

Investigation of EDFA based 32 Channel C-Band Optical WDM System for Different Pumping Techniques

Mehtab Singh¹ and Rajveer²

ECE Department

Satyam Institute of Engineering and Technology, Amritsar, India
¹mehtab91singh@gmail.com, ²rajveerbhagat@yahoo.com

Abstract

With the rise in demand for channel capacity, Wavelength Division Multiplexing (WDM) technique is employed in optical communication networks. Gain Flattened Erbium Doped Fiber Amplifier (EDFA) is used in optical WDM system to obtain a uniform output power level. The performance of EDFA depends on various parameters such as fiber length, pump power, pumping wavelength and pumping technique. The objective of this paper is to analyze the performance of EDFA for different pumping techniques namely co-propagating, counter-propagating and bidirectional propagating in a 32 channel C-band optical WDM transmission system at different levels of pump power and different fiber lengths. The system has been analyzed on the basis of received power, BER, gain, noise figure and Q- Factor in the wavelength range of 1528nm to 1562nm at -25dBm transmission power and 0.5nm channel spacing. The results obtained using different pumping techniques are compared to find an appropriate pumping technique which optimizes the performance of the optical WDM transmission system.

Keywords: WDM, EDFA, pumping techniques, BER, Q- Factor, received power

1. Introduction

In order to achieve high data transmission rate, long lifespan, and large capacity optical amplifiers are essential features in optical WDM communication system networks as they are capable of compensating the loss incurred by transmission of information signal through the transmission medium, power splitters for multiple connectivity points and passive networks components [1]. In optical WDM transmission technique, many information carrying signals at different wavelengths are transmitted using the same fiber at the same time in order to increase the capacity of the transmission system of the order of hundreds of Gigabytes per second over a transmission distance of hundreds of kilometer [2]. Today, many nations have employed optical WDM system as a backbone to their Internet Infrastructure to achieve high data rates and channel capacity.

Optical Amplifiers can be utilized as in-line optical amplifiers, pre-optical amplifiers and booster optical amplifiers, in order to efficiently transmit the information carrying signal at a distance of more than 100 km, which has been a major area of concern for communication systems these days.

In order to reduce loss in data transmission, optical amplifiers are capable of providing an advance complicated solution. Optical amplifiers are capable of increasing the power of incident light carrying information by a stimulated emission process or optical power transmission process. Optical amplifiers are largely used in optical WDM systems which have high number of channels and require high pump power. Optical pumps generally consist of semiconductor lasers having an output range varying from 20-40 dBm, which can cause great damage to the human eye, skin and also possibly can cause fiber damage if the information carrying beams are intense and are spread throughout the edges of the fiber [3, 7]. Another important challenge which is faced by optical amplifier is the noise

which is generated by the amplifier also known as Amplifier Stimulated Noise (ASE) and also the cross talk between different channels produced due to non-linear effects in optical fiber link [4].

Optical Amplifiers are capable of enhancing power budget, which as a result reduces total number of connectivity points. Optical amplifiers designs are also capable of reducing the disastrous effects of chromatic dispersion and fiber attenuation which as a result improves the performance of long-haul fiber optic transmission link [12]. Optical amplifiers provide a better performance than old generation electronic regeneration systems which convert electrical signal to optical signal and vice-versa to transmit signal in a long-haul optical communication link.

In this paper, analysis has been done to evaluate the performance of EDFA in a 32-channel C-band WDM optical communication link for different pumping techniques. Performance has been evaluated on the basis of received power, BER values, eye diagrams, gain, noise figure and Q-Factor values.

The rest of the paper is organized as follows: In Section 2, a literature survey is presented. In Section 3, Erbium Doped Fiber Amplifier (EDFA) is discussed in brief and also simulation setup is presented. Results and discussions are discussed in Section 4. The conclusion to this paper is given in Section 5.

2. Literature Review

The following section shows researches carried out by different authors to investigate the performance of EDFA in an optical WDM transmission link.

- M.C. Paul, A. Pal, M. Pal, A. Dhar, R. Sen, S.K Bhandra, K. Dasgupta [5], presents the comparison of EDFA noise figure and power gain using different pumping techniques for a 16 channel WDM optical transmission link. Brief introduction about different pumping techniques has been given and also the comparison between them has been presented.
- R.S Kaler and R. Kaler [6], discussed to the performance of EDFA on the basis of noise figure and gain of EDFA and compact EDFA.
- M.A Malek and A. Malekmohammadi [7], described the gain optimization of EDFA having 32X10 Gbps data rate. In this paper, the technique to optimize gain of EDFA for a 32 channel optical WDM system is presented.
- R. Vijaya and R. Deepa [8], presented the scope of utilization of bidirectional pumping technique in EDFA for single and multiple channel optical WDM systems.
- F. Vasile and P. Schiopu [9], discussed the performance analysis of different pumping techniques in an EDFA for optical WDM transmission system.
- R.F Souza, S Milo, M.B.C. Silva, E. Conforti and C. Bordonalli [10], presented the theoretical of utilization of different wavelength and configuration of EDFA in a WDM system.

3. Simulation Design and Analysis

3.1. System Consideration

Any communication system consists of three basic sections: transmitter, communication channel, and a receiver. In this investigative study Optisystem 7.0 simulation software has been used to carry out different simulations and to compare results. The transmitter section consists of a 32 channel optical WDM transmitter and an ideal multiplexer which combines all the channels into a single fiber. The communication channel consists of an ideal isolator which prevents the light from propagating in the

backward direction. Communication channel also consists of an EDFA amplifier which amplifies the input signal. An optical fiber of length 50 km is used in this analysis. At the receiver end, PIN diode is used as a photo detector followed by a low pass filter which removes any high-frequency noise present in the signal.

3.2. WDM System Design

The WDM system used for this analysis is designed using Optisystem 7.0 simulation software. In this simulation, 32 channels have been used at the input having wavelength range between 1530nm to 1560 nm with channel spacing of 0.8nm at a data rate of 10 Gbps. -25 dBm input power is given to all the channels. The length of optical fiber is taken to be 50 km. EDFA fiber amplifier is used to amplify the input signal which is pumped at different power levels at 980 nm wavelength. The isolator is used at the input side in order to avoid any effects of ASE produced during amplification in WDM system. Isolator also prevents the information signal from traveling in the backward direction. In this paper, a comparison between three pumping techniques is considered *i.e.*, co-directional pumping, counter pumping, and bidirectional pumping.

3.2.1. Co-directional Pumping (Forward Pumping): In co-directional pumping, both input signal and power signal travel in the same direction inside the optical fiber. A pump combiner or wavelength division multiplexer is used to combine both input signal and pump signal. The pump signal transfers its energy to input signal and the information carrying signal gets amplified at the output of the fiber. Isolators are also used to ensure that signal travel only in forward direction and are not reflected backward. Figure 1 shows the basic principle of co-direction pumping laser.

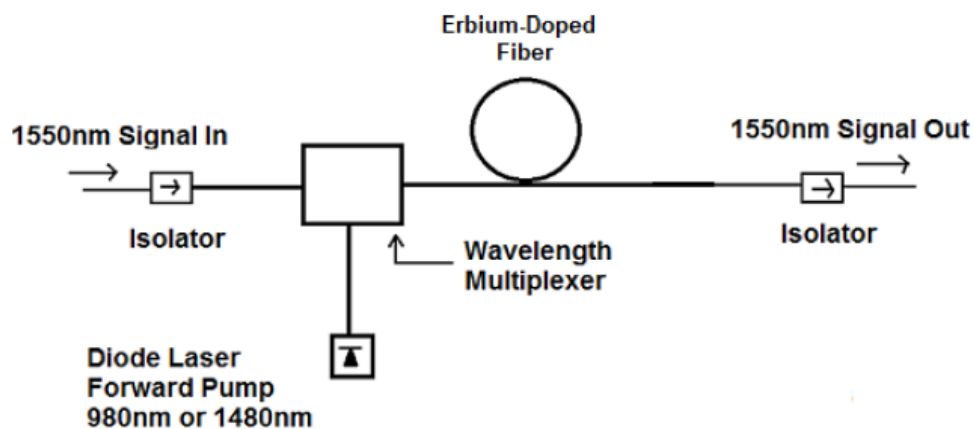


Figure 1. Co-direction Pumping [11]

3.2.2. Counter Pumping (Backward Pumping): In counter pumping, the input signal and the power signal travel in opposite direction inside the optical fiber. In backward pumping, the direction of the signal is insignificant. The information carrying signal gets amplified while traveling in opposite direction. Figure 2 describes the principle of counter pumping laser.

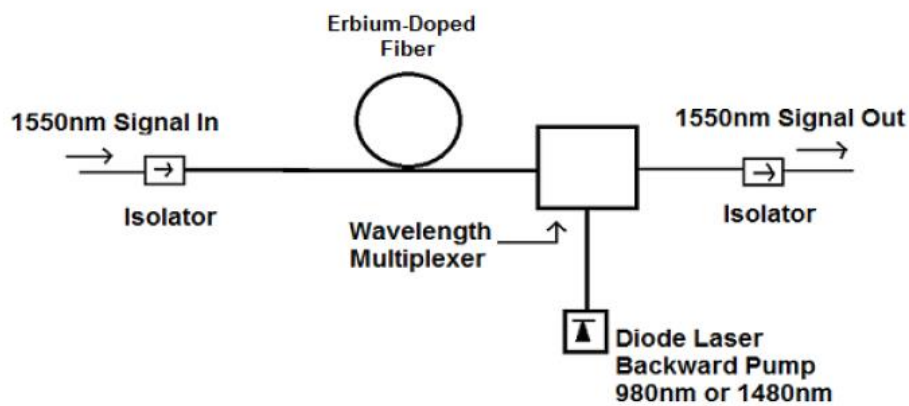


Figure 2. Counter Pumping [11]

3.2.3. Bidirectional Pumping: In bidirectional pumping, the input signal travels in the forward direction. But in bidirectional pumping, two pump laser are used which travel in both forward and backward direction inside the fiber along with the input signal. Figure No. 3 describes the principle of bidirectional pumping.

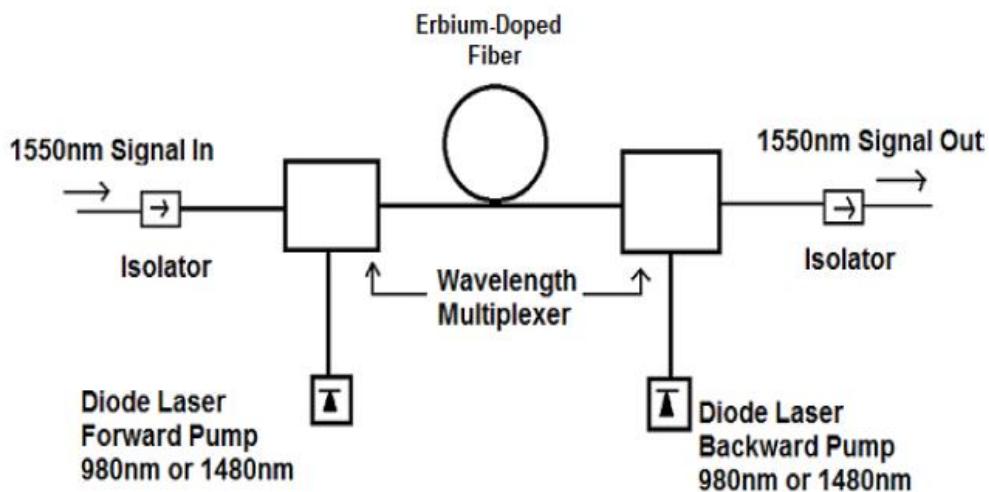


Figure 3. Bidirectional Pumping [11]

4. Results and Discussions

In this paper, Optisystem 7.0 simulation software has been used to carry out various simulations. Different pumping techniques are considered in a 32 channel optical WDM transmission system and their results are compared at different power levels of pump transmitting power and different fiber lengths. The input power of all the optical channels is taken to be -26 dBm, fiber length is taken to be 50 km. The transmitting power of pump laser is varied from 20 mW to 100 mW and EDFA length is varied from 20 m to 60 m in all configurations of EDFA pumping. Table 1 shows a comparison between the value of input power levels and output power levels of EDFA at different power levels of pump lasers for co-directional pumping technique.

Table 1. Input and Output Power Levels for Different Pump Power Levels in Co-directional Pumping Technique

Pump Power to EDFA (mW)	Input Power (dBm)	Output Power (dBm)
20	-12.593	7.940
40	-12.593	12.593
60	-12.593	14.834
80	-12.593	16.320
100	-12.593	17.432

Table 2 shows a comparison between the value of input power levels and output power levels of EDFA at different power levels of pump lasers for counter pumping technique.

Table 2. Input and Output Power levels for different Pump Power Levels in Counter Pumping Technique

Pump Power to EDFA (mW)	Input Power (dBm)	Output Power (dBm)
20	-12.593	-1
40	-12.593	-1
60	-12.593	-1
80	-12.593	17.078
100	-12.593	15.998

Table 3 shows a comparison between the value of input power levels and output power levels of EDFA at different power levels of pump lasers for Bidirectional pumping technique.

Table 3. Input and Output Power Levels for Different Pump Power Levels in Bidirectional Pumping Technique

Pump Power to EDFA (mW)	Input Power (dBm)	Output Power (dBm)
20	-12.593	12.488
40	-12.593	16.164
60	-12.593	18.136
80	-12.593	19.489
100	-12.593	20.521

From the above-presented tables, it can be seen that best performance is given by bidirectional pumping technique as it gives the maximum value of output power for each case whereas in the case of counter pumping technique the output power is negligible up to 80 mW input power which is considered as very high value.

The performance comparison between co-directional, counter and bidirectional pumping techniques in terms of BER and Q-factor is shown in Table 4.

Table 4. BER and Q-factor for Different Pumping Techniques at Different Pump Power Levels

Pump Power to EDFA (mW)	Co-Directional Pumping				Counter Directional Pumping				Bidirectional Pumping			
	Channel 1		Channel 2		Channel 1		Channel 2		Channel 1		Channel 2	
	BER	Q - Factor	BER	Q - Factor	BER	Q - Factor	BER	Q - Factor	BER	Q - Factor	BER	Q - Factor
20	1.23 e-024	10.1686	2.05 e-023	9.88909	1	0	1	0	5.45 e-025	10.2471	3.26 e-024	10.0715
40	8.94 e-25	10.1992	2.32 e-024	10.1048	1	0	1	0	8.50 e-026	10.4246	1.11 e-025	10.3988
60	6.17 e-026	10.4556	5.66 e-025	10.3434	1	0	1	0	3.83 e-026	10.5005	1.58 e-026	10.5837
80	1.08 e-025	10.4015	3.56 e-024	10.2872	1.68 e-025	10.3604	1.48 e-024	10.1486	6.30 e-027	10.6696	8.16 e-026	10.8583
100	8.31 e-027	10.6448	3.17 e-026	10.5177	7.71 e-024	9.98669	2.87 -024	10.0843	5.06 e-028	10.9020	4.10 e-028	10.921

From Table 4, it can be seen that the value of Q-factor and minimum BER is highest in both channel 1 and channel 2 at the output of the WDM transmission system for bidirectional pumping technique. Also it can be seen that for counter-propagating technique, Q-Factor is 0 for low values of input power levels whereas, in the case of bidirectional and co-propagating technique, Q-Factor increases as input power of pump laser increases.

In this paper, the performance of EDFA has been analyzed on the basis of gain and noise figure for different pumping techniques at different EDFA lengths (20, 40 and 60m) and pump power levels (20, 60 and 100 mW).

4.1. Gain Characteristics

The gain for different pumping configurations has been analyzed on the basis of varying fiber lengths at different levels of pump power 20, 60 and 100 mW as shown in Figure 4, 5 and 6 having a constant value of the signal input. By observing the results, it can be seen that bidirectional pumping technique presents maximum flatness of gain for a larger range of length of fiber at pump power levels of 100 mW whereas counter pumping technique gives worst performance of all the techniques. From the results, it can be concluded that pump power should be increased in the case of larger fiber lengths for more gain flatness and gain.

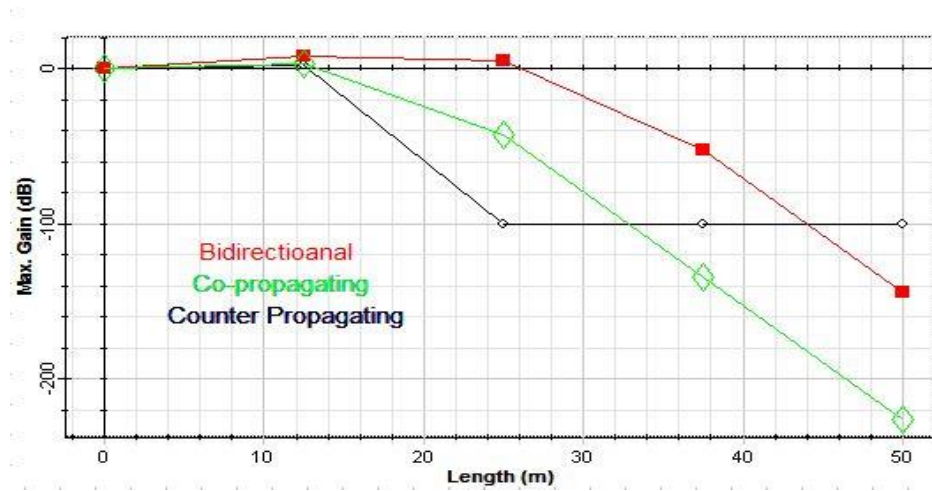


Figure 4. Gain vs. Fiber Length at 20 mW Pump Power

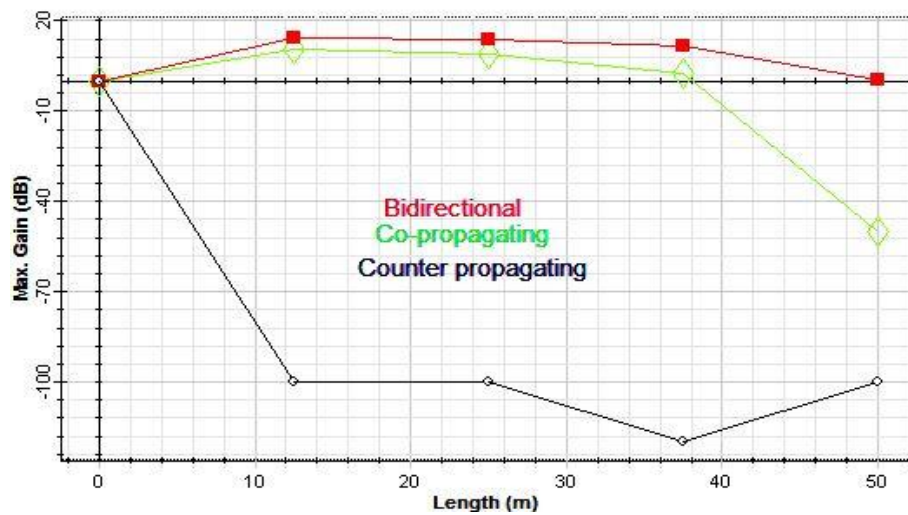


Figure 5. Gain vs. Fiber Length at 60 mW Pump Power

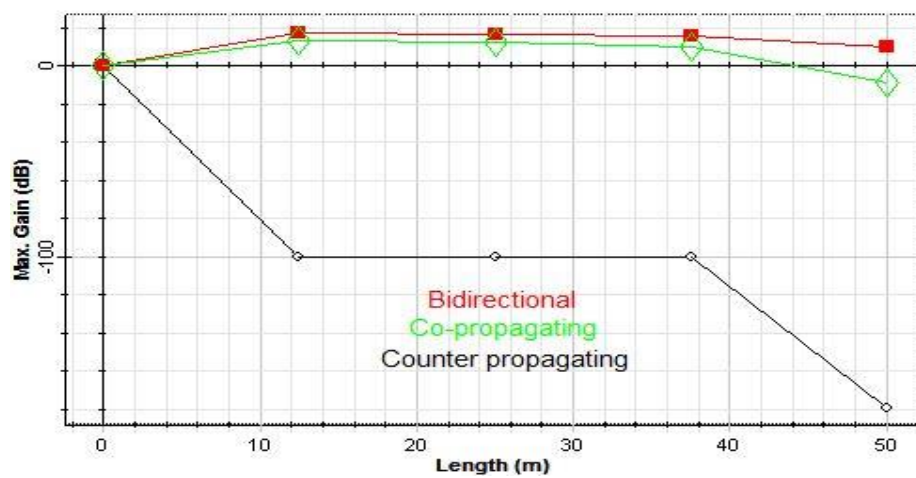


Figure 6. Gain vs. Fiber Length at 100 mW Pump Power

Now the gain for different pumping configurations has been analyzed on the basis of varying pump power levels at different fiber lengths 20, 40 and 60 m as shown in Figure 7, 8 and 9 having a constant value of the signal input. By observing the results, it can be seen that bidirectional pumping technique has more gain flatness for higher values of pump powers at 20 m fiber length. But the gain flatness decreases as the length of the fiber is further increased.

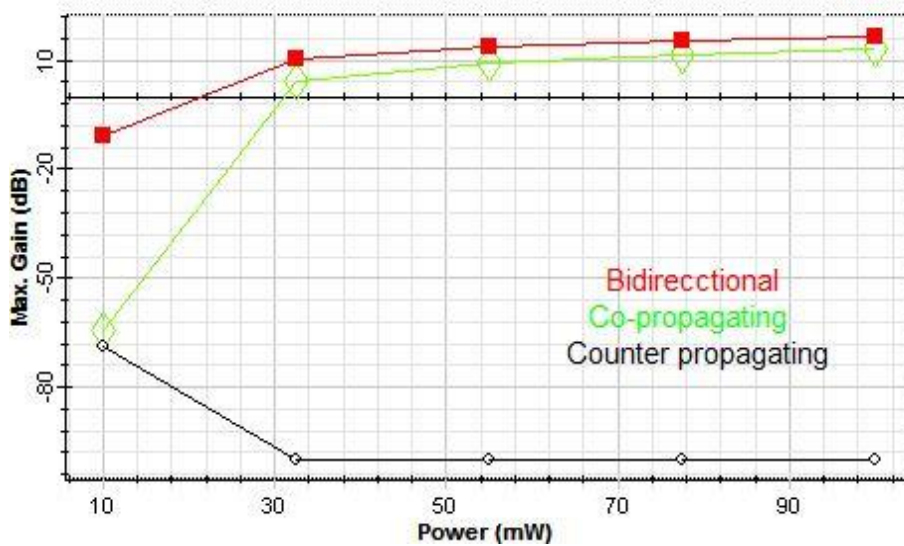


Figure 7. Gain vs. Pump Power at 20 m Fiber Length

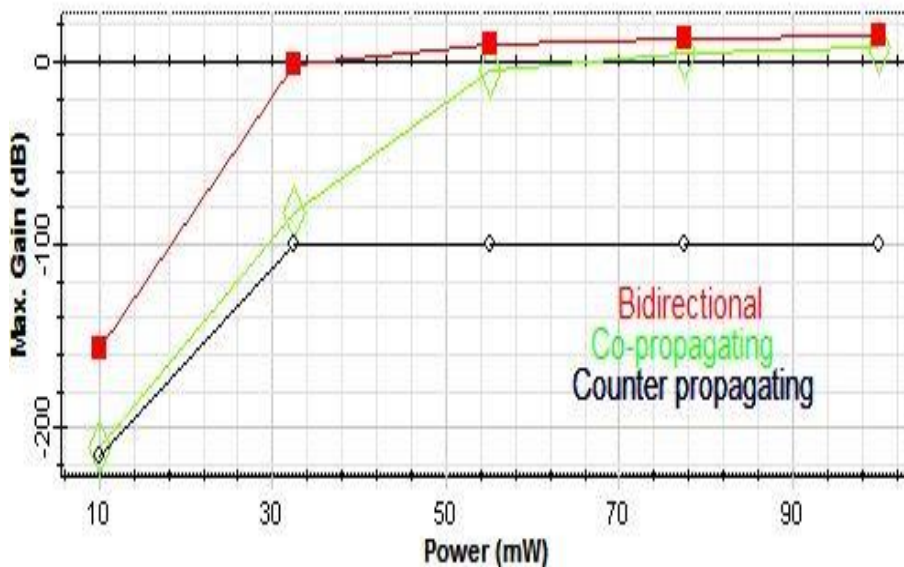


Figure 8. Gain vs. Pump Power at 40 m Fiber Length

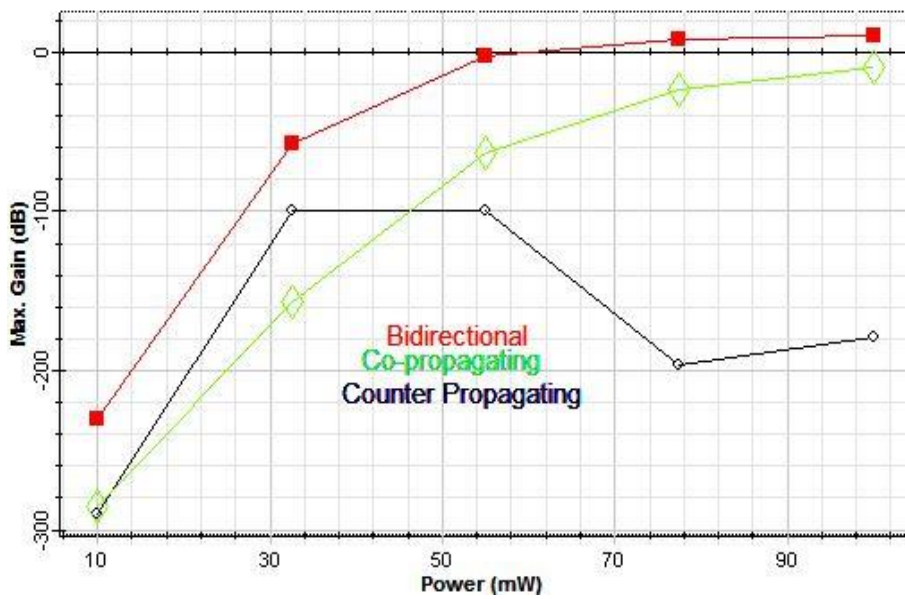


Figure 9. Gain vs. Pump Power at 60 m Fiber Length

4.2. Noise Figure Characteristics

The Noise Figure for different pumping configurations has been analyzed on the basis of varying fiber lengths at different pump power levels 20, 60 and 100 mW as shown in Figure 10, 11 and 12 respectively.

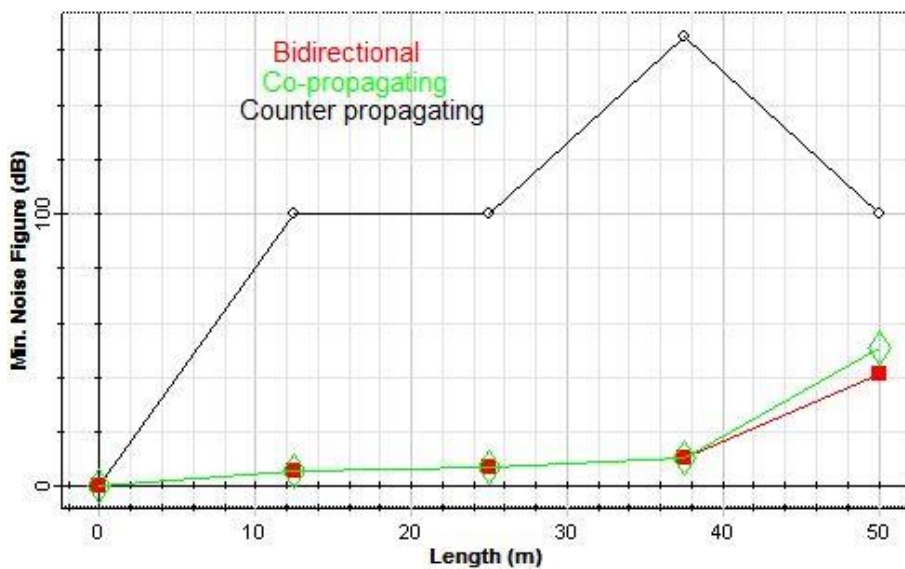


Figure 10. Noise Figure vs. Fiber Length at 20 mW Pump Power

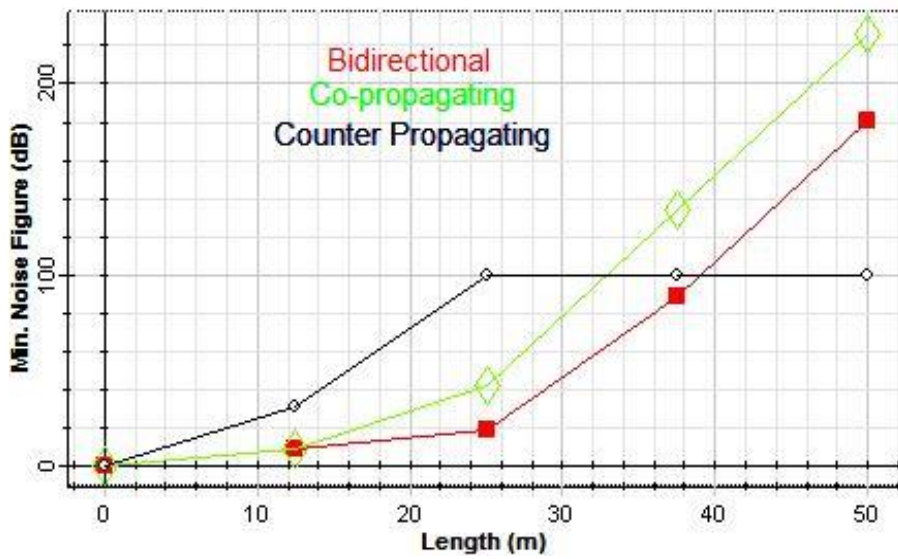


Figure 11. Noise Figure vs. Fiber Length at 60 mW Pump Power

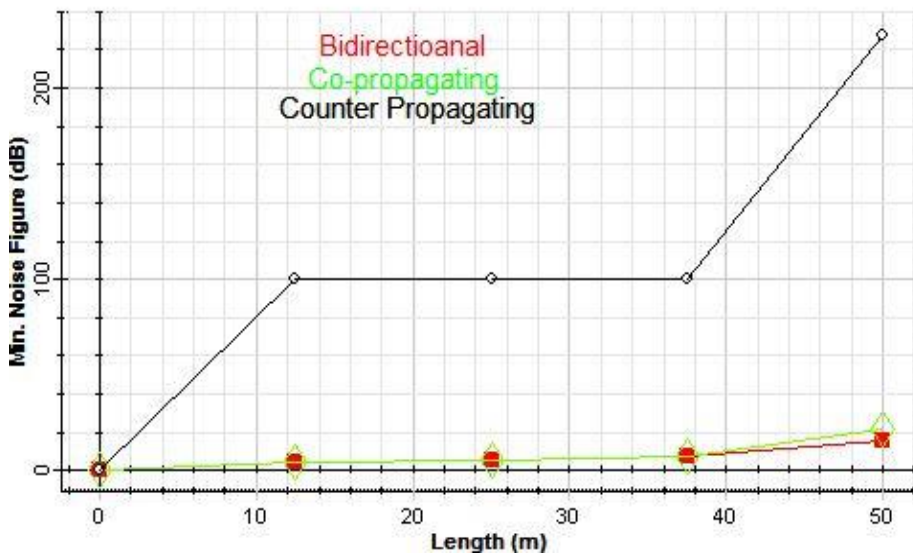


Figure 12. Noise Figure vs. Fiber Length at 100 mW Pump Power

By observing the above-presented results, it can be seen that bidirectional pumping technique provides minimum noise figure at pump power level of 100 mW. The noise figure of different pumping techniques at varying pump power levels at different fiber length 20, 40, 60 m is shown in Figure 13- 15 respectively.

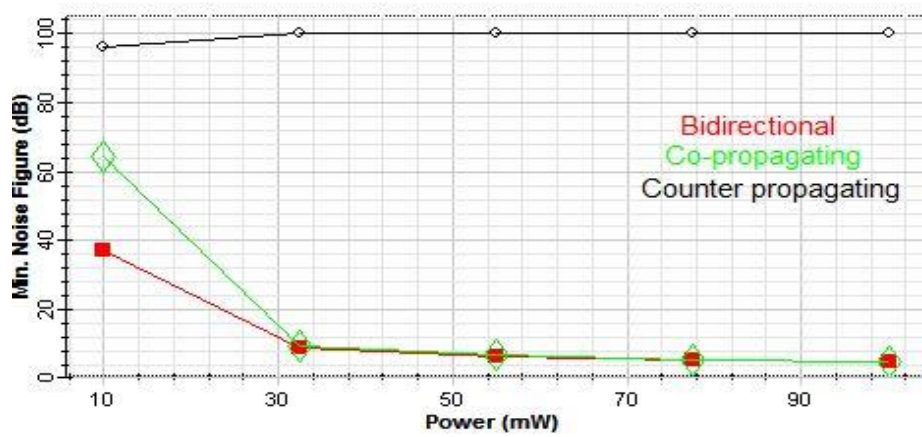


Figure 13. Noise Figure vs. Pump Power at 20 m Fiber Length

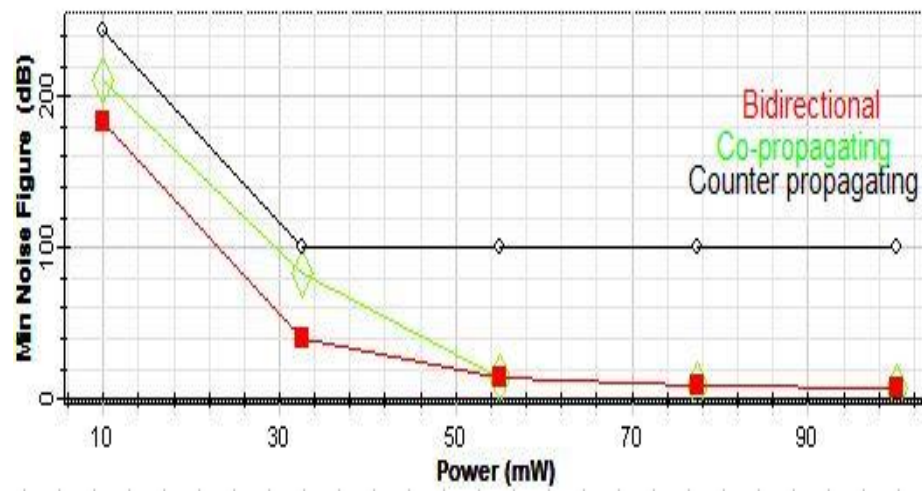


Figure 14. Noise Figure vs. Pump Power at 40 m Fiber Length

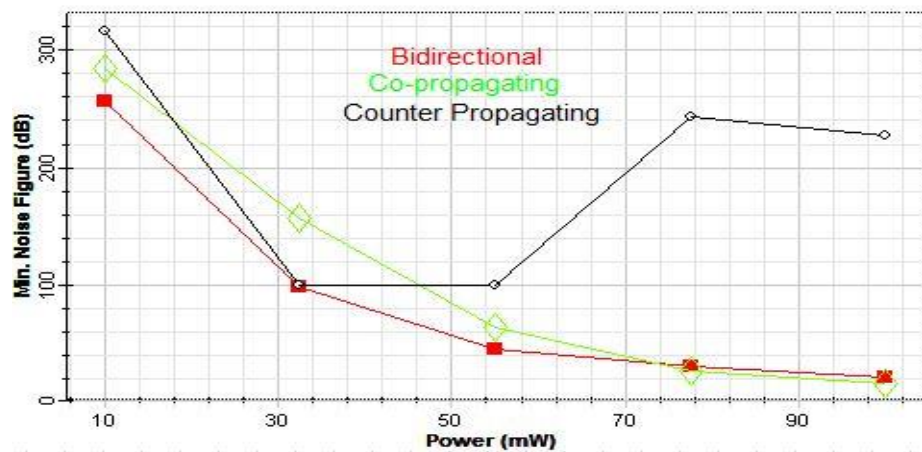


Figure 15. Noise Figure vs. Pump Power at 60 m Fiber Length

From the above-presented results, it can be seen that bidirectional pumping and co-directional pumping provide minimum noise figure in the case of 20 m fiber length but as the length of fiber is further increased, the pumping power levels should also be increased to reduce the noise figure.

5. Conclusion

In this paper, comparison of performance has been done for three different pumping techniques *i.e.*, co-directional pumping, counter pumping, and bidirectional pumping in terms of received power level, BER, gain, noise figure and Q-factor values for pump power varying from 20 mW to 100 mW and fiber lengths varying from 20m to 60 m in an Erbium Doped Fiber Amplifier (EDFA) in C-band at an input power level of -25 dBm and 980 nm wavelength of pump laser. From the results discussed above it can be concluded that the best performance is given by bidirectional pumping technique which gives the highest value of Q-factor, BER and received power levels in each case discussed. By observing the results presented, it can also be concluded that bidirectional pumping provides maximum value of gain with gain flatness over a wide range of pump power levels and a minimum value of noise figure. In the case of counter pumping, the received power is negligible up to 60 mW and then start to increasing as the power of pump laser is further increased.

References

- [1] P. C. Becker, N.A. Olsson and J.R. Simpson, "Erbium-Doped Fiber Amplifiers: Fundamentals and Technology", Academic Press, New York, (1999).
- [2] G. P. Agarwal, "Fiber-Optic Communication Systems", John Wiley & Sons, New York, (1997).
- [3] C. Headley and G.P. Agarwal, "Raman Amplification in Fiber Optical Communication Systems", Elsevier Academic Press, (2005).
- [4] M.N. Islam, "Raman Amplifiers for Telecommunications 1", Physical principles, Springer, (2004).
- [5] M.C. Paul, A. Pal, M. Pal, A. Dhar, R. Sen, S.K Bhandra and K. Dasgupta, "Investigation of the optical gain and noise figure for multichannel amplification in EDFA under optimized pump condition", pp.407-412, Elsevier, (2007).
- [6] R.S Kaler and R. Kaler, "Gain and Noise figure performance of Erbium doped fibre amplifiers (EDFA) and compact EDFAs", Elsevier, (2011), pp. 440-443.
- [7] M.A Malek and A. Malekmohammadi, "Limitation in the intrinsic method of EDFA gain optimization for 32X10 Gbps WDM systems", Elsevier, (2011).
- [8] R. Vijaya and R. Deepa, "Influence of bidirectional pumping in high-power EDFA on single-channel, Multichannel and pulsed signal amplification", Elsevier, (2008), pp. 20-26.
- [9] F. Vasile and P. Schiopu, "The EDFA Performance with gain versus pump power", IEEE Semiconductor Conference, vol. 1, (2004).
- [10] R. F. Souza, S. Milo, M.B.C. Silva, E. Conforti and C. Bordonalli, "An EDFA Theoretical Analysis Considering Different Configuration and Pumping Wavelengths", IEEE Microwave and Optoelectronics Conference, vol. 1, (2003), pp. 105-110.
- [11] A.C. Cokrak and A. Altuncu, "Gain and Noise Figure Performance of Erbium Doped Fiber Amplifiers", Journal of Electrical & Electronics Engineering, vol. 4, (2004), pp. 1111-1122.
- [12] S. Raghavan, J Downie, J Hurley, Y. Mauro and M. Sauer, "Fiber Attributes & Dispersion Compensation Strategies in Optical Communication Systems", International conference on Fiber Optics and Photonics, (2008).

Authors



Mehtab Singh did his B.E in Electronics and Communication Engineering from Thapar University, Patiala, India in the year 2013 and M.Tech in Electronics and Communication Engineering with specialization in Communication Systems from Guru Nanak Dev University, Amritsar, India in the year 2015. Presently, he is working as an Assistant Professor in the department of Electronics and Communication Engineering, Satyam Institute of Engineering

and Technology, Amritsar, India. His areas of interests include Optical Fiber Communication and Communication Systems.



Rajveer did his B.Tech in Electronics and Communication Engineering from Amritsar College of Engineering and Technology, Amritsar, India in the year 2012 and M.Tech in Electronics and Communication Engineering with specialization in Communication Systems from Guru Nanak Dev University, Amritsar, India in the year 2014. Presently, he is working as an Assistant Professor in the department of Electronics and Communication Engineering, Satyam Institute of Engineering and Technology, Amritsar, India. His areas of interests include Optical Communication and Optoelectronic Devices.

