

Performance Analysis of EDFA for different Pumping Configurations at High Data Rate

Prachi Shukla, Kanwar Preet Kaur

Abstract: - The performance of Erbium Doped Fiber Amplifier (EDFA) depends on various parameters like, Er^{+3} doping concentration, active fiber length, pump power, pumping wavelength etc. In this paper, the analysis of gain and noise figure (NF) of EDFA is done at different pump power (10, 50, & 100mw) and at different fiber length (10, 30, & 50m) for different pumping configuration i.e. forward pumping, backward pumping, and bidirectional pumping operating in C-band at high data rate.

Key Words: Erbium Doped Fiber Amplifier (EDFA), Erbium Doped Fiber (EDF), Gain, Noise Figure (NF).

I. INTRODUCTION

In long-haul point-to-point optical fiber communication the signal traveling inside the fiber suffers from various losses like fiber attenuation losses, fiber tap losses, fiber splice losses, etc., due to these losses it is difficult to detect the original signal at the receiver side. So in order to transmit signal over a long distance in a fiber it is necessary to compensate all losses in the fiber. The introduction of optical amplifiers allowed the signal amplification in optical domain. There was no need to convert the optical signal to electrical signal. There are mainly two types of optical amplifiers: semiconductor optical amplifier and fiber amplifiers. Fiber amplifiers are classified as erbium doped fiber amplifier (EDFA), Raman amplifier and Brillouin amplifier. EDFA is made by a popular material for long-haul telecommunication applications that is a silica fiber doped with erbium (Er^{+3}) ions [1, 2]. Er^{+3} ions are having the optical fluorescent properties that are suitable for the optical amplification. The advent of EDFA has enable the optical signals in an optical fiber to be amplified directly in high bit rate systems beyond Terabits. One of the most important factors limiting the transmission distance in fiber optical communication systems is the optical power loss caused by scattering and absorption mechanisms in optical fiber [4, 7]. EDFA is suitable to operate at the conventional (C) band from about 1530 to 1565 nm. Since the entire C band of EDFA is fully utilized, the need for more optical channels and wider optical bandwidth urges EDFA technology to develop beyond its present limits. To extend the optical bandwidth and increase the number of WDM channels, L-band optical amplifiers are used to operate in longer wavelength from about 1570 to 1605 nm. EDFA by itself has a very low-gain at the L-band, most realizations of L-band EDFA implement a long length of erbium-doped fiber (EDF) to pump up its gain. A typical L-band EDFA also has larger noise figure than C-band EDFA.

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Unlike EDFA have the problems of unpumped amplifier attenuations and the operation wavelength constrained at 1.53-1.56 μm region, Raman fiber amplifier (RFA) has merit of arbitrary gain bandwidth, which were recently being recognized as an enabling technology for high capacity and long-haul density wavelength-division-multiplexing (DWDM) systems. RFA can be used to amplify not only the C-band, but also the S-, L- and other bands, depending on the usage of the pumped wavelengths. RFA has several advantages including lower noise figure (NF), flexibility on the selection of gain medium, and wide gain bandwidth, especially that RFA has the capability to “distribute” the gain over a long distance in the transmission fiber. Thus, L-band optical amplifier is better to adopt RFA rather than L band EDFA [11]. As EDFA can operate in a broad range within the 1550 nm [9, 10] window at which the attenuation of silica fiber is minimum and therefore it is ideal for the optical fiber communication systems operating at this wavelength range. Hence it is very useful in WDM for amplification. According to the research performed in recent years, it is known that the pumping of EDF at 980 nm or 1480 nm is the most efficient way. High gain (30~50dB), large bandwidth (>90 nm), high output power (10~20 dBm) and low NF (3~5 dB) can be obtained using an EDFA optimized for 1550 nm range [3, 5].

II. EDFA ARCHITECTURE

An optical fiber consists of a doped fiber, one or more pump lasers, a passive wavelength coupler, optical isolators, and tap couplers. The wavelength selective coupler couples both the pump and signal optical power efficiently into the fiber amplifier. The tap couplers are wavelength insensitive and are generally used on both sides of the amplifier to compare the incoming signal with the amplifier output. The optical isolators prevent the amplified signal from reflecting back into the device, where it could increase the amplifier noise and decrease its efficiency [2]. Typically, the EDFA configuration can be categorized by pumping schemes into three particular arrangements. These schemes are Forward-pumped (co-pumped), Backward-pumped (counter-pumped), and Bidirectional-pumped (Dual-pumped) [6]. Pumping at a suitable wavelength provides gain through population inversion the gain spectrum depends on the pumping scheme as well as on the presence of other dopants, such as germanium and alumina, within the fiber core [1, 6].

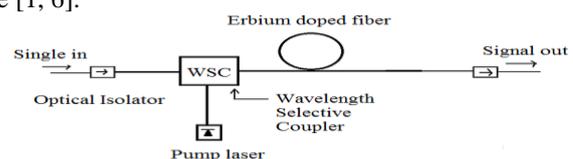


Figure1: Forward pumped EDFA structure

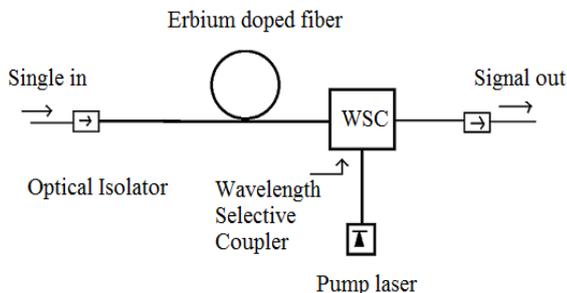


Figure 2: Backward pumped EDFA structure

In forward pumping, figure 1, the input signal and the pump signal propagate in the same direction inside the fiber [2]. The input signal and pump are combined using a pump combiner or wavelength selective coupler. Inside the fiber the pump energy is transferred to the input signal and the signal is amplified at the output of the amplifier. Isolators are used in the scheme to make sure that the signal will travel only in one direction and no feedback of signal will occur.

In backward pumping, figure 2, the input signal and the pump signal propagate in the opposite direction to each other inside the fiber.

In Bi-directional pumping, figure 3, the input signal travels in one direction. But there are two pump signals that travel inside the fiber. 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.

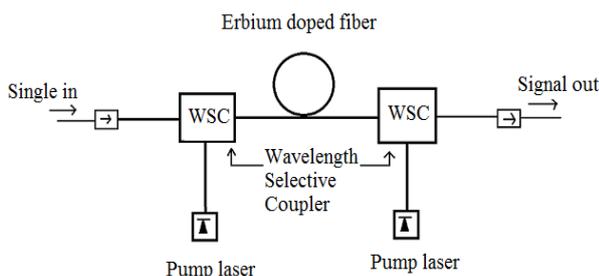


Figure 3: Bidirectional pumped EDFA structure

III. SIMULATION SETUP

An EDFA model based on work by Giles is used to find the amplifier performance at a high bit rate. The simulation set up consist of the continuous wave laser, 100mW peak power of pump laser, operates in single mode and no laser random phase. The optical multiplexer is used to combine the signals obtained from the output of pump laser and CW Laser. EDF has 1552.5 nm wavelength, length 50m (maximum), metastable lifetime of 10ms. The bit-time in simulation, i.e. the time-duration of the bit, must be an integer number of time-samples NS (samples per bit value). Parameters of basic attribute section taken are 10 and 40 Gb/s bit rate and 64 samples per bit. The measurement components used are optical spectrum analyzer and dual port WDM analyzer.

Table I

Typical EDFA Parameters Used In The Simulation Program

Model Parameter	Value
Pump absorption cross section	$1.8 \times 10^{-25} \text{ m}^2$
Signal absorption cross section	$2.14 \times 10^{-25} \text{ m}^2$
Pump emission cross section	$3.15 \times 10^{-25} \text{ m}^2$

Signal emission cross section	$3.80 \times 10^{-25} \text{ m}^2$
Fiber radius	2 μm
Length of EDF	10,30, & 50m
Pumping power	10,50,& 100mw
Signal input power	10 dBm
Signal wavelength	1552.5 nm
Pump wavelength	980nm
Er ⁺³ ion density	$1 \text{e}+025 \text{ m}^{-3}$

This paper focuses on the performance characteristics of the amplifier (gain and NF) assuming the fundamental LP₀₁ mode exciting at the pump wavelength ($\lambda_p = 980 \text{ nm}$) [6]. The gain and NF can be obtained for all the three pumping configurations as a function of two fundamental fiber parameters namely: fiber length, and pump power. Thus, the required fiber parameters and pump power values can be optimized for a desired EDFA gain-NF performance at 10 and 40 Gbps. The main parameters of the simulation are shown in Table I.

IV. RESULTS & DISCUSSION

In this paper the variation of Gain and NF for EDFA is analyzed with different pumping techniques i.e. forward pumping, backward pumping and bidirectional pumping. And also the variation of gain and NF is analyzed for different EDF length (10, 30, & 50 m) and at different pumping power (10, 50 & 100 mW). The length of the EDF depends upon the input signal power, pump power, Er⁺³ ion density and the signal and pump wavelength.

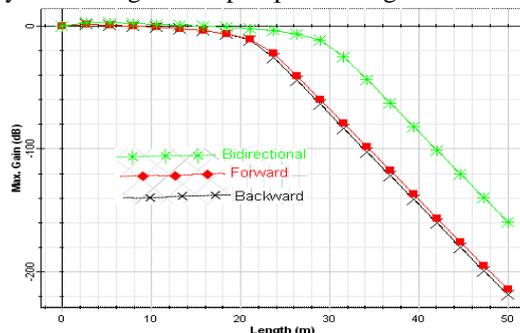


Figure 4: Gain vs. fiber length at 10mW pump power

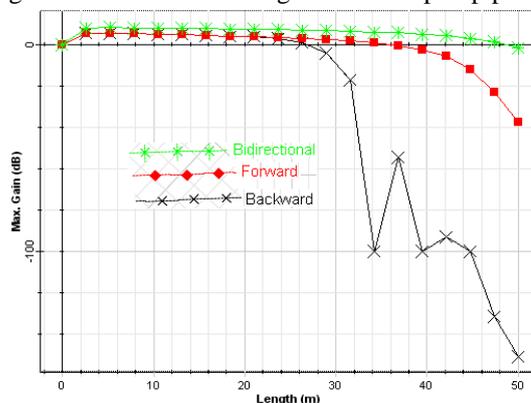


Figure 5: Gain vs. fiber length at 50mW pump power.

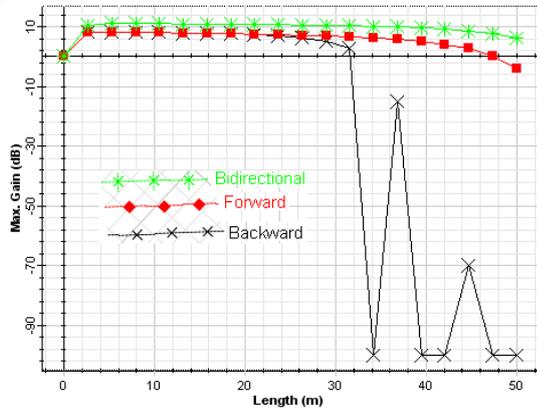


Figure 6: Gain vs. fiber length at 100mW pump power.

Almost same results are obtained for high data rates of 10 Gbps and 40 Gbps. This means that change in data rate does not affect the gain and NF of the three pumping configurations for single channel signal transmission.

A. Gain Characteristics:

The gain of different pumping configuration is varied along with the fiber length is shown in figures 4, 5, and 6 at different pump powers 10, 50, and 100 mW, respectively, having a constant signal input power, Er^{+3} ion density, signal wavelength, and pump wavelength. From the figures it is seen that the maximum gain flatness is obtained for a wider range of fiber length in case of bidirectional pumping configuration at a higher pump power of 100 mW. On comparing the graphs it can be concluded that in case of bidirectional pumping configuration as the fiber length is increased the pump power should be increased to obtain higher value of gain and its flatness for higher range of fiber length. Whereas backward pumping gives the worst results but forward pumping shows acceptable results but values are less than bidirectional pumping configuration. If the Er^{+3} ion density is decreased to $1e+024 m^{-3}$ forward and backward pumping configurations gives flat gain for fiber length range which is less as compared to the Er^{+3} density of $1e+025 m^{-3}$ for bidirectional pumping configuration.

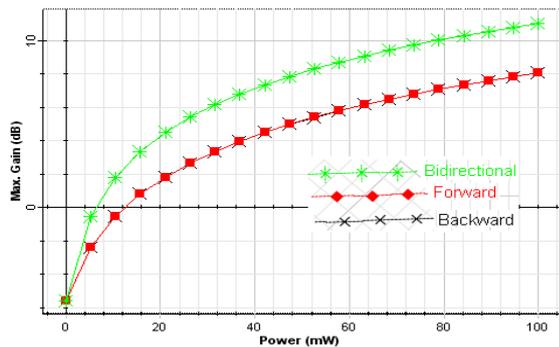


Figure 7: Gain vs. pump power at 10m fiber length

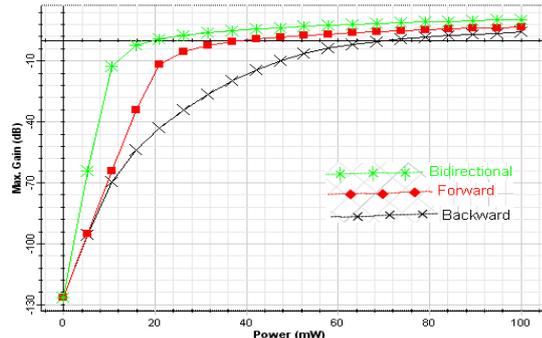


Figure 8: Gain vs. pump power at 30m fiber length

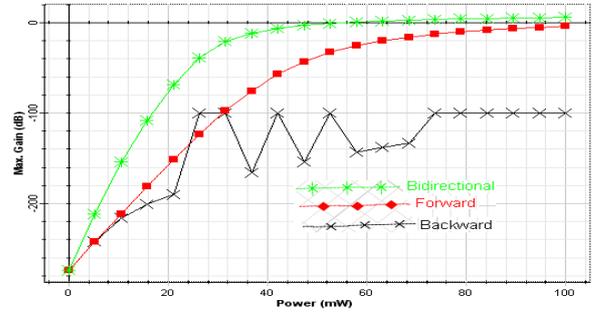


Figure 9: Gain vs. pump power at 50m fiber length

Now gain of different pumping configuration is varied along with pump power for different fiber lengths 10, 30, and 50m at constant parameters mentioned above and is shown in figures 7, 8, and 9, respectively. Comparing figure 7, 8, and 9 it is seen that in the case of bidirectional pumping configuration gain is much flat for wider range of pump power at the fiber length of 30m as compare to forward and backward pumping configuration. But as length further increases gain value decreases. To maintain consistent results Er^{+3} ions density should be kept at $1e+025 m^{-3}$ and is obtained for bidirectional pumping configuration.

B. Noise Figure Characteristics:-

The NF of different pumping configuration is varied along with the fiber length at different pump power 10, 50, and 100 mW as shown in figure 10, 11, and 12, respectively, and the variation of NF with the pump power at different fiber length of 10, 30, and 50m is shown in figure 13, 14, and 15, respectively, having a constant signal input power, Er^{+3} ions density, signal wavelength, and pump wavelength.

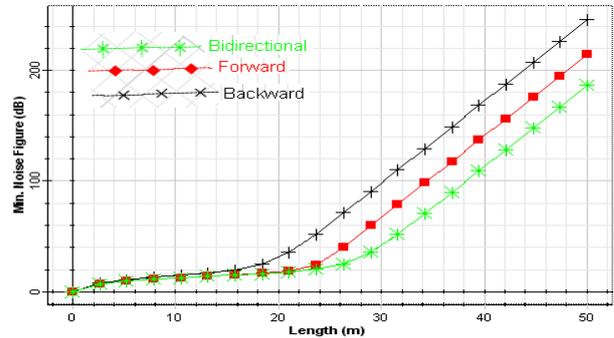


Figure10: Noise figure vs. fiber length at 10mW pump power

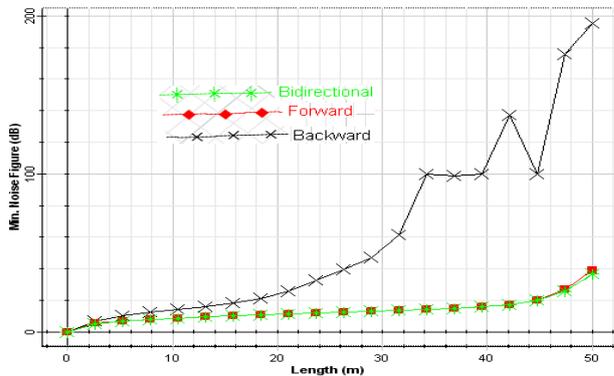


Figure11: Noise figure vs. fiber length at 50mW pump power

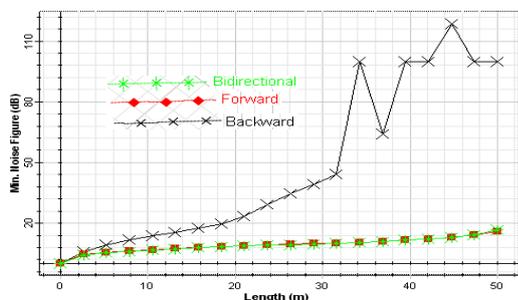


Figure12: Noise figure vs. fiber length at 100mW pump power

From the figures 10, 11, and 12 the bidirectional and forward pumping configuration gives minimum NF at the pump power of 100mW as compare to backward pumping configuration. Also from the figures 13, 14, and 15 in the case of bidirectional and forward pumping configuration the minimum NF is obtained at the fiber length of 30m for a wide range of pump power. But as the fiber length increases pump power should also be increased to minimize NF. Thus when the pump power increases the minimum NF is achieved at the fiber length of 30m for forward and bidirectional pumping configuration. But the Er^{+3} ion density is kept at $1e+024 m^{-3}$ then as the fiber length increases the NF increases even if the pump power is increased. Hence the Er^{+3} ion density is set as $1e+025 m^{-3}$.

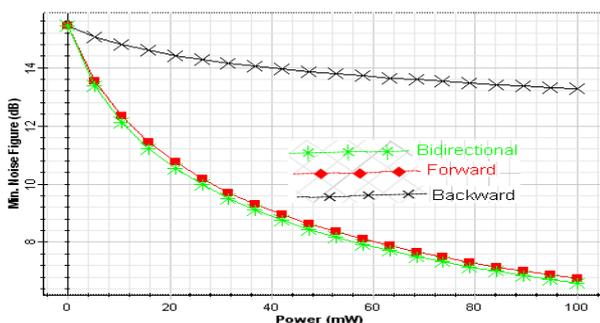


Figure 13: Noise figure vs. pump power at 10m fiber length

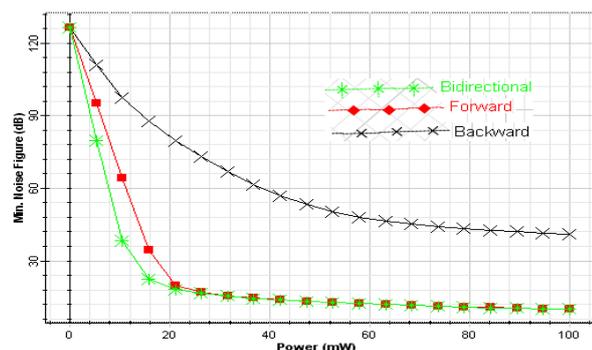


Figure 14: Noise figure vs. pump power at 30m fiber length

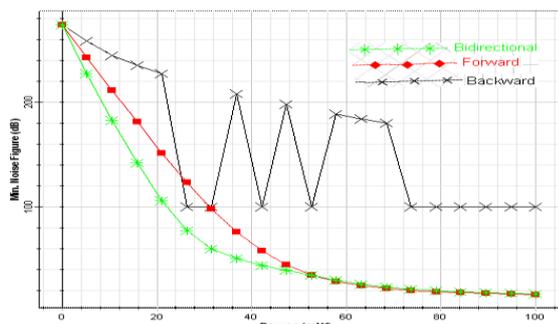


Figure 15: Noise figure vs. pump power at 50m fiber length

V. CONCLUSION

This paper gives the comparison of the three pumping configurations, i.e., forward, backward, and bidirectional pumping based on gain and NF at different pump power (10, 50, & 100mW) and at different fiber length (10, 30, & 50m) operating in C-band, 10dBm signal input power, 980nm pump wavelength, and Er^{+3} ion density of $1e+025 m^{-3}$. It is found that the minimum NF occurs for both forward and bidirectional pumping configuration whereas flat gain is obtained by using bidirectional pumping configuration. Thus bidirectional pumping configuration can be said to be the best configuration. It is also seen that when the fiber length increases the pump power should be increased in order to achieve the flat gain and minimum NF by maintaining the Er^{+3} ions density at higher value. Also any increase in data rate doesn't cause any change in the results of all the configurations. This paper shows that although the flat gain is achieved but efforts must be done to increase the value of gain.

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