STUDY ON THE PERFORMANCE OF C-BAND ERBIUM DOPED FIBER AMPLIFIER

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***Abstract*— This work analyzed the performance of erbium doped fiber amplifier (EDFA) using different EDF length and pump power. In this study, an EDFA simulation program has been written in Matlab to analyze the active fiber length in around 3m, 15m, 20m, 50m, 80m and 100m to characterize the Gain, ASE power and amplifier output power versus fiber length and input signal power variations of a forward pumping and backward pumping. These EDFA operating in C band (1525-1565 nm) as functions of Er3+ fiber length, injected pump power, signal input power and Er3+ doping density. The program solves the rate and propagation equations numerically and shows the results graphically. Thus, Gain and ASE performance of an EDFA given with its physical parameters can be graphically obtained and the required physical parameters of an EDFA with desired operating performance can be easily optimized.**

Keywords*: *Optical Amplifiers, EDFA, Erbium Doped Fiber, Gain, ASE

I. INTRODUCTION

In recent decades, the optical fiber is representative of the advancement, speed of adoption and commercialization of technology. Environmental ruggedness, wide bandwidth, high sensitivity, resistant to electromagnetic interference, low power loss, passive, small size and lightweight is among of the advantages of fiber optic technology. That is why a fiber optic can find an application in various fields such as structural heath monitoring [1], medicine, power generation and transmission. The most important thing in communication is limiting the optical power loss in optical fiber [2]. The use of rare-earth-ion doped fiber in amplifier and laser application is overwhelming due to its numerous benefits to the communication industry. Example of rare earth doped fiber such as like Neodymium (Nd^{3+}), Ytterbium (Yb^{3+}), Erbium (Er^{3+}), Thulium(Tm^{3+}), Praseodymium (Pr^{3+}) and Holmium (Ho^{3+}) [3].

Fiber amplifier is totally based on a glass fiber which is doped with laser-active rare earth ions which is normally in fiber core. These ions absorb a pump light, typically its wavelength are smaller than amplifier wavelength [4]. Like electrical amplifier, the optical amplifier can amplify a laser beam directly without needing any sort of electrical-to-optical conversion [5]. Nowadays, a popular amplifier used in is Erbium Doped Fiber Amplifier (EDFA), Ytterbium Doped Fiber Amplifier (YDFA) and Raman Amplifier (RA) [5]. However, the most interesting element listed is erbium, due to the fact that EDFA are made from silica and these erbium ions can be operated in range within 1550nm. It is usually standard wavelength that is commonly used in telecommunication field. The erbium-doped fiber amplifier (EDFA) is the most deployed fiber amplifier as its amplification window coincides with the third transmission window of silica-based optical fiber which represent the low-loss region [6].Two bands have developed in the third transmission window the conventional, or C-band, from approximately 1525 nm to 1565 nm, and the long, or L-band, from approximately 1570 nm to 1610 nm [7]. Both of these bands can be amplified by EDFA, but it is standard practice to use two different amplifiers, each optimized for one of the bands [6, 7].

The principal difference between C- and L-band amplifiers is that a longer length of doped fiber is used in L-band amplifiers [8]. The longer length of fiber allows a lower inversion level to be used, at longer wavelengths (due to the band-structure of Erbium in silica) while still providing a useful amount of gain. EDFA have two commonly-used pumping bands namely 980 nm and 1480 nm [8]. The 980 nm band has a higher absorption cross-section and is generally used where low-noise performance is required. The absorption band is relatively narrow and so wavelength stabilized laser sources are typically needed. Therefore, pre-amplifier version of EDFA chooses 980 nm for pumping wavelength. The 1480 nm band has a lower, but broader, absorption cross-section and is generally used for higher power amplifiers.

In the present work, simulation of different fiber length in C-band and L-band telecommunication with EFDA in forward pump is presented. The gain, pump signal, and amplified spontaneous emission (ASE) were investigated with the variation in EDF length and signal power. The simulation was carried out using MATLAB compares it between long and short length of EDFA

II. EDFA ACHITECTURE

The EDFA are mainly constructed by short length of optical with less 0.1% erbium. An optically, the erbium is an active rare earth has many unique intrinsic properties for optical amplification [9]. Mostly the silicate and phosphate type used

Erbium glasses [10]. Commonly, the EDFA setups have three categories. These categories are forward-pumped, backward-pumped, and bidirectional-pumped [11]. In Figure 2.1 its show the simulation setup with forward pump configuration. In forward pump, the pump and input signal travel in the same direction in the cavity [12].An EDFA are consist of an erbium-doped silica fiber, and the other photonic components such as pump source, isolator, WDM/WSC and monitoring diode.

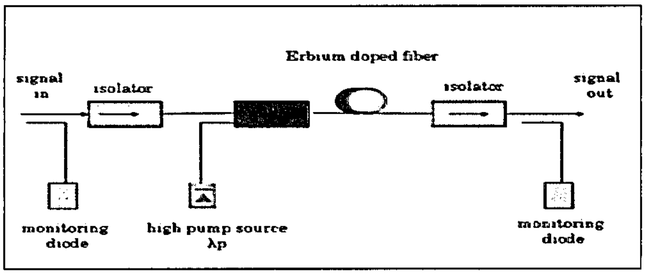


Figure 1: Forward pump EDFA setup

Different forward pump, the backward pump as Figure 2.2 is has different way of the input and pump signal. From Figure 2.1 and Figure 2.2, the optical filter maybe required EDFA improvement EDFA performance [13]. The ASE noise can be reduced using this optical filter and its can protect the amplifier from saturation cause by accumulated ASE. The typical pump source used for erbium is 980nm and 1480nm which is this source can provide higher pump gain. From these pump laser provide energy transfer from the source into the gain medium.

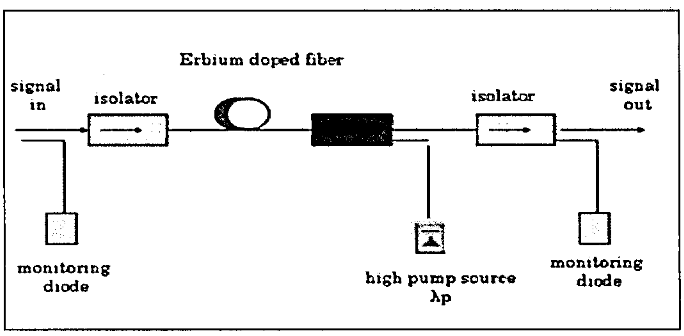


Figure 2: Backward pump EDFA setup

The energy is absorbed in the medium, producing excited states in the atoms. When the number of particles in excited states exceeds the number of particles in the ground state, population inversion is achieved and the medium can act as an optical amplifier. The isolator is used to make sure the signal travel in one direction and also to eliminate the back reflection which causes noise in the cavity. The WDM/WSC is used to combine the pump sources and the incoming signal. The pump light waves are guided and propagating along the EDF length and the depleted erbium ions then raise it to an excited state by absorption the energy.

III. MATLAB SIMULATION

The parameters of EDFA are shown in the Table 1.

Table 1: Parameters of EDFA

Pump wavelength	980nm
Signal wavelength	1550nm
Pump power	100mW
Signal power	0.03mW, 0.1mW
Er+3 fiber length	3m, 20m
Er+3 fiber diameter	9m
Core E-field overlap	0.75
Planck's constant	6.626e-34
speed of light vacuum	3e8m/s
RI for ZBLAN fiber	1.5

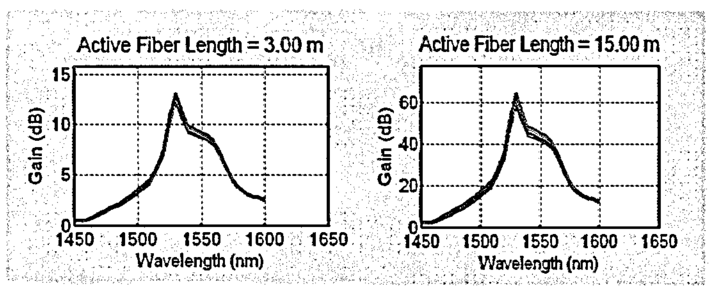
The performance characteristics of the amplifier such as gain, ASE and amplifier output power versus fiber length and input signal power is analyzed assuming the fundamental LP_{01} mode exciting at the pump wavelength (λp= 980 nm) [12,13]. The EDFA is tested with different fiber length in forward pumping.

IV. RESULT AND DISCUSSION

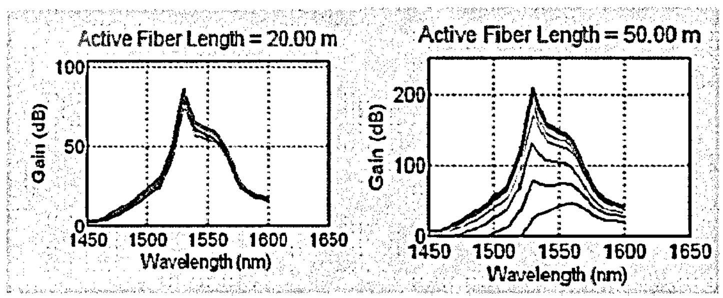
The gain, ASE power distribution and amplifier output power is analyzed using different fiber length (3m and 20m).

Forward Pump

Gain characteristics



(a) (b)



(c)

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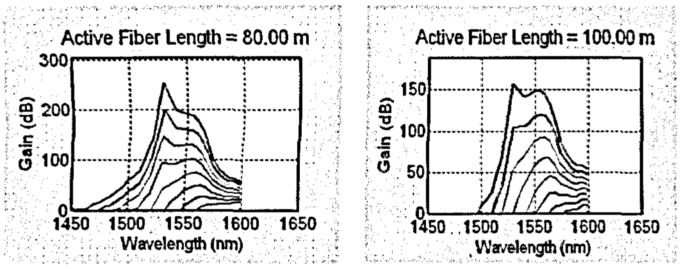


(e) (f)

Figure 3: Performance comparison of gain for different signal wavelength at varying EDFA length in Pump Power between 50mW to 120mW forward pump for (a) 3 m (b) 15 m (c) 20 m (d) 50 m (e) 80 m and (f) 100 m

Using Matlab, Table 3 below is the comparison of Gain in various EDFA lengths. From the Figure 3, the signal wavelength range used is between 1520nm to 1560nm. This is due to the fact that range possesses higher gain as the ASE level is highest along this point.

Table 2: comparison Gain (dB) in EDFA length 3 m, 15 m, 20 m, 50 m, 80 m and 100 m forward pump

Signal Wavelength	EDFA length 3m	EDFA length 15m	EDFA length 20m	EDFA length 50m	EDFA length 80m	EDFA length 100m
	Gain (dB)					
1520nm	8dB	35.5dB	50dB	114dB	70dB	0dB
1530nm	13.2dB	65dB	85.3dB	200dB	140.5dB	50dB
1540nm	9.9dB	45.8dB	65dB	158dB	125dB	70dB
1550nm	9.25dB	45dB	60.2dB	142.5dB	125.2dB	85dB
1560nm	8.4dB	42dB	55dB	130dB	122dB	92dB

From the Table 2, the 1530nm are got the highest gain for 3 m, 15 m, 20 m, 50 m, and 80 m, which are 13.2dB, 65dB, 85.3dB, 200dB and 140.5dB. But, for fiber length 100m, wavelength at 1560nm recorded the highest gain where of 92dB. Since 1550nm are standard wavelength are used in telecommunication area, its absorption by the silica fiber is acceptable in this region. In this case, the EDFA has higher gain if the pump power is kept constant as shown at Figure 4.1, which is pump wavelength is 980nm.

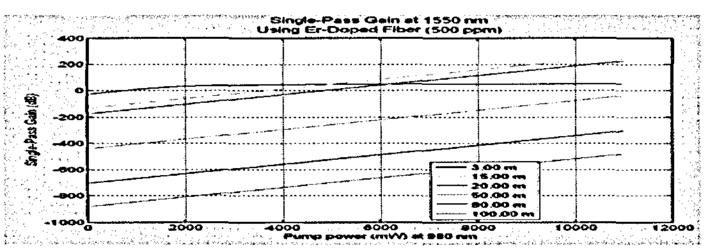


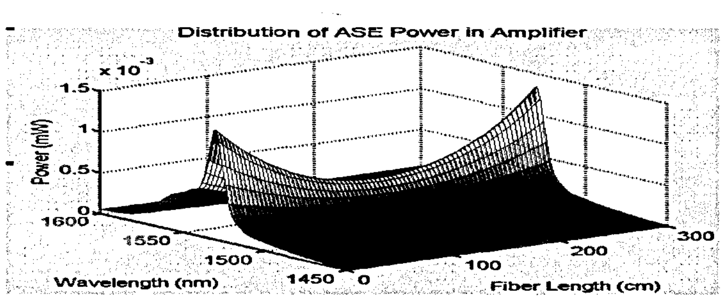
Figure 4: Single-Pass Gain at 1550nm for fiber length range 3, 15, 20, 50, 80, and 100 m forward pump

Figure 4 shows the variation of gain with pump power for different fiber lengths, a constant signal input power and erbium doping density. In this simulation the signal and pump wavelength used was 980nm and signal at wavelength 1550nm respectively. For short distance, EDF length used is between 3m to 100m.The pump power supplied was varied from 0mW to 120mW.

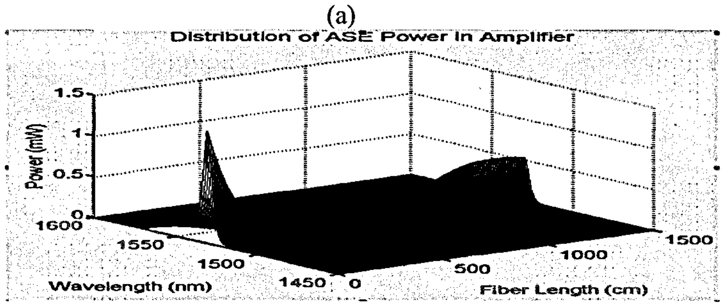
It is observed that the gain of the EDFA increases with the increasing pump power and then goes to saturation after a certain level of pump power. From these figure, it is shown that, the gain of the EDFA sharply increases with increasing pump power; after a certain level of gain, the increase in gain becomes smaller when the population inversion is provided for all the erbium ions in the fiber and therefore amplifier goes to saturation.

As a result, the gain efficiency defined in terms of dB gain per unit mW pump power reduces for high pump powers. In addition, a higher gain can be obtained if a longer erbium doped fiber is used with sufficient pumping.

ASE Power Distribution



(a)



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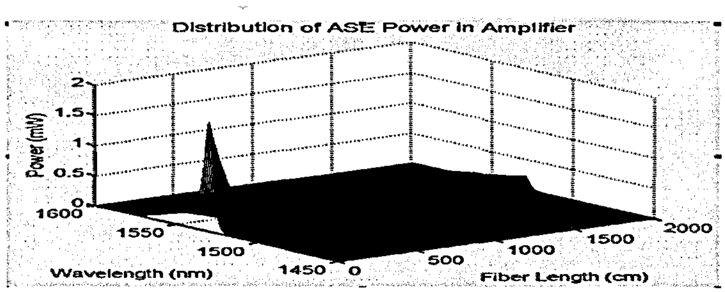

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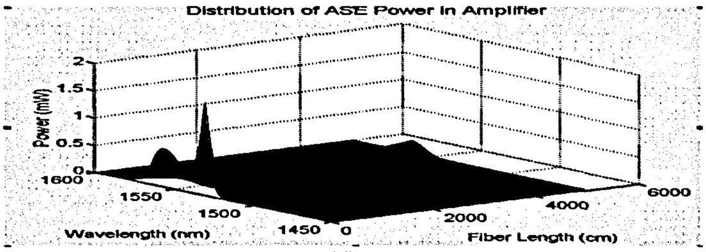

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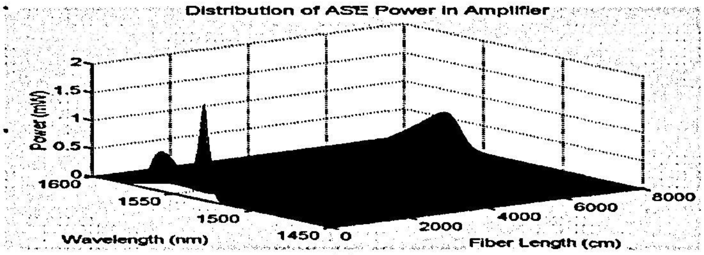

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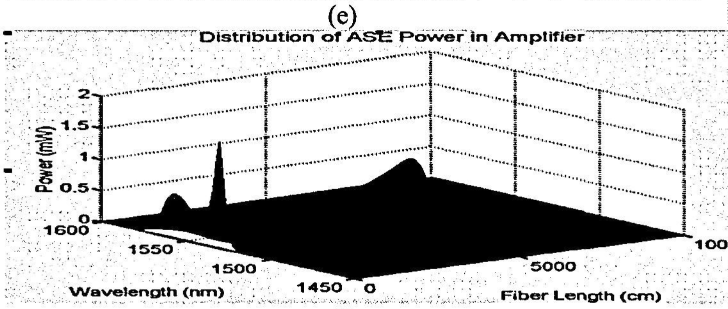


(f)

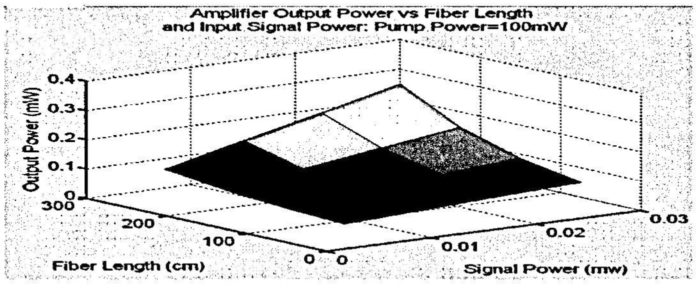
Figure 5 Distribution of ASE power in amplifier (a) 3 m (b) 15 m (c) 20 m (d) 50 m (e) 80 m and (f) 100 m forward pump configuration

In Figure 5 show the distribution of ASE power in amplifier which is simulated for EDF length of 3 m, 15 m, 20 m, 50 m, 80 m and 100 m. In these entire ASE distribution figure, the pump power used is 100mW and get spectrum shows an overall bandwidth of ASE distribution and a peak around 1550 nm are become worst when fiber length increases with same pump power. For need a good ASE graph, the pump power can be adjust in range between 0 to 10000 mW. .

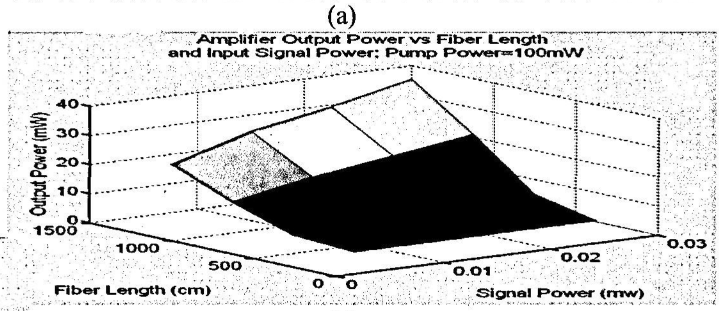
However, the actual maximum power was slightly higher at 1532 nm but the respective output fiber length saturated the detector as evident by the peak observed in the data with square markers. From all Figures, we can conclude, the power spectrum also observed indicates in the spectral region where spontaneous emission of photons takes place once the medium is pumped.

The higher pump/signal power and the larger of ASE power can change a rate of EDFA. In high-gain amplifiers, ASE is often a factor limiting the achievable gain. Due to the quasi-three-level nature of the erbium ions, ASE powers can be different between forward and backward direction, and the maximum ASE can occur at a wavelength which differs from that of maximum gain.

Amplifier performance in Pump Power=100mW



(a)



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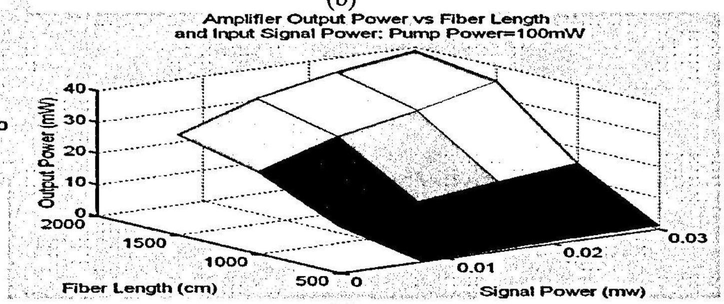

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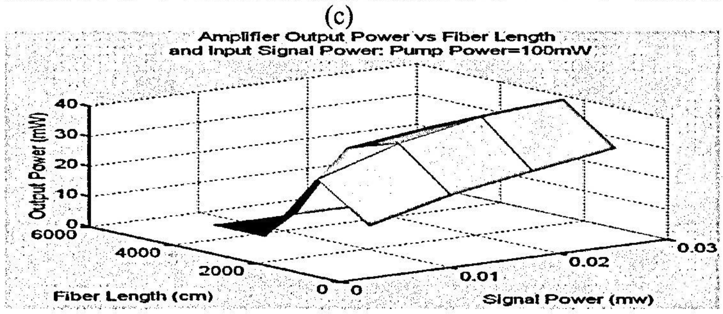

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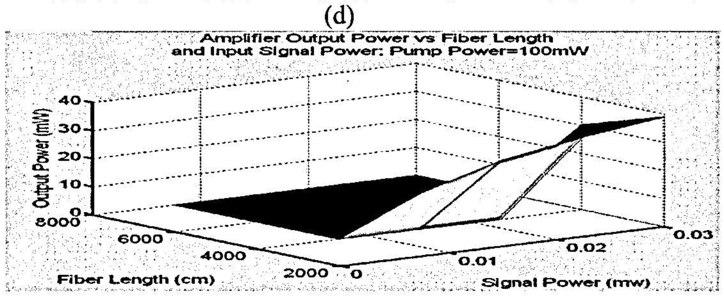

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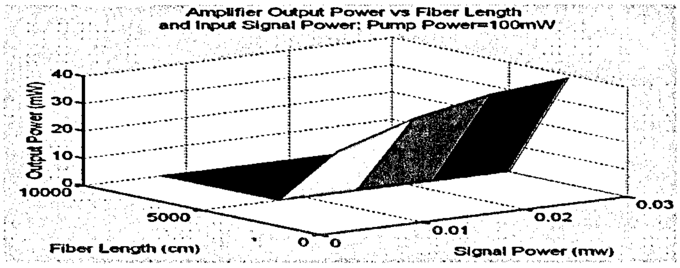


(f)

Figure 6: The evolution of amplifier output power across EDF length with varying input signal power for (a) 3 m, (b) 15 m, (c) 20 m, (d) 50 m, (e) 80 m and (f)100 m forward pump

From in Figure 6, we can state that in active fiber length range between 3, 15, and 20m the graph are so smooth. The amplifier performances are good increases when the signal power and output power increased. Different when the fiber length for long distance where is we can see in fiber length range in between 50m, 80m, and 100. Same with ASE noise, the pump power need to increase to get a good result in amplifier performance. The pump power maintains population inversion and it decreases exponentially along the EDFA. However, the signal power increases exponentially.

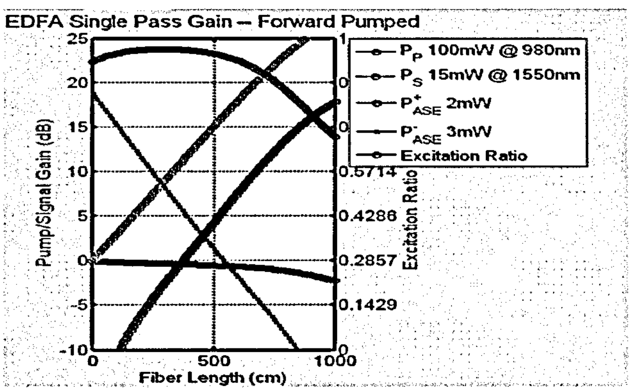
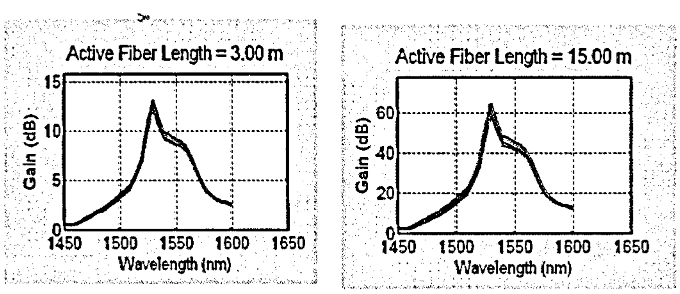


Figure 7: EDFA Single Pass Gain forward pump

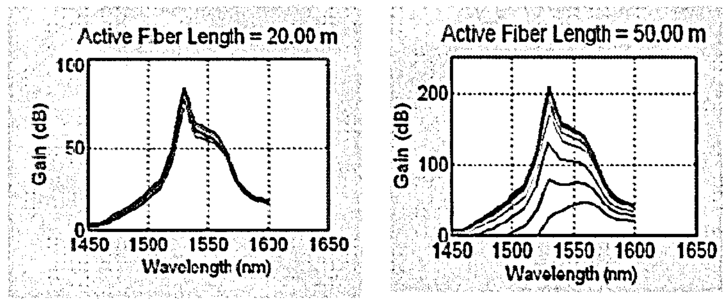
If inject a 0.03-mW input signal at 980 nm, gain saturation keeps the ASE at a lower level, and most of the power can be extracted with the signal.

Backward Pump

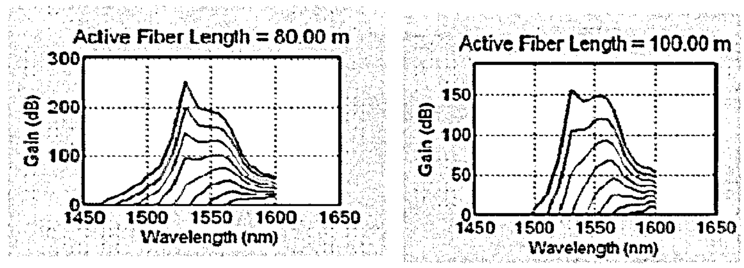
Gain Characteristic



(a) (b)



(c) (d)



(e) (f)

Figure 8: Performance comparison of gain for different signal wavelength at varying EDFA length in Pump Power between 50mW to 120mW backward pump (a) 3 m (b) 15 m (c) 20 m (d) 50 m (e) 80 m and (f) 100 m

Based on Figure 8 gain performance for backward pumping shown approximate similarity with the forward pump.

Table 3: comparison Gain (dB) in EDFA length 3 m, 15 m, 20 m, 50 m, 80 m and 100 m backward pump

Signal Wavelength	EDFA length 3m	EDFA length 15m	EDFA length 20m	EDFA length 50m	EDFA length 80m	EDFA length 100m
	Gain (dB)					
1520nm	6dB	31.26dB	46.9dB	110.1dB	65.4dB	-1dB
1530nm	11.2dB	62dB	76.3dB	198.2dB	137.5dB	49.6dB
1540nm	7.6dBdB	42.1dB	62.3dB	157.5dB	119dB	68.2dB
1550nm	7.15dB	43dB	59.2dB	141.1dB	116.1dB	81.2dB
1560nm	9.61dB	40.2dB	53.1dB	126.5dB	119.1dB	87.1dB

Compare with forward pump with backward pump, the forward pump shown better gain performance. Same with forward pump, in backward pump in range wavelength 1530nm are got the higher gain reading compared to the others wavelength. Just in fiber length at 100m, the 1560nm have a higher gain in 1560nm. Typically, the distance used in telecommunication network is more than 100m.

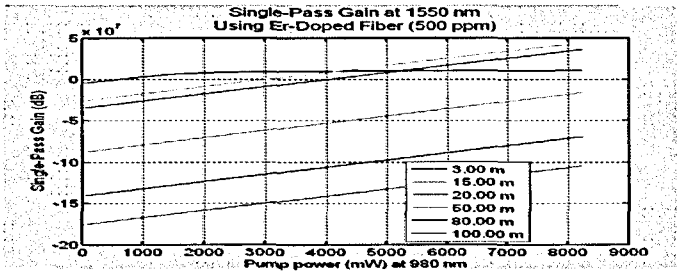
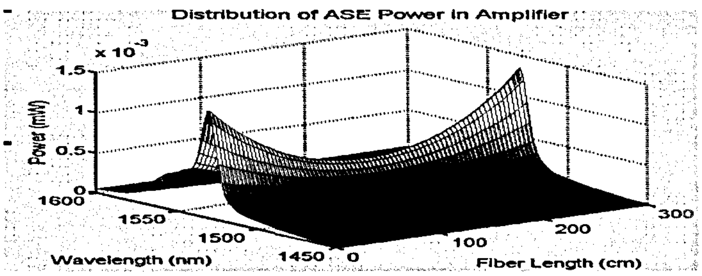


Figure 9: Single-Pass Gain at 1550nm for fiber length range 3, 15, 20, 50, 80, and 100m backward pump

In Figure 9, are shown a Single-Pass gain for backward pump. Contrary forward pump, the backward pump single-pass gain are range between -20x10³dB to 5x10³dB. Based on this result we can conclude that the forward pump has better gain performance compared to its counterpart.

ASE Power Distribution



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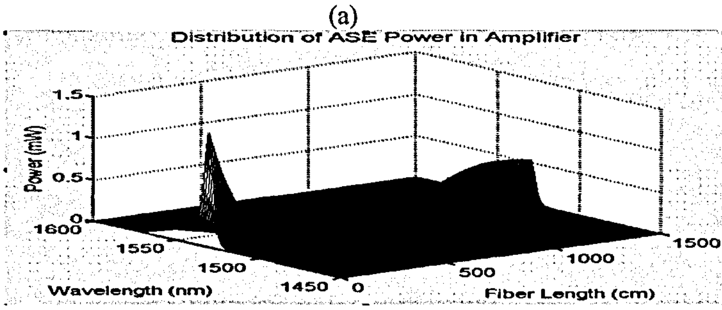

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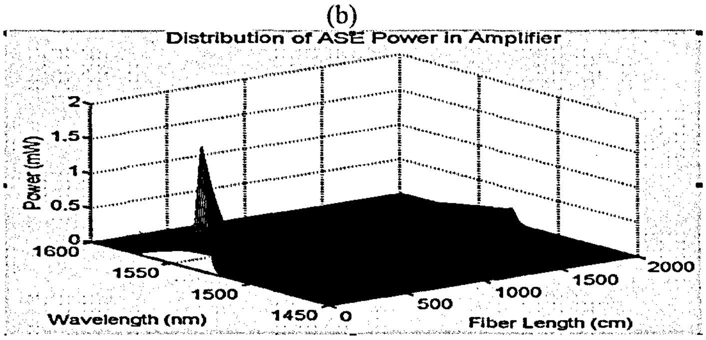

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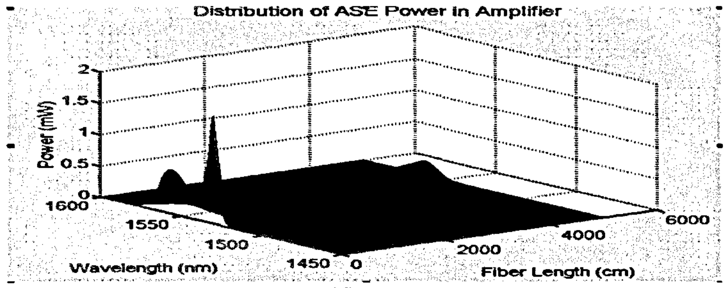

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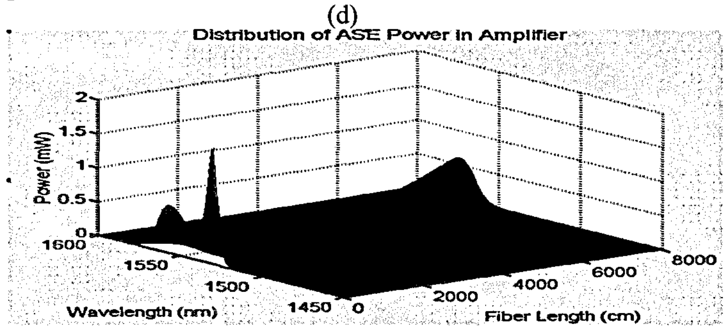

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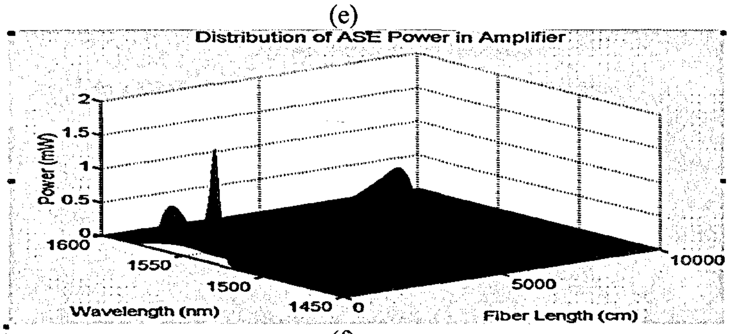


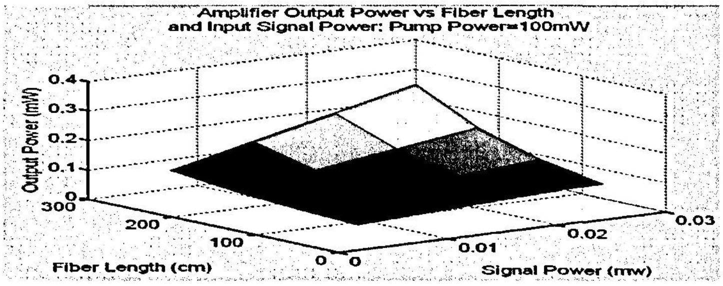
(f)

Figure 10 Distribution of ASE power in amplifier (a) 3 m (b) 15 m (c) 20 m (d) 50 m (e) 80 m and (f) 100 m backward pump

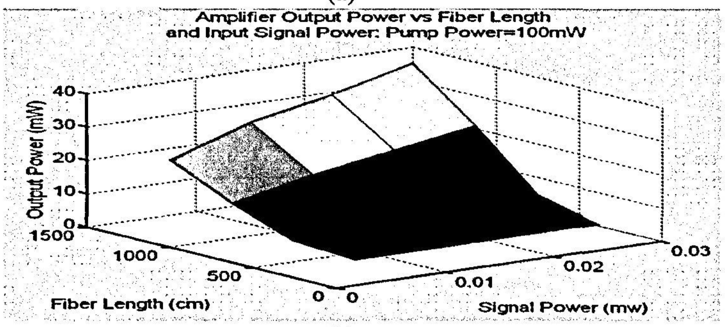
The impact of varying EDF length to the ASE distribution for backward pumping is shown in Figure 10 (a) to (f). This concludes that without the presence of input signal, the ASE distribution is approximately the same along the EDF length for forward and backward configuration.

Amplifier performance in Pump Power=100mW

Figure 11 (a) to (f) shows the evolution of amplifier output power across varying EDF length for backward pumping. The pump power used is kept constant at 100mW. For 3 m with signal power 0.01mW can conclude the output power is 0.25mW, 15 m is 30.5mW, 20 m is 40mW, and for 50 m, 80 m and 100 m the output power is 0 mW. Herewith this graph, its shown that the fiber length are more than 50 mW are not suitable using pump power 100mW and this pump power need to adjust more than 100mW.



(a)



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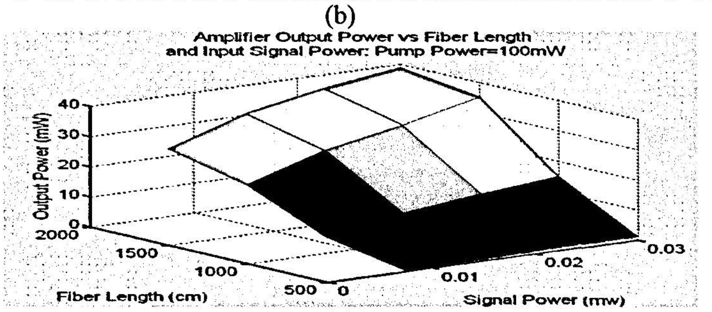

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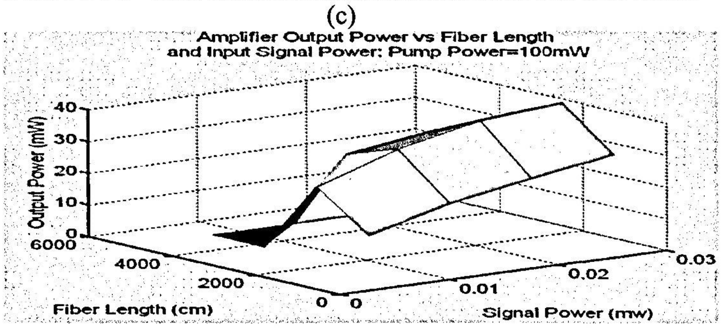

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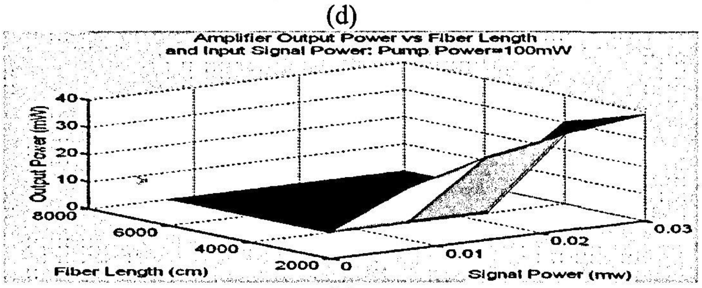

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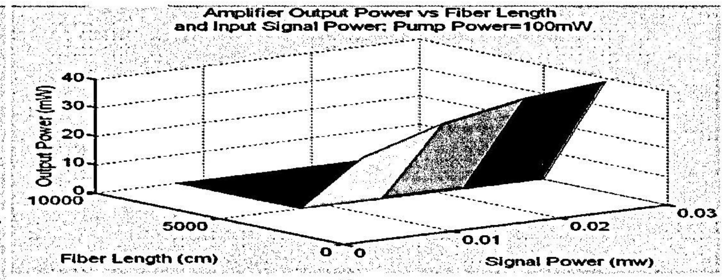

(f)

Figure 11: The evolution of amplifier output power across EDF length with varying input signal power for (a) 3 m, (b) 15 m, (c) 20 m, (d) 50 m, (e) 80 m and (f)100 m backward pump

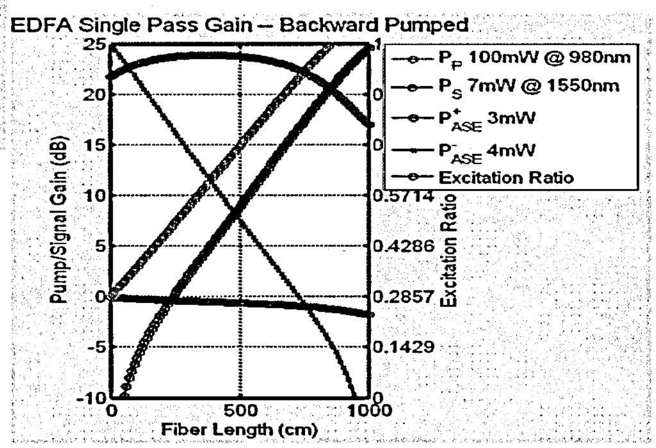

Figure 12: EDFA Single Pass Gain backward pump

Figure 12 are shown the EDFA single pass gain for backward pump with pump power 100mW and pump signal 7mW. Like forward pump, the backward pump P-ASE is 4mW higher than P+ASE where is 3mW.

V. CONCLUSION

This work presents a theoretical analysis on constant Erbium doping concentration to analyze how gain of the signal wavelength varies under different circumstances like different pump powers, signal powers and fiber length in 3 m, 15 m, 20 m, 50 m, 80 m and 100 m in EDFA forward and backward pumping. The results shows that the gain performance of forward pumping is better than backward pumping for input signal wavelength between 1520 nm to 1560 nm. for forward pumping, the highest gain obtained is for input signal wavelength of 1530 nm, with 200 dB gain compared 198.2 dB for backward pumping for the same EDF length (50 m) and pump power (100 mW). This corresponds to the highest gain spectrum of the EDF used in this simulation. Longer EDF length requires higher launched pump power in order to achieve population inversion. In this situation still have good amount of gain is observed in 1550nm range which was not at all noticed in any combination in short or long distance.

VI. ACKNOWLEDGMENT

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