International Journal of Advances in Engineering Research http://www.ijaer.com

(IJAER) 2013, Vol. No. 6, Issue No. VI, December **e-ISSN: 2231-5152, p-ISSN: 2454-1796**

POWER PENALTY VERSUS CROSSTALK IN OPTICAL ACTIVE NETWORK COMPONENTS : A COMPARATIVE ANALYSIS

Dr. Manoj Mittal

Ex Academic Indian Institute of Technology Delhi.

ABSTRACT

Transmission distance in optical communication can be increased by using either regenerators or optical amplifiers. Advantage of optical amplifiers over regenerators is that they boost the power without any optoelectronic conversation and hence, reduce the system manufacturing cost. The invention of the optical fiber amplifier is the innovation making it possible to realize the WDM system. An optical amplifier may be thought of as a laser without an optical cavity, or one in which feedback from the cavity is suppressed. Optical amplifier is characterized by gain, gain efficiency, gain bandwidth and noise. Current repeater spacing and speed of Erbium Doped Fiber Amplifier (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.

INTRODUCTION

Optical amplifiers are employed at various other points in a network. Optical amplifiers are typically used in three different places in a fiber transmission link [2]: Power Amplifiers (Boosters), Line Amplifiers, and Preamplifiers. One proposed approach is shown in Figure 1.

The desired properties of three optical amplifiers are different. Power amplifier need high gain, Preamplifiers requires low noise Figure and line amplifier need both. EDFA plays an important role in extending the research of optical transmission systems. But still it had drawback of operation confined to a limited optical spectrum band.

Also, EDFA has a non-flat gain profile. Raman amplifiers were first demonstrated well before the EDFA, have now more attracted recently. This is due to their ability to increase bit rate carried on a fiber. Various Characteristics of different types of Optical amplifiers is shown in Table 1 [3].

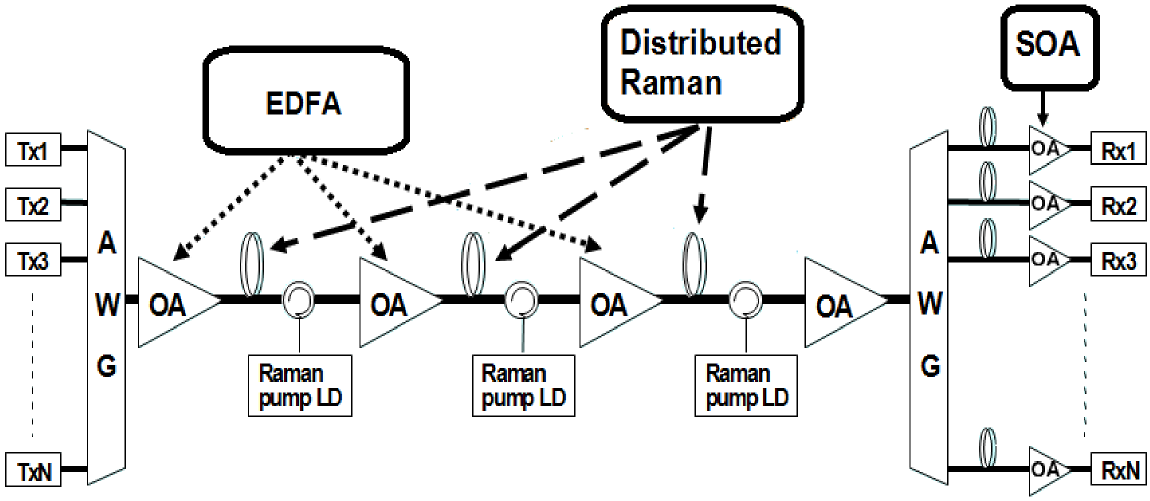


Fig. 1: *Proposed Model with EDFA, RA and SOA as Booster Amplifier, Line Amplifier and Pre Amplifier, respectively. OA: Optical Amplifier, EDFA: Erbium Doped Fiber Amplifier, SOA: Semiconductor Optical Amplifier, Tx: Transmitter, LD: Laser Diode and Rx: Receiver, AWG: Arrayed Waveguide Grating.*

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

CALCULATION OF BIT ERROR RATE (BER)

The performance of Optical fiber amplifiers is influenced by Amplified Spontaneous Emission (ASE) noise. The main effect of this noise is to introduce bit errors into the received signal. The presence of a bit error causes symbol 1 to be mistaken for symbol 0, or vice versa. The number of bit errors that occur within the space of one second. The ASE noise may be measured in terms of the average probability of symbol error, which is defined as the probability that the reconstructed symbol at the receiver output differ from the transmitted binary symbol. The average probability of symbol error also referred as the Bit Error Rate (BER). For most practical WDM networks, this requirement of BER is $10^{-12}(\sim 10^{-9}\ to\ 10^{-12})$, which means that a maximum one out of every 10^{12}bits can be corrupted during transmission. Therefore, BER is considered an important Figure of merit for WDM networks; all designs are based to adhere to that quality. Optical amplifier noise Figure is given by [4]:

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

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]:

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

From (1) and (2):

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

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

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

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

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

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

where G = Gain, n_{sp} = Spontaneous Emission Factor or Population-Inversion Factor, $h = 6.634 \times 10^{-34}$ = Planck's constant, ν = Frequency of the signal = c/L,c = speed of light = $3 \times 10^8 m/s$, L= wavelength, B_0 = Band width, a measure of the width of a range of frequencies, measured in hertz (Hz). In optical communication Q factor is used as a Figure of merit instead of SNR. Here, Q is a function proportional to the receiver signal-to-noise ratio (SNR). It is expressed as:

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

In practical case, zero crosstalk is not possible. So, BER is calculated with (6) taking in the value ofσ_c. For the same input power, crosstalk can be calculated for different number of channels and hops using the Eq[5]:

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

Where M = Number of Hops, b = Ratio of signal peak power, N = Number of channels, R_d = Detector responsivity, P_s = Input Power, $\acute{\varepsilon}_{adj}$ = Effective adjacent channel crosstalk, $\acute{\varepsilon}_{nonad}$= 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. In ideal case, σ_c = 0, which is with no cross talk.

Hence,Eq. (6) becomes:

$Q = (R_b \times P_s)^2 / \sigma_{ase}$

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.

ANALYSIS OF POWER PENALTY IN DIFFERENT TYPES OF OPTICAL AMPLIFIERS

Power Penalty is the increase in receiver power needed to eliminate the effect of some undesirable system noise or distortion. Typically power penalties can result from dispersion, reflection from passive components, crosstalk in couplers, modal noise in the fiber etc. In order to calculate Power Penalty from in-band Crosstalk, we first calculate the power without crosstalk and then,calculate power with crosstalk. The difference between the two powers will give us the Power Penalty. This approach authors have used in this paper for the calculation of power penalties for EDFA, RA and SOA.

Erbium Doped Fiber Amplifier *(EDFA)*

One of the major eventin the history of optical communication was the invention of the EDFA in 1980's. The 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 for broad optical spectrum operation within 1550 nm low attenuation window. This is the reason that high bandwidth optical communication systems could be constructed using EDFA. 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. NewErbium doped telluritefiber amplifier (EDTFA) has broad gain region from C to L band [7].

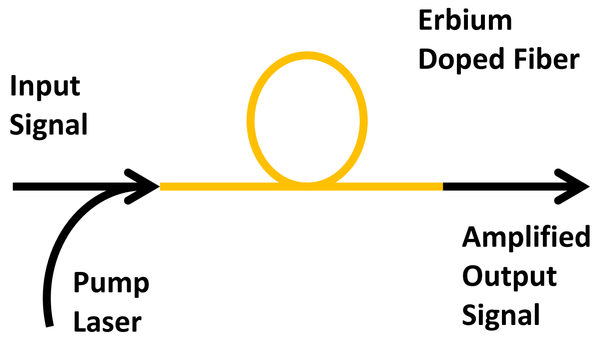


Fig.2: *Erbium Doped Fiber Amplifier.*

Analysis of Bit Error Rate (BER)for Different Bandwidths

The performance of a optical power amplifier is characterized through the BER. It is customary to define the BER as the average probability of incorrect bit identification. Therefore, a BER of 10^{-6} corresponds to an average one error per billion bits. Most lightwave systems specify a BER of 10^{-9}as the operating requirement. We can increase the power level of the system so that the power per bit is increased. But this has to be balanced against factors like the interference levels to other users and the impact of increasing the power output on the size of the power amplifier. Using Eqs. (6, 8) and considering following variable values a Bit Error Rate (BER) is plotted as a function of input power (dBm) as shown in Figure 3.Bit rate (R_b) nearly equal to 10 GHz, input power between the range from –8 to 100 dBm, spontaneous emission factor (n_{sp}) equal to 1.8 and Gain (G) of 40dB (means 1000 photon out per photon in) for EDFA.

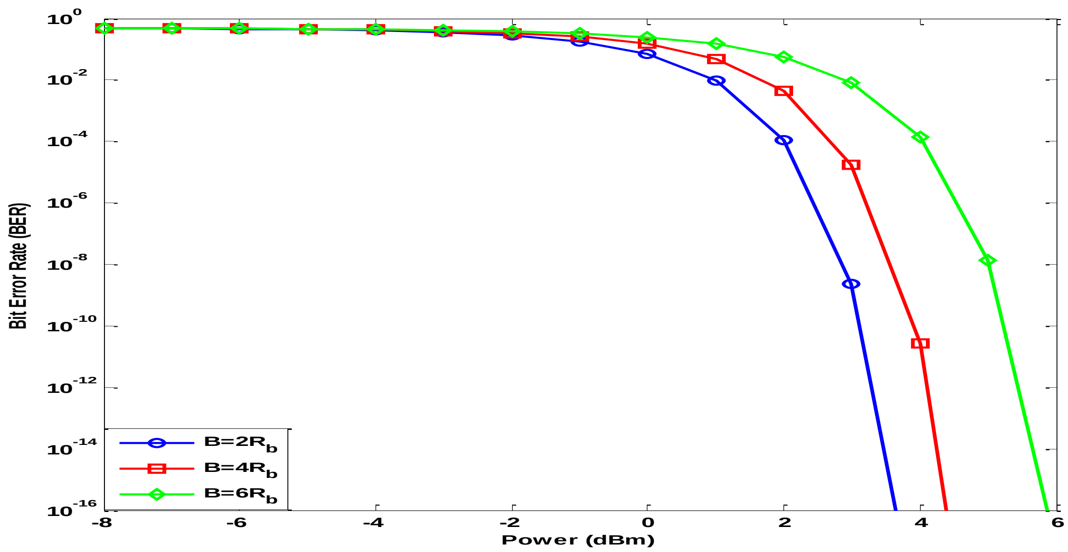


Fig.3:*BER as a Function of Input Power (dBm) withDifferent Bandwidths for EDFA.*

It is seen that BER increases with increase in input power and bandwidth. Plot of Figure 3 shows that to use more bandwidth we need more input power. For example, when we use 4* R_b, we need 4.4dBm whereas for 6* R_b, we need 5.8dBm. Here, effect of crosstalk is not considered for different bandwidths.

Power Penalty Analysis for EDFA

In order to calculate Power penalty from crosstalk, we first calculate the power without crosstalk and then calculate the power with crosstalk. The difference between the two will gives us Power penalty. We have computed the Power Penalty at reference BER scale of 10^{-10}.Consider the following values:

Bit Rate (R_b) equal to 10 GHz, spontaneous emission factor (n_{sp}) equal to 1.8, $h = 6.634 \times 10^{-34}$ and Gain (G) of 40dB.

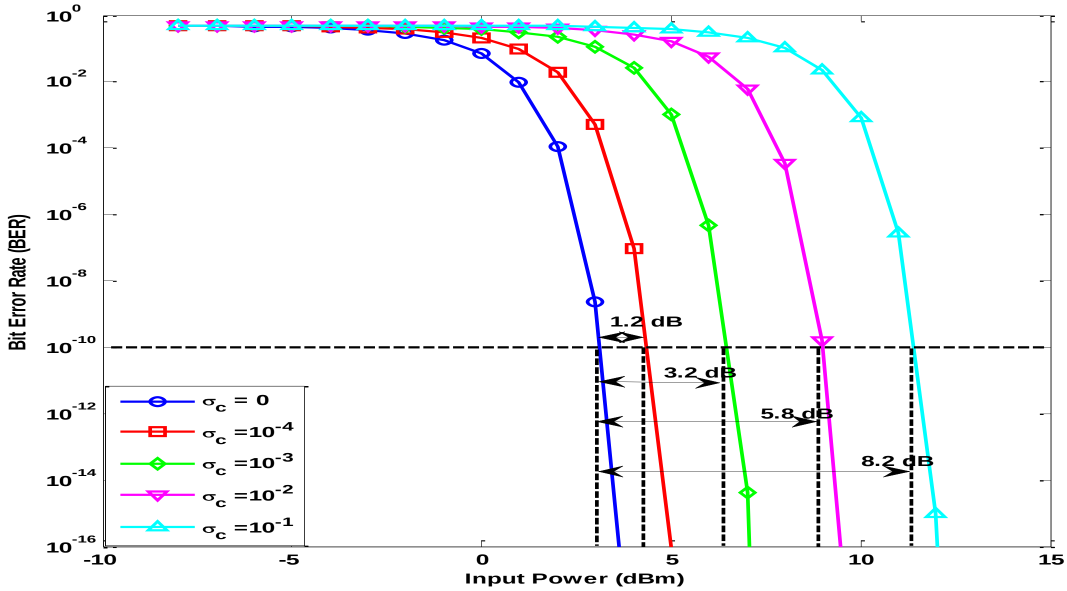


Fig.4: *BER as a Function of Input Power (dBm) with Different Crosstalk for EDFA.*

Using the above method and putting values in Eq. (8), from Figure 4 we will get the result as shown in Table 2.

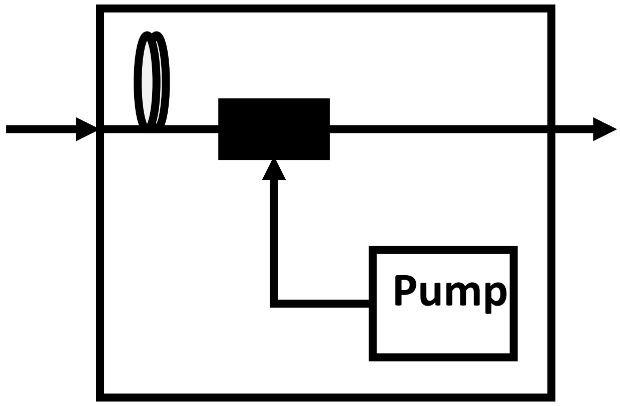
Table 2*: Shows Values of Power Penalty Corresponding to Crosstalk for EDFA.*

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} $or - 10db$	$8.2\ dB$
0	$3.2\ dB$

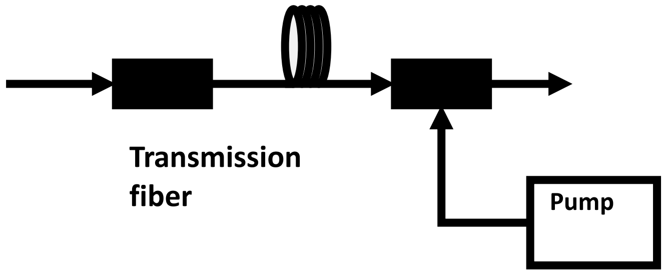
Above table shows as the crosstalk value increases, the requirement of input power increases and of course power penalty increases. This is a major problem in WDM systems.

Raman Amplifier

Raman fiber amplifier utilizes a stimulated Raman scattering. If the frequency of the scattered photon is the same as that of a signal photon propagating in the fiber, it can stimulate the emission of a second signal photon, thereby amplifying the signal, a process identical to that which occurs in the EDFA. Hence, the main principle of Raman effect is the power transfer from lower wavelength (pump source) to higher wavelengths. A Raman amplifier can be distributed type or discrete type.



(a)



(b)

Fig.5: *Raman Amplification (a) Discrete (b) Distributed.*

In case of discrete Raman amplifier, as shown in Figure 5 (a), Dispersion compensating fiber (DCF) is used as a gain medium for amplification and Raman gain coefficient is independent of type of transmission fiber used. In case of distributed amplification, as shown in Figure 5(b), gain medium is transmission fiber and Raman gain coefficient depends on the type of transmission fiber used.An important difference between the RA and the EDFA is that due to fixed energy levelsof Er^{3+}, the amplification band of the EDFA devices are fixed.

Analysis of BER for Different Bandwidths

When data is transmitted over a data link through optical amplifiers, there is a possibility of errors being introduced into the system due to the Amplified Spontaneous emission (ASE) noise. If errors are introduced into the data, then the integrity of the whole system may be decrease. As a result, it is necessary to assess the performance of the proposed system. The performance of the proposed system is judge through BER. BER help in testing the actual performance of a system, rather than testing the component parts.Using Eqs.(6), (8) and considering following variable values a Bit Error Rate (BER) is plotted as a function of input power (dBm) as shown in Figure 6. An 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 15dB (means 31.62 photon out per photon in) for existing fiber Raman Amplifier.

It is seen that BER increases with increase in input power and bandwidth. Figure 6 shows that to use more bandwidth we need more input power. For example, when we use 4* R_b, we need –1.8 dBm whereas for 6* R_b, we need –1.2 dBm. Here effect of crosstalk is not considered for different bandwidths.

Power Penalty Analysis for Raman Amplifier

In order to calculate Power penalty from crosstalk, we first calculate the power without crosstalk and then calculate the power with crosstalk. The difference between the two will gives us Power penalty. We have computed the Power Penalty at reference BER scale of 10^{-10}. Consider the following values:

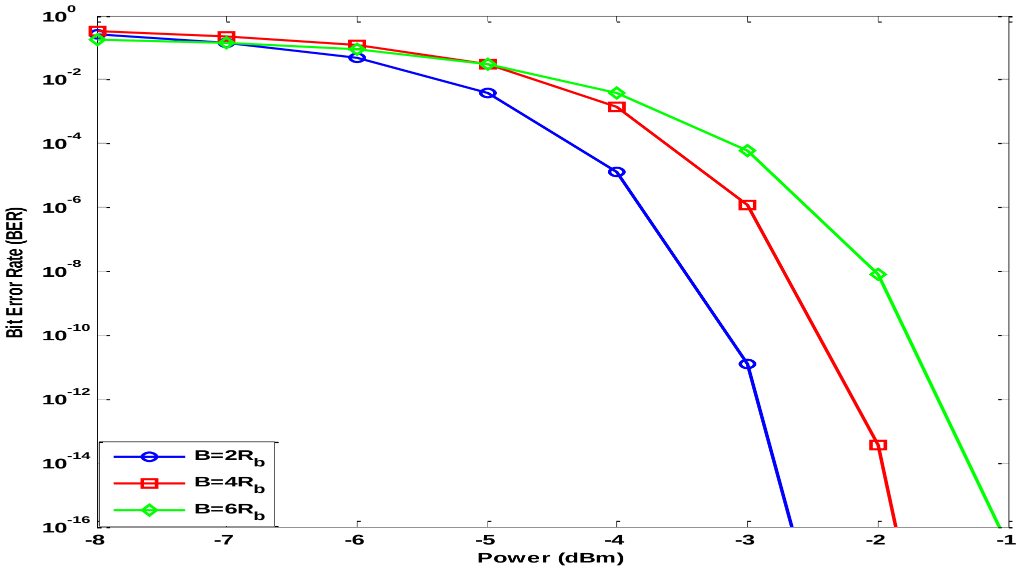


Fig.6: *BER as a Function of Input Power (dBm) withDifferent Bandwidths for RA.*

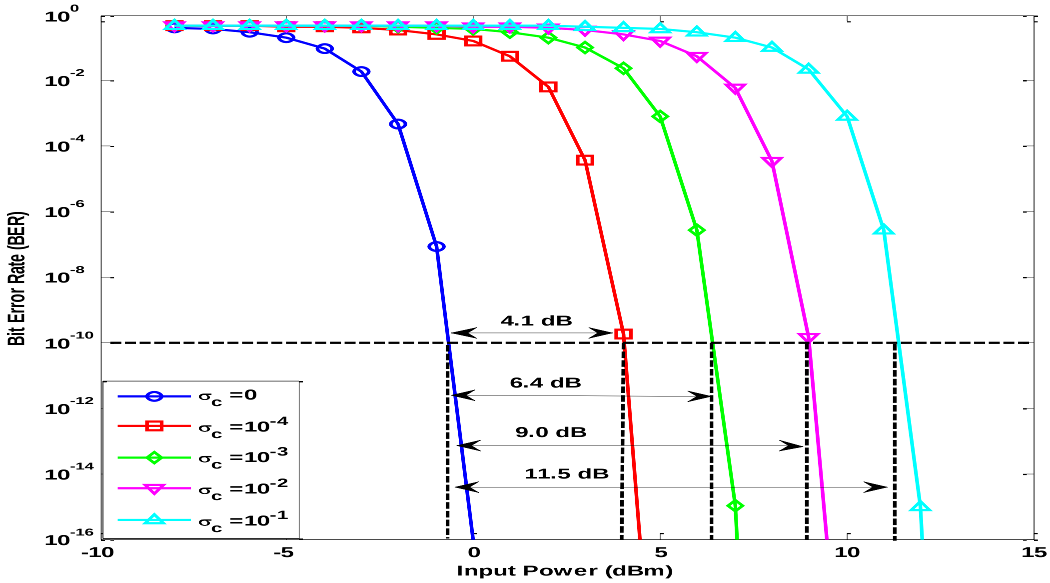


Fig.7:*BER as a Function of Input Power (dBm) with Different Crosstalk for RA.*

Bit Rate (R_b) equal to $10\,GHz$, spontaneous emission factor (n_{sp}) equal to 1.8, $h = 6.634 \times 10^{-34}$ and Gain (G) of 40 dB. Using the above method and putting values in (8),from Figure 7 we will get the result as shown in Table 3.

Table 3:*ShowsValues of Power Penalty Corresponding to Crosstalk for Raman Amplifier.*

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

Above table shows as the crosstalk value increases, the requirement of input power increases and of course power penalty increases. This is a major problem in WDM systems.

Semiconductor Optical Amplifier

Semiconductor Optical Amplifier (SOA) is similar to that of a semiconductor laserwithout the end mirrors. It is similar to a double hetero structure laser diode [3].In the 1970's Zeidler and Personick carried out early work on SOA [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 Figure 8.

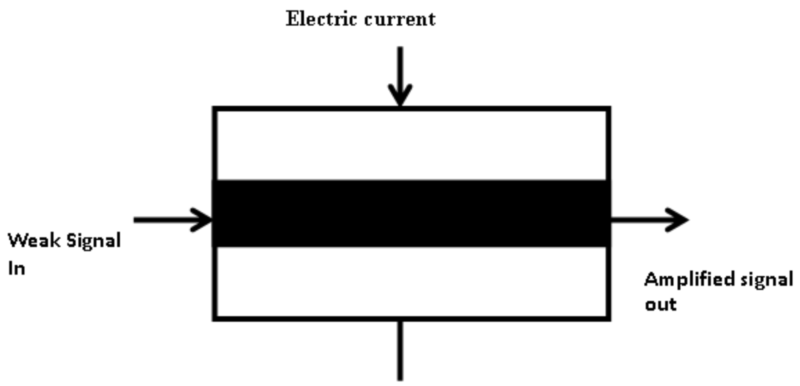


Fig.8: *Semiconductor Optical Amplifier*.

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]. Transfer of an electron from the valence band to the conduction band (with the absorption of energy) results in the creation of an electron-hole pair. One way in with this occurs is through the absorption of a photon, as in a photodetector. The reverse phenomenon, electron-hole recombination (with release of energy), occurs either nonradiatively (by transferring energy to the crystal lattice) or radiatively, with the emission of a photon [13].

Analysis of BER for Different Bandwidths

Using Eqs.(7, 8) and considering following variable values a Bit Error Rate (BER) is plotted as a function of input power (dBm) as shown in Figure 9.Bit rate (R_b) nearly equal to 10 GHz, input power between the range from –8 to 100 dBm, spontaneous emission factor (n_{sp}) equal to 1.8 and Gain (G) of 25 dB (means 316.22 photon out per photon in) for SOA.

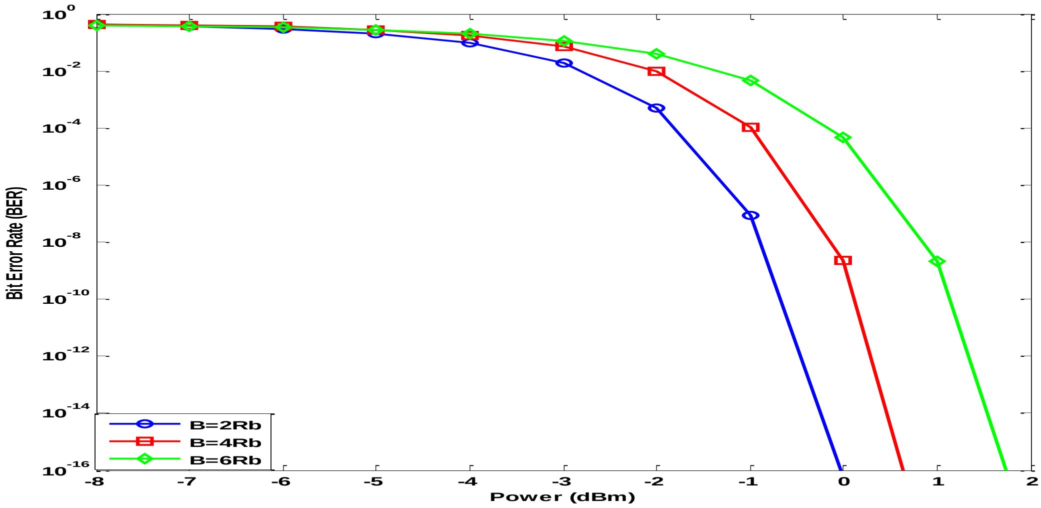


Fig.9:*BER as a Function of Input Power (dBm) withDifferent Bandwidths for SOA.*

It is seen that BER increases with increase in input power and bandwidth. Plot Figure 9 shows that to use more bandwidth we need more input power. For example, when we use 4* R_b, we need 0.6dBm whereas for 6* R_b, we need 1.7dBm.Here effect of crosstalk is not considered for different bandwidths.

Power Penalty Analysis for Semiconductor Optical Amplifier (SOA)

In order to calculate Power penalty from crosstalk, we first calculate the power without crosstalk and then calculate the power with crosstalk. The difference between the two will gives us Power penalty. We have computed the Power Penalty at reference BER scale of 10^{-10}. Consider the following values:

Bit Rate (R_b) equal to 10 GHz, spontaneous emission factor (n_{sp}) equal to 1.8, $h = 6.634 \times 10^{-34}$ and Gain (G) of 40 dB.

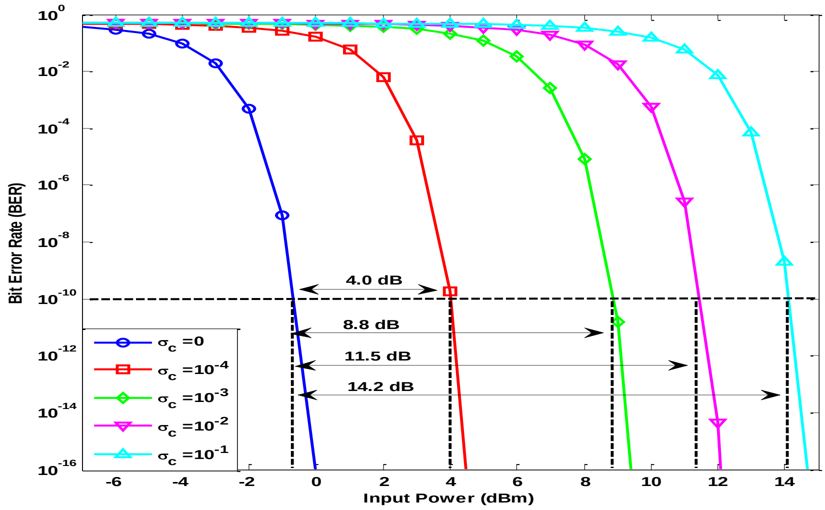


Fig.10:*BER as a Function of Input Power (dBm) with Crosstalk for SOA.*

Using the above method and putting values in (8), from Figure 10 we will get the result as shown in Table 4.

Table 4: *Shows Values of Power Penalty Corresponding to Crosstalk for SOA.*

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

Above table shows as the crosstalk value increases, the requirement of input power increases. This is a major problem in WDM systems and of course Power Penalty increases. Using values of Tables 2–4 the following plot between the Power Penalty and crosstalk is plotted for various cases.

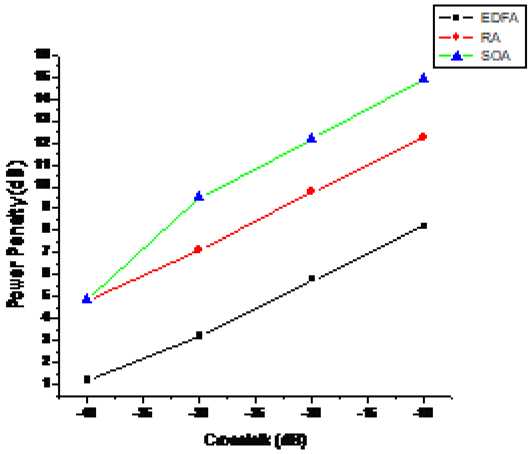


Fig. 11: *Power Penalty as a Function of Crosstalk for EDFA, RA and SOA.*

EDFA has high pump power utilization due to less power penalty increment with increase in crosstalk as shown in Figure 11. So, EDFA simultaneously amplify a wide wavelength band in the 1550 nm region, with a flat gain. Power Penalty is less for EDFA and highest for SOA. That is why, SOA amplifiers do not use in WDM optical networks much.

CONCLUSION

Authors try to calculate the power penalty for EDFA, RA and SOA with gain (G) of 40, 15,25 dB, respectively at 1550 nm. Various plots showthat BER increases, with the increase in input power and also with increase in bandwidth. Authors have calculated the Power penalties for EDFA, RA and SOAwith the help of graph of BER against input power (dBm) for different crosstalk with fixed bandwidth.It has been found that power penalty of SOA w.r.t to other optical amplifier is high at 1550 nm wavelength and also increases with the increase of crosstalk phenomenon. But non linearity can be of use in SOA as wavelength converter. RA is compatible with installed Single Mode Fiber and hence can be used to extend EDFA as shown in Figure 1. Only problem with EDFA is that EDFA are not small and cannot be integrated with other semiconductor devices.

REFERENCES

1. Mahmud Wasfi. Optical Fiber Amplifiers-Review. International Journal of Communication Networks and Information Security 2009; 1(1): 42p.
2. N. A. Olsson. Lightwave Systems With Optical Amplifiers.*J. Lightwave Technol.* 1989; 7: 1879p.
3. Rajappa Papannareddy. *Lightwave Communications Systems: A Practical Perspective*", 2007; 95p.
4. O.Belker and J.R. Simpson. *Erbium doped fiber amplifier-Fundamental and Technology*1999; 204p.

5. John D. Downie, and A. Boh Ruffin. Analysis of Signal Distortion and Crosstalk Penalties Induced by Optical Filters in Optical Networks. *J. Lightwave Technol.* 2003; 21: 1879p.
6. Govind P. Agrawal. *Fiber – Optic Communication systems*. 3rd Edn., 262p.
7. A. Mori, Y. Ohishi and S. Sudo. Erbium-doped tellurite glass fibre laser and amplifier. *Electron. Lett*. 1997; 33(10): 863–864p.
8. V. Kalavally, M. Premaratne, I. Rukhlenko,T. Win , P. Shum, M. Tang. Novel Directions in Raman Amplifier Research. *Information, Communications and Signal Processing-7th International Conference*, 8–10 Dec.2009.
9. G. Zeidler and D. Schicetanz. Use of laser amplifiers in glass fibre communication systems. *Siemens Forchu. Entwickl. Ber.* 1973; 2: 227–234p.
10. S. D. Personick. Applications for quantum amplifiers in simple digital optical communication systems, *Bell Syst. Tech. J.*1973;52: 117–133p.
11. Vikas Thakur, Ms. Geetanjli Pandove, Tarun Gupta. Optical Wavelength Converters based on cross gain modulation and cross phase modulation in SOA. *International Journal of Electronics and Computer Science Engineering*2012; 1: 1274–1280p.
12. Kristian E. Stubkjaer. Semiconductor Optical Amplifier-Based All-Optical Gates for High-Speed Optical Processing. *IEEE Journal on selected topics in Quantum Electronics*2000; 6(6): 1428–1435p.
13. Stefan Diez, Carsten Schmidt, Reinhold Ludwig, Hans G. Weber, Kristof Obermann, Stefan Kindt, Igor Koltchanov, and Klaus Peterman. Four-Wave Mixing in Semiconductor Optical Amplifiers for Frequency Conversion and Fast Optical Switching. *IEEE Journal on selected topics in Quantum Electronics* 1997; 3(5): 1131–1145p.