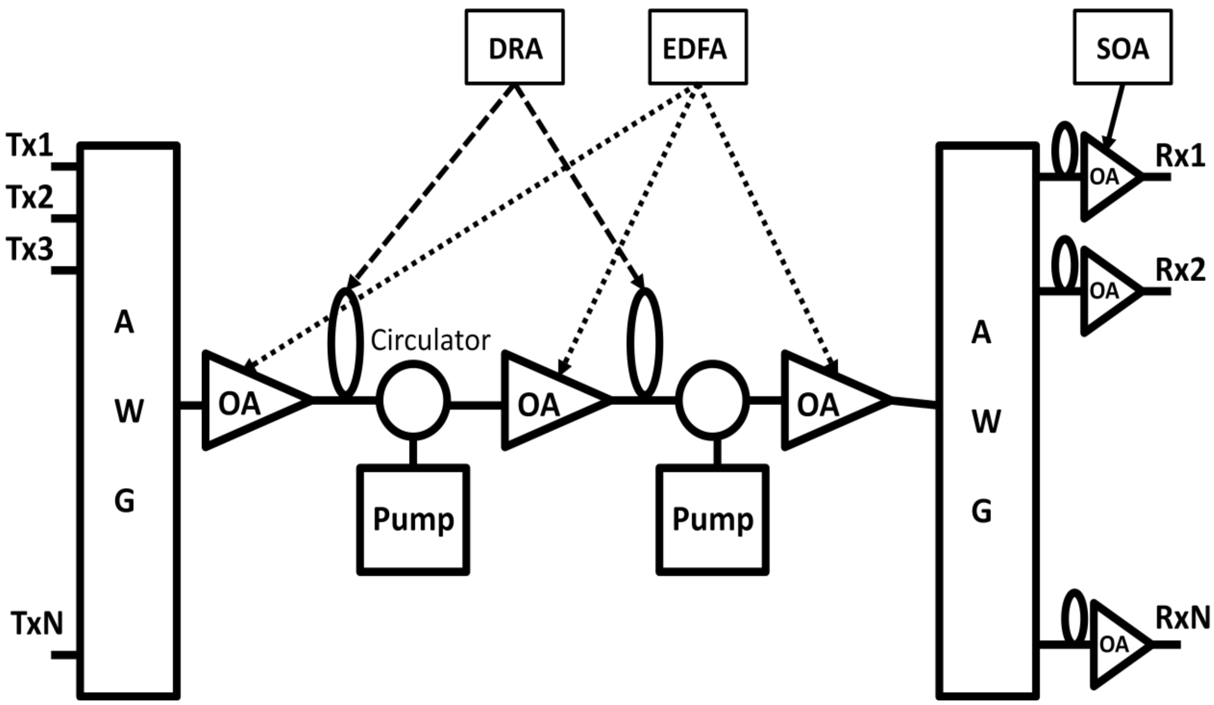


Fig.1. Schematic of proposed model with Erbium Doped Fiber Amplifier, Raman Amplifier and Semiconductor Optical Amplifier. OA: Optical Amplifier,Tx: Transmitter, LD: Laser Diode and Rx: Receiver, AWG: Arrayed Waveguide Grating

2. BIT ERROR RATE (BER) CALCULATION

Amplified Spontaneous Emission (ASE) noise influences the performance of various optical fiber amplifiers. This noise introduces bit errors into the received signal. The ASE noise may be measured in terms of the average probability of symbol error. The average probability of symbol error is generally expressed as the Bit Error Rate (BER). Generally, the BER range is 10^{-12}, which means that a maximum one out of every 10^{12} bits can be corrupted during transmission. The optical amplifier noise figure is given by [4],

$$F = 2n_{sp}\left(1-\frac{1}{G}\right) \approx 2n_{sp} \quad (1)$$

where, $n_{sp} = \frac{N_2}{N_2 - N_1}$ is Spontaneous emission factor, G is the net rate of stimulated emission. Noise introduced by spontaneous emission is given by [2],

$$S_{sp} = \frac{(G-1).F.h.v}{2}. \quad (2)$$

From Eq.(1) and Eq.(2)

$$S_{sp} = (G-1).n_{sp}.h.v. \quad (3)$$

The total power of the spontaneous emission noise for an amplifier followed by an optical filter of bandwidth (B_0) is given by [4],

$$P_{sp} = S_{sp}.B_0 \quad (4)$$

From Eq.(3) and Eq.(4)

$$P_{sp} = (G-1).n_{sp}.h.v.B_0$$

Using, $\sigma_{ase}^2 = P_{sp}$. The noise introduced by spontaneous emission has a following relation [2]

$$\sigma_{ase} = \sqrt{((G-1).n_{sp}.h.v.B_0)} \quad (5)$$

where, G = Gain,

n_{sp} = Spontaneous Emission Factor,

h = Planck's constant, v = Frequency of the signal,

c = speed of light,

L = wavelength,

B_0 = Band width a measure of the width of a range of frequencies.

As Q is a function proportional to the receiver signal-to-noise ratio (SNR). It is expressed as,

$$Q = (R_b \times P_s)^2 \Big/ \sqrt{(\sigma_{ase}^2 + \sigma_c^2)} \quad (6)$$

For the same input power, crosstalk can be calculated for different number of channels and hops using the equation [5],

$$\sigma_c^2 = M \times b^2 \times R_d^2 \times P_s^2 \times \left(2 \times \varepsilon'_{adj} + (N-3)\varepsilon'_{nonad} + X_{switch}\right) \quad (7)$$

where, M = Number of Hops,

b = Ratio of signal peak power,

N = Number of channels,

R_d = Detector responsivity,

P_s = Input Power,

ε'_{adj} = Effective adjacent channel crosstalk,

ε'_{nonad} = Effective Non adjacent channel crosstalk,

X_{Switch} = Crosstalk value (in linear units) of the optical switch fabric.

R_b = Bit Rate,

P_s = Signal power in dBm,

σ_c = Crosstalk,

σ_{ase} = ASE (amplified spontaneous emission) noise induced by parametric gain and spontaneous Raman scattering in optical fiber Raman amplifier.

BER in WDM system is calculated by the equation below [6],

$$BER = \frac{1}{2} erfc\left(\frac{Q}{\sqrt{2}}\right) \quad (8)$$

For different values of bandwidth, BER without crosstalk can be calculated using Eq.(8) for the above equation of Q with different bandwidth of 2 * R_b, 4 * R_b, 6 * R_b etc.

3. POWER PENALTY ANALYSIS IN VARIOUS OPTICAL AMPLIFIERS

In this work, we first calculated the power without crosstalk and then calculated the power with crosstalk. The difference between the two powers result as the Power Penalty.

3.1 ERBIUM DOPED FIBER AMPLIFIER (EDFA)

Most important doped fiber is an EDFA, which is currently used for long distance optical communication system. EDFA does operation of amplification without converting into the electrical domain. EDFA could be used within 1550 nm low attenuation window. This optical amplifier is generally dope with rare earth ion such as erbium (Er^{3+}) which is excited to a higher level by laser pumping and hence resulting in a signal gain [7].

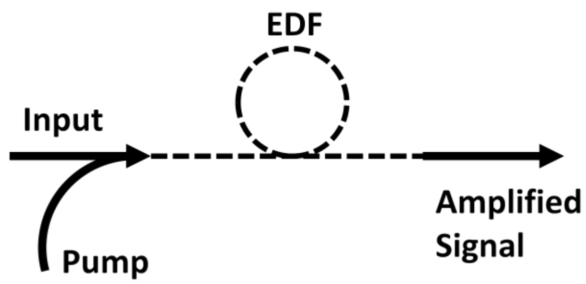


Fig.2. Schematic of Erbium Doped Fiber Amplifier

3.1.1 Bit Error Rate (BER) Analysis for Different Bandwidths:

Performance of an optical power amplifier is characterized through the BER. Using Eq.(6), Eq.(8) and considering following variable values a Bit Error Rate (BER) is plotted as a function of input power (dBm) as shown in Fig.3. Bit rate (R_b) nearly equal to 10 GHz, input power between the range from -8 dBm to 100 dBm, spontaneous emission factor (n_{sp}) equal to 1.8 and Gain (G) of 35 dB. Fig.3 shows that with the increase in input power and bandwidth, BER increases.

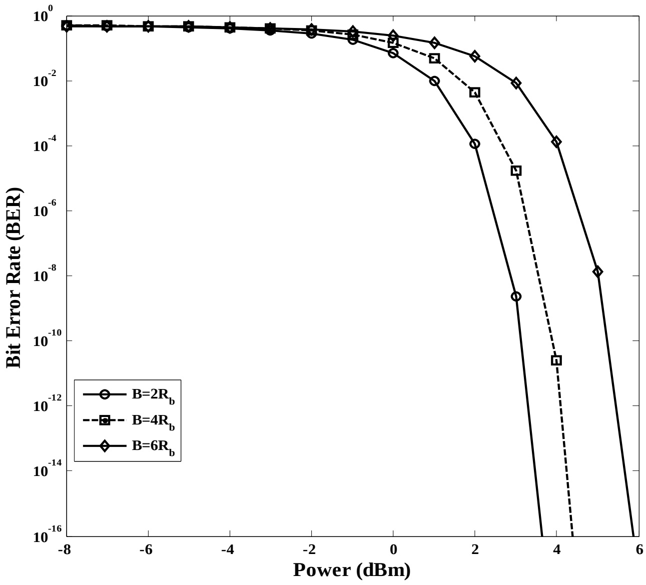


Fig.3. Plot of BER vs Input Power for EDFA

3.1.2 Analysis for EDFA:

We have computed the Power Penalty with BER of 10^{-10} (as shown in Fig.4). Considering the following values: Bit Rate (R_b) equal to 10 GHz, spontaneous emission factor (n_{sp}) equal to 1.8 and Gain (G) of 43 dB.

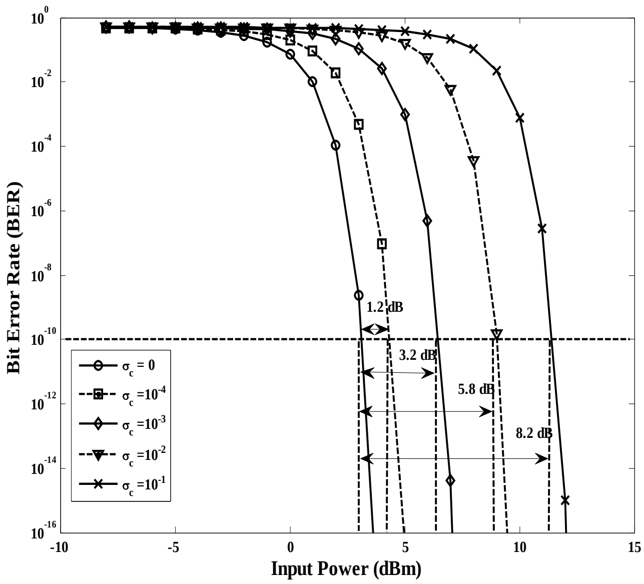
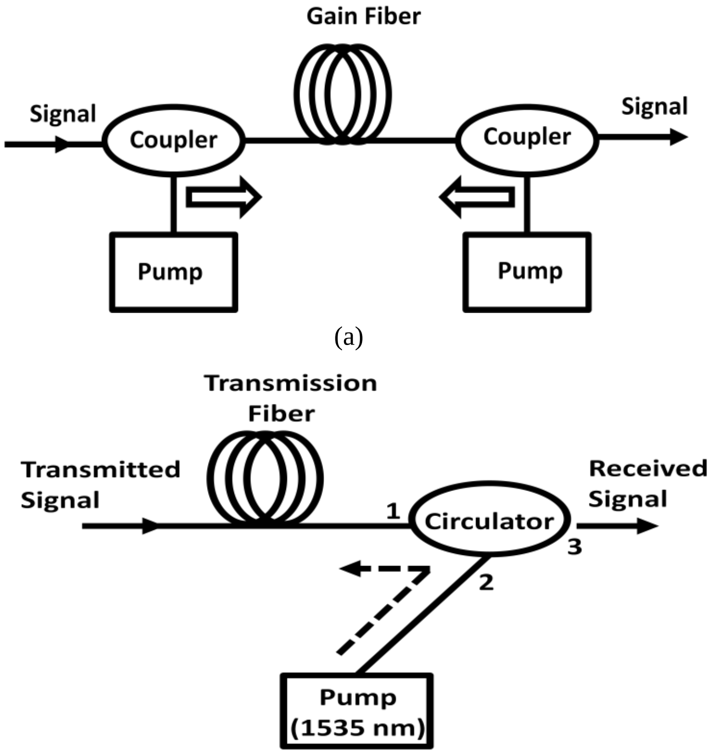


Fig.4. Plot for BER vs Input Power with different Crosstalk for EDFA

Table.2. Power penalty corresponding to crosstalk for EDFA

Crosstalk	Power Penalty
10^{-4} or -40 dB	1.2 dB
10^{-3} or -30 dB	3.2 dB
10^{-2} or -20 dB	5.8 dB
10^{-1} or -10 dB	8.2 dB
0	3.2 dB



(a)

(b)

Fig.5. Raman amplification (a) Discrete (b) Distributed

Table.2 shows that as crosstalk value increases, the requirement of input power.

3.2 RAMAN AMPLIFIER

Unlike EDFA, the amplification is achieved by a non linear interaction between the signal and a pump laser within an optical amplifier. The main principle of Raman effect is the power transfer from lower wavelength (pump source) to higher wavelengths [8]. A Raman amplifier can be distributed type or discrete type. In case of discrete Raman amplifier, as shown in Fig.5(a), Dispersion compensating fiber (DCF) is used as a gain medium. In case of distributed amplification, as shown in Fig.5(b), gain medium is transmission fiber. It generally comprises a gain fiber, a directional coupler for combining the pump and the signal wavelength, and isolators at the input and output ends. The orientation of the pump can be either forward or backward with respect to the signal propagation, whereas the counter propagating one is called counter pumping; the copropagating pumping scheme is called copumping. There is also an option of bidirectional pumping, in which the gain fiber is pumped in both directions[8].

3.2.1 BER Analysis for Different Bandwidths:

If errors are introduced into the data, then the integrity of the whole system may be decreased. The performance of the proposed system is judged through BER. Using Eq.(6) and Eq.(8), a Bit Error Rate (BER) is plotted as a function of input power (dBm) as shown in Fig.6. Considering following variable values: Bit rate (R_b) nearly equal to 10 GHz, input power between the range from -8 dBm to 100 dBm, spontaneous emission factor (n_{sp}) equal to 1.8 and Gain (G) of 15 dB. Fig.6 shows that with the increase in input power and bandwidth, BER increases.

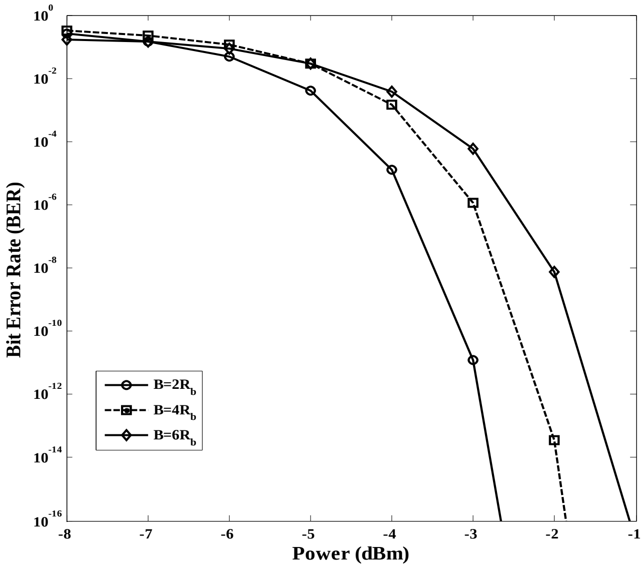


Fig.6. Plot for BER vs Input Power (dBm) for Raman Amplifier

3.2.2 Analysis for Raman Amplifier:

Consider the following values: Bit Rate (R_b) equal to 10 GHz , spontaneous emission factor (n_{sp}) equal to 1.8 and Gain (G) of 18 dB. Fig.7 shows graph between BER vs Input Power.

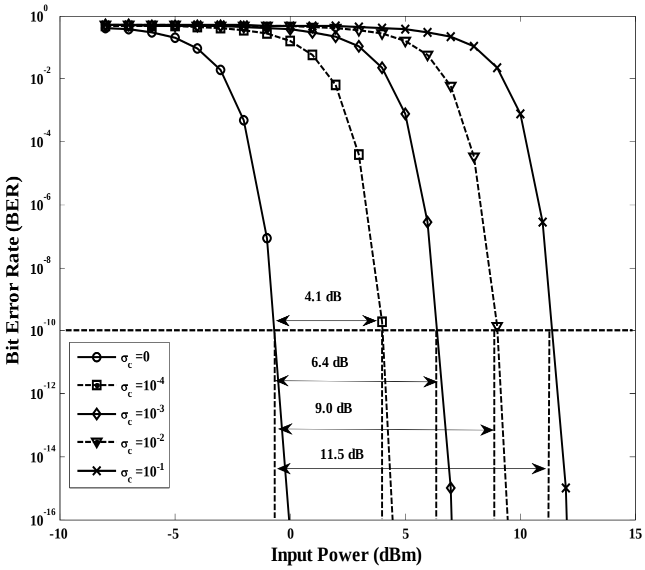


Fig.7. Plot for BER vs Input Power with different Crosstalk for Raman Amplifier

Table.3. Power penalty corresponding to crosstalk for Raman Amplifier

Crosstalk	Power penalty
10^{-4} or -40 dB	4.1 dB
10^{-3} or -30 dB	6.4 dB
10^{-2} or -20 dB	9.0 dB
10^{-1} or -10 dB	11.5 dB
0	-0.7 dB

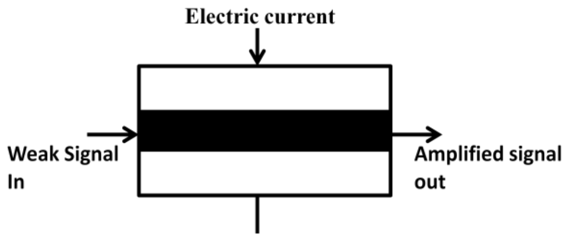


Fig.8. Schematic of Semiconductor Optical Amplifier

Table.3 shows that as the crosstalk value increases, the power penalty increases.

3.3 SEMICONDUCTOR OPTICAL AMPLIFIER

Semiconductor Optical Amplifier (SOA) is similar to a double hetero-structure laser diode [9-10]. In the 1980's there were further important advances on SOA devices design and modeling. A diagram of a basic SOA is shown in Fig.8. The active region in the SOA imparts gain to an input signal [11]. The energy levels of the electrons in a semiconductor are confined to two bands: the conduction band, containing those electrons acting as mobile carriers, and the valence band, containing the non mobile electrons [12-13].

3.3.1 BER Analysis for Different Bandwidths:

Using Eq.(7) and Eq.(8), a Bit Error Rate (BER) is plotted as a function of input power (dBm) as shown in Fig.9. Considering following variable values:

Bit rate(R_b) nearly equal to 10 GHz, input power between the range from -8 dBm to 100 dBm, spontaneous emission factor (n_{sp}) equal to 1.8 and Gain (G) of 26 dB.

The Fig.9 shows that with the increase in input power and bandwidth, BER increases.

3.3.2 Analysis for Semiconductor Optical Amplifier:

Consider the following values:

Bit Rate (R_b) equal to 10 GHz spontaneous emission factor (n_{sp}) equal to 1.8 and Gain (G) of 40dB.

Putting values in Eq.(8), we will get the result as shown in Table.4.

Table.4. Power penalty corresponding to crosstalk for SOA

Crosstalk (dB)	Power penalty (dB)
10^{-4} or - 40 dB	4.0 dB
10^{-3} or - 30 dB	8.8 dB
10^{-2} or - 20 dB	11.5 dB
10^{-1} or - 10 dB	14.2dB
0	-0.7 d B

Table.4 shows that as the crosstalk value increases, the requirement of input power increases. Considering Table.2, Table.3 and Table.4, Power Penalty vs crosstalk is plotted in Fig.11.

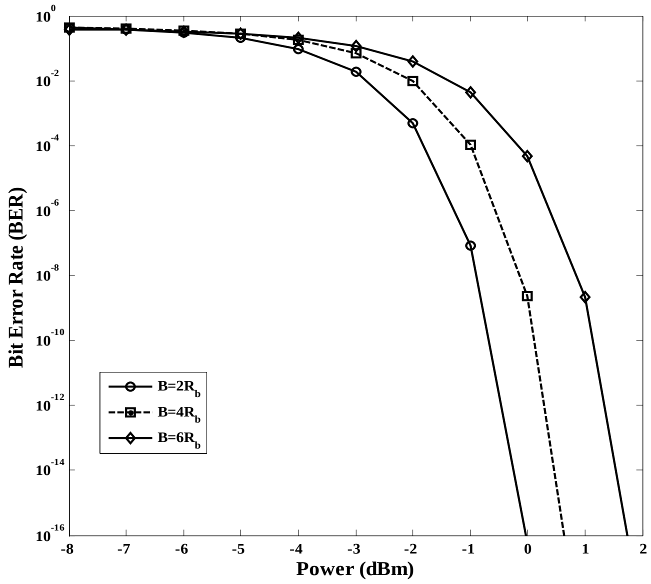


Fig.9. Plot for BER vs Input Power for SOA

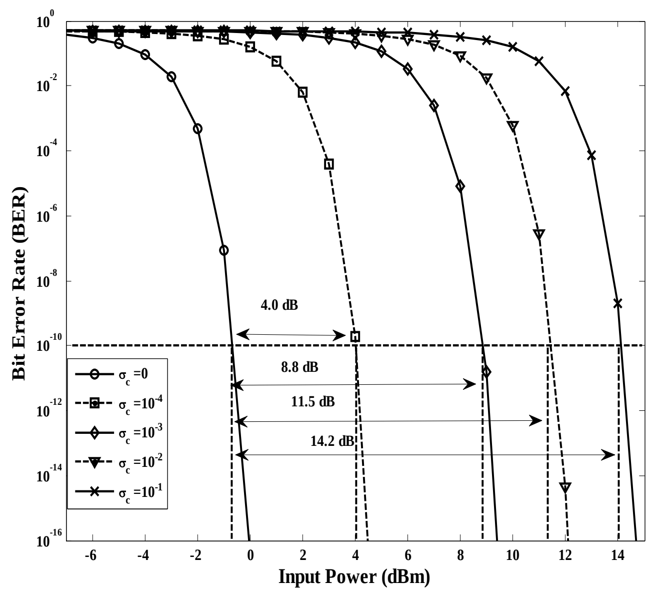


Fig.10. Plot for BER vs Input Power (dBm) with different Crosstalk for SOA

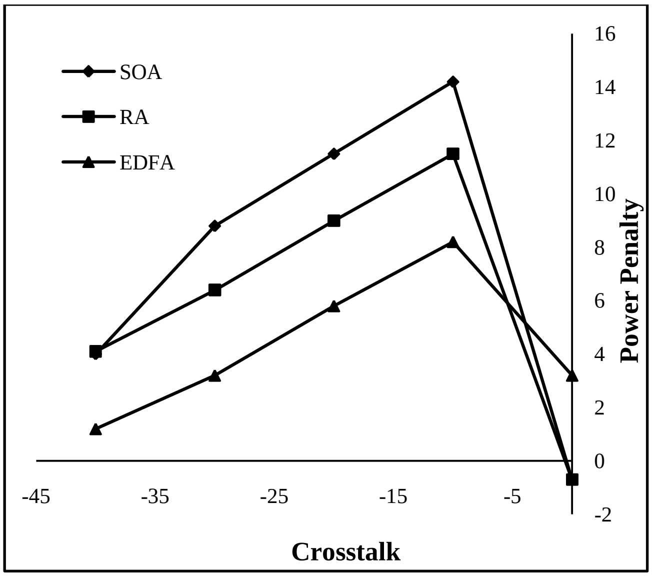


Fig.11. Plot of Power Penalty vs Crosstalk for different Amplifiers

4. CONCLUSION

In this work, we try to analyize the Crosstalk for different amplifiers. It has been found that power penalty of SOA w.r.t to the other optical amplifier is high at 1550nm wavelength. Also, as Raman Amplifier is compatible with installed Single Mode Fiber, therefore RA can be used to extend EDFA as shown in Fig.1.

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