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Analysis of EDFA based 16-Channel C-Band Optical WDM System for Different Pumping Schemes

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ABSTRACT: In this paper, performance of EDFA for different pumping namely co-propagating, counter-propagating and bidirectional in a 16-channel C-band optical WDM transmission system at different levels of pump power and different fibre lengths. Different pump configurations with varying input signal levels show interesting features on gain flatness. The system has been analysed on the basis of gain and noise figure in the wavelength range of 1544.09nm to 1558.17nm with 0.8nm channel spacing at different transmission power. The performance of the WDM system with bidirectional pumping is compared to that with counter pumping and co-pumping. The gain is flattened ≥40dB from 1544.09nm-1558.17nm band of wavelength with noise figure (NF) < 5dB.

Keywords: WDM, EDFA, Pumping configurations, Gain, Noise Figure.

I.INTRODUCTION

Erbium-doped fibre amplifier (EDFA) has revolutionized the optical fibre communication system where propagation losses are no longer a problem now. Further, they are extremely useful in wavelength division multiplexing because they provide uniform gain over a wide range of wavelengths [1]. EDFAs have gain in the range of 40–50 dB amplifier gain depends on various parameters like pump power, length hence is not flat [2]. Therefore, the gain flattening of EDFA is the most important feature especially for the multi-channel amplified WDM systems. After the doped fibre, the output power will become constant for all channels. Several gain flattening techniques have been developed to different pumping schemes used as forward, backward and bi-directional. Gain flattening filters (GFF), Fibre Bragg gratings are used for more optimization [3]. The pump laser is coupled to the erbium fibre by a pump coupler. An input optical isolator prevents amplified spontaneous emission (ASE) and signals from propagating in the backward direction. Otherwise, reflected ASE noise would reduce the population inversion, thereby reducing the gain and increasing the noise figure [4].

F.R.M. Adikan et.al. L-band amplifier system employing ASE noise to improve gain, pumping the system counter-directionally with ASE while the 980-nm pump is being used in a co-propagating configuration would yield the best overall performance in terms of gain and noise figure. For high power applications, the 980nm and ASE sources must be counter-directionally pumped to the direction of the L - band signal. Gain improvement of 1570nm signal in between 6 and 8.5 dB is attained at 12mW of 980nm pump laser.[5].

Mrinmay Pal et al. reported is observed that bi-directional pumping manifests the best combination of low noise and high gain of EDFA which are useful as in-line repeaters in WDM network. The obtain 30±1.5 dB intrinsically flat small signal gain from 1538nm to 1558nm band of wavelength with noise figure <4 dB for 16-channel simultaneous amplification in a single stage EDFA without gain flattening filter [6].

Ramgopal Gangwar et.al. Reported the variation of gain with different parameters is obtained and the values of these parameter are optimized to achieve a maximum value of gain. A two-stage gain-flattened amplifier consisting of two EDFAs are series is also simulated in the operating range of 1565–1610nm, the flat gain of 46 dB is obtained [7]. M.

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M.Ismail et al. simulated using Optical system to achieve gain flatness <10 and noise figure (NF) >9dB for 16-channels simultaneous amplification in a single stage EDFA [8].

It is apparent from the above literature that the methods to reduce the noise figure and maximum gain by the use of EDFA based different pumping schemes in the optical communication system have been comprehensively studied in the past decade. However, the schemes to preserve the pattern of co pumping, counter pumping and bidirectional are still being explored and accessed quantitatively.

In this paper, extended the work for maximum gain flat and low noise figure with using different pumping schemes and without using gain flatting filter (GFF) techniques. After introduction in Section 1, Section 2 presents the EDFA based WDM system description. The results are discussed in Section 3 and conclusions are summarized in Section 4.

II.EDFA BASED WDM SYSTEM DESCRIPTION

The schematic of WDM system used for the analysis is shown in fig1 here, 16 channels have been used at the input having wavelength range between 1546.12nm to 1558.17nm with channel spacing of 0.8nm at a data 10Gb/s with varying input power -30 to -10dBm input power with the advancement of technology, demand for the bandwidth increases. As the number of channels increases and also called dense WDM [9]. As the comparison between three pumping techniques is pumping, and bidirectional pumping.

Table 1 Wavelength of specific channels (ITU-T grid)

Channel no.	Ch#1	Ch#2	Ch#3	Ch#4	Ch#5	Ch#6	Ch#7	Ch#8
Wavelength (nm)	1546.12	1546.91	1547.71	1548.51	1549.31	1550.11	1550.92	1551.72
Channel no.	Ch#9	Ch#10	Ch#11	Ch#12	Ch#13	Ch#14	Ch#15	Ch#16
Wavelength (nm)	1552.52	1553.33	1554.13	1554.94	1555.74	1556.55	1557.36	1558.17

In co-directional pumping, both input signal and power signal pass through in the same direction inside the optical fibre. A pump combiner or wavelength division multiplexer is used to combine both input signal and pump signal. In Backward pumping the input signal and the pump signal propagate in the opposite direction to each other inside the fibre. In Bi-directional pumping the input signal travels in one direct ion. But the there are two pump signals that travel inside the fibre. One pump signal travels in the same direction as the input signal and the other pump signal travels in the opposite direction to that of the input signal [10].

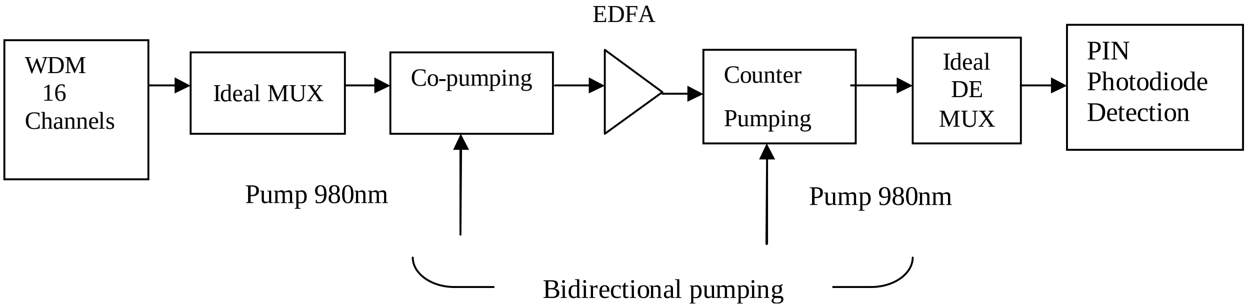

Fig.1 Block diagram of the different pumping techniques

Each input signal is fed to the multiplexer of WDM transmitter. The 16 channels have been used having wavelength range from 1546.12nm to 1558.17nm with 0.8nm channel spacing. An EDFA model based on work by Giles is used the amplifier performance at a high bit rate, the continuous wave (CW) laser, operates in single mode. The optical

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multiplexer is used to combine the signals obtained from the output of pump laser and CW laser, EDFA has metastable lifetime of 10ms [11].The simulation set-up of 16 channel for the different pumping techniques is shown in fig.1. The amplified signals to the channel where these signal are transmitted the different pumping techniques and input power signal. In order to generate the maximum flat gain and low noise fig.2 and 3 In the counter propagating configuration, the situation gets reverse, the lower gain per unit length at the beginning of the fiber is equivalent to having some amount of loss for the signal, before it enters the amplifier. The absence of any other effects, the co-propagating pump configuration is preferred for obtaining a low noise figure and bi-directional pumping results the best combination of gain and NF of EDFA [6].

Table2. Parameters of the different pumping techniques components

Parameters	value
Wavelengths	1546.12 to 1558.19nm
Power	-10,-20,-30dBm
Frequency Spacing	0.8nm
Line width	10MHz
Pumping frequency	980nm /1480nm
Pumping power	200mW
EDFA length	5m to 10m

III. RESULTS AND DISCUSSION

The 16 channel WDM system is carried out to evaluate the performance of co-pumping, counter-pumping and bidirectional pumping technique using EDFA. The input wavelength range between 1546.12nm from 1588.17nm with channel spacing of 0.8nm at a data rate of 10Gb/s with 30dBm input power is given to all the channels.

Table3. Parameters of the different pumping techniques for EDFA

Parameters	EDFA
Length	5m to 10m
Core radius	2.2µm
Er doping radius	2.2µm
Er ion density	1e+025m^-3
Numerical aperture	0.32
Er metastable life	10ms

Table 3 and described the various parameter of the WDM system and different pumping techniques for EDFA. The fibre considered has a core radius of 2.2µm, numerical aperture of 0.32 and is assumed to be uniformly doped with erbium ions of density 1e+025m^-3.

The 16 channel WDM system are shown that the fig.2 maximum flat gain. The important parameter of optical amplifier is amplifier gain, gain efficiency and gain bandwidth, gain saturation and noise. The gain of the amplifier is denoted by G and is given as [12].

$$G = \frac{P_{in}}{P_{out}} \quad (1)$$

Here, P_{in} = input power and P_{out} = output power of continuous wave (CW) signal. The optical gain is maximum flat to the bidirectional pumping schemes as compare to counter and co pumping schemes. It observed that gain for 980nm pump is almost same for forward and backward pumping and for bi directional pumping gain is quite high because two

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laser diodes emitting at 980nm with maximum powers of 200 and 200mW each are used as pump source. Signal is derived from a narrow line width distributed feedback laser lasing at 1546.12nm with a maximum power of 200mW.

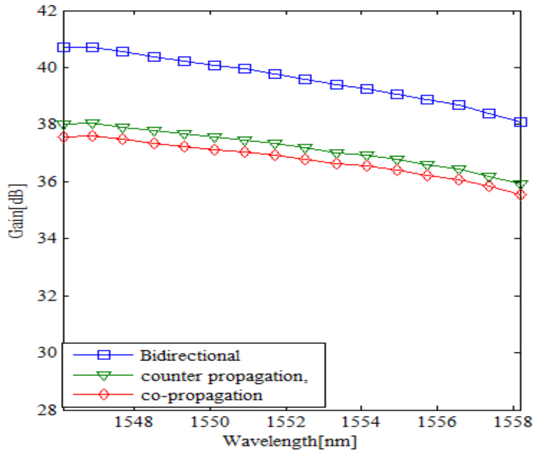

Fig. 2 Gain characteristics for different pumping schemes. No. of signal channel, 16; signal level, -30 dBm/ch; pump power, 200mW, pump frequency 980nm.

ASE noise generated during amplification process is added to the signal leading to decrease in signal to noise ratio (SNR) at the amplifier output. SNR reduction ratio from input to output of the amplifier is defined as Noise Figure (NF), which is also used for electronic amplifiers[12].

$$NF = \frac{SNR_{in}}{SNR_{out}} \qquad (2)$$

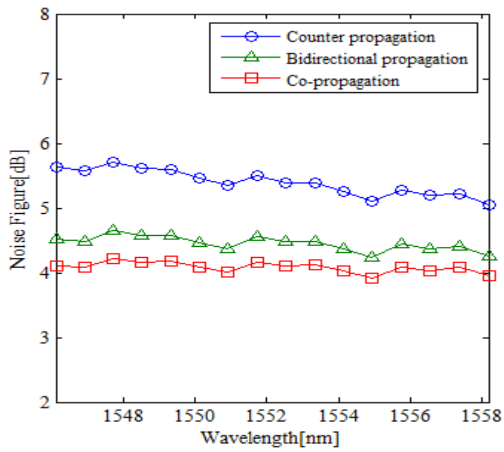

Fig. 3 Noise Figure characteristics for different pumping schemes. No. of signal channel, 16; signal level, -30 dBm/ch; pump power, 200mW, pump frequency 980nm.

It is observed that shown the fig. 3 noise figure for Counter pumping is high than the other pumping schemes. Noise figure for bidirectional pumping and co-pumping is same

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Table4: Comparison of Gain and NF

Different techniques	Gain	NF
Bidirectional pumping [dB]	<40	>4.5
Counter pumping [dB]	<39	>6.5
Co-pumping [dB]	<37	>4

Table 4 represents the comparison of the gain and noise figure for 10Gb/s WDM system. It is evident from the bidierectional pumping value of gain ≤40dBm and noise figure is ≥4.5dBm that -30dBm input power is quite better,where the other pumping schemes gain descreases ≤37dBm and noise figure is increases the ≥6.5dBm.

The constant signal input power, Er^{+3} ion density signal wavelength and pump wavelength from fig4 it is seen that the maximum gain flat is obtained for a wider range of different amplifier length[m] in case of bidirectional pumping configuration at a higher pump power of 200mW.

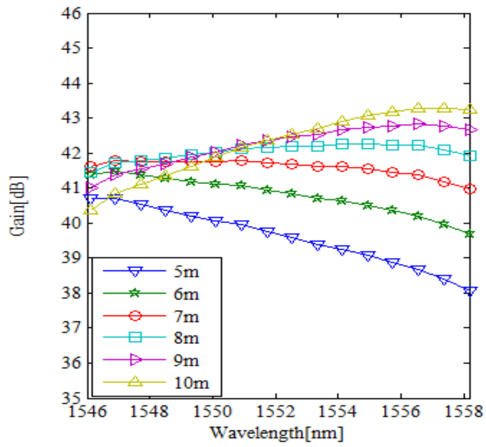

Fig. 4 Different length for bidirectional pumping Configuration No. of signal channel, 16; signal level, -30 dBm/ch; pump power, 200mWpump frequency 980nm.

Table5: Maximum gain of different length (EDFA)

Length[m]	Flat Gain[dB]
5	40.71 to 38.07
6	41.38 to 39.69
7	41.60 to 40.95
8	41.45 to 41.92
9	41.00 to 42.65
10	40.37 to 43.23

The output signal power is calculated as:

$$p_{out} = p_{in} G \quad (3)$$

Where G is the EDFA power gain and p_{in} is the input signal power. The most important feature of the EDFA is gain as it determines the amplification of individual channels for WDM signal is amplified.

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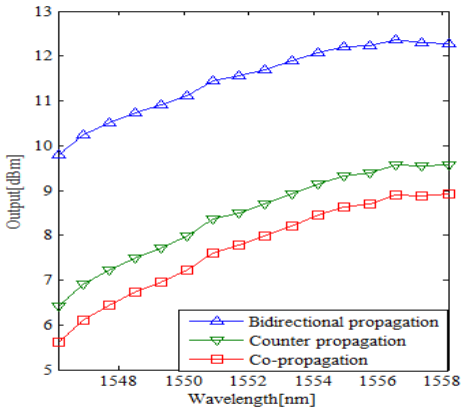

Fig. 5 Output Power [dBm] characteristics for bidirectional pumping configurations. 16 channel, Signal level, -30 dBm/ch; pump power, 200mW, pump frequency 980nm.

The amplified output signal power is degraded due to the ASE noise and the output signal power increases due to the stimulated emission and this is due to population inversion and population inversion is due to pumping power[11]. The fig. 5 is shown that output power is increase with respect to the wavelength.

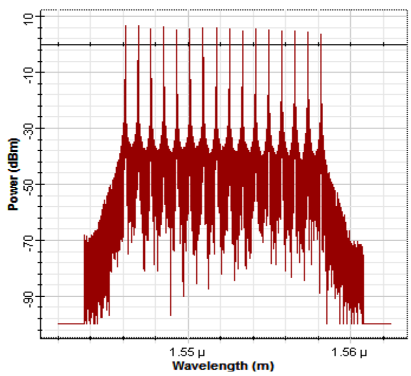

Fig. 6 Optical spectrum of bidirectional pumping Signal channel, pump frequency 980nm.

It has been observed in fig. 6 that optical spectrum of maximum gain flat to using the bidirectional pumping Frequency 980nm. The maximum gain flat is maintained to 16 channels input having wavelength between 1546.12 to 1558.17nm with channel spacing of 0.8nm at 10Gb/s.

IV. CONCLUSION AND FUTURE SCOPE

The successful employment of WDM systems is directly connected to the appearance of high-performance optical amplifiers. Flat-gain optical amplifiers across the whole communication bandwidth are needed to make sure appropriate amplification of each channel in WDM communication systems. In this study, a bi-directional EDFA is designed in such a way that a flattened spectrum is received in C-band with a good gain performance. The co-pumping techniques were founded to be more suitable for techniques its low noise figure and bidirectional pumping is the most suitable for high and low noise figure. Counter pumping design slow high gain but high noise figure also so if good noise figure is requirement then co-pumping is the best method. For high low noise figure bidirectional pumping is most suitable if constant gain is required then counter pumping scheme can be applied.

In future work, the model can be modified and enhanced further by Gain flattening filters (GFF) based on advanced fibre Bragg gratings (FBG) allow amplifier manufacturers to improve gain flatness. Advanced FBGs can be used to replace other GFF technologies in current generation amplifier designs as a simple means to improve gain ripple

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