# Gain Characteristic in L-Band EDFA

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# Gain Characteristic in L-Band EDFA

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***Abstract –***

*An EDFA consists of a short length of optical fiber which has been doped by certain amount of the rare earth element erbium to the glass in the form of ion $Er^{3+}$. The erbium atom has a metastble state with remarkable long lifetime of about 10 ms. EDFAs consist of an erbium doped fiber, WDM coupler, and a pump light source. The laser pump light (980 nm) is combined with the input signal by using the WDM coupler. There are bands in the third transmission window, C-band (1525 nm – 1560 nm), and the Long, or L-band (1560 nm to 1640 nm)[2]. These new L-band amplifiers will be essential to enable enabling for future lightwave communication systems operating in what has come to be called the fourth generation telecommunications window. In this paper the analysis on gain characteristic with variations of pump power, fiber length, signal power and signal wavelength of L-Band EDFA has been explored. It is found that the gain is really depends on pump power and signal power strength. The analysis have been performed by solving the amplifiers coupled equation using the fourth Runge-Kutta integration scheme.*

***Keywords**: Telecommunication, Optic, Amplification, EDFA, Erbium, L-Band.*

## 1.INTRODUCTION

One of the greatest benefits of fiber optic communication is the ability to send thousands of signals through one fiber, while copper wire only allows the transmission of one signal at a time. Development of fibers and devices for optical communication began in the 1970s, with low enough attenuation for communication purposes (about 20 dB/km). An optical communication system is a method of transmitting information from one place to another by sending pulses of light through an optical fiber [1].

in optical trasmission systems, there are losses when moving through the fiber optic signal. The loss value is about 0,22 dB/km. After several kilometres along a fiber, the optical signal can become very weak. To amplify the optical signal, the amplification is used by optical amplifier.

An optical amplifier is a device that amplifies an optical signal directly, without the need to first convert it to an electrical signal. Optical Amplifiers are important in optical communications. There are many types of optical amplifier, there is EDFA (Erbium Doped Fiber Amplifier), Semiconductor Optical Amplifier (SOA), Raman amplifier, etc. In this paper, we will discuss about the L-Band EDFA and its gain characteristic.

An EDFA consists of a short length of optical fiber which has been dopping by certain amount of the rare earth element erbium to the glass in the form of ion $Er^{3+}$. The fiber core consists of glass material such as $SiO_2$ and $GeO_2$. Rare earth ions like Er is doped into the core. The cladding material is mainly $SiO_2$. The erbium atom has a metastable state with remarkable long lifetime of about 10 ms. An EDFA is constructed by fusion splicing discrete fiber components. It consist of an erbium doped fiber, WDM coupler, and a pump light source. EDFAs have been succesfully in WDM transmission system as optical amplifier to boost the optical signal at the point in the transmission line.

The pump source used a diode laser with appropriate wavelength. The laser pump light is combined with the input signal by using the WDM coupler. WDM Coupler is a optical device that combines two-wavelength lights at certain wavelength. Both the light entering through a different fiber and exits at the same single fiber.

Two bands have developed in the third transmission window – the Conventional, or C-band, from approximately 1525 nm – 1560 nm, and the Long, or L-band, from approximately 1560 nm to 1640 nm[2]. Both of these bands can be amplified by EDFAs, but it is normal to use two different amplifiers, each optimized for one of the bands. These new L-band amplifiers will be essential enabling components for future lightwave communication systems operating in what has come to be called the fourth generation telecommunications window.

## 2. THEORITICAL BACKGROUND

Three-level rate equation system is a mathematical solutions approach to the behavior of erbium are reviewed from three levels of energy. In order to understand the workings of this EDFA see diagram level energy and the various processes of transition of $Er^{3+}$ ions in a simplified Silica by taking the bottom three of the energy level structure of $Er^{3+}$ is shown by Fig. 1. As the concept of an atomic energy level is always comprised of : (a) Ground-state (stable state) is labeled by 1; (b) Metastable state labeled by 2; (c) Unstable state labeled by 3.

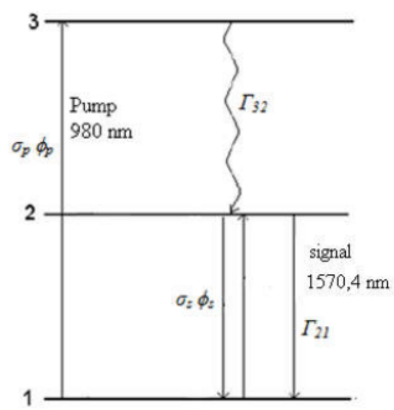


Fig. 1. Three level systems for amplification EDFA model.[10]

In three level system like $Er^{3+}$ pumped at 980 nm, the lower level of the stimulated emission transition corresponds to the ground state[5]. To obtain gain, more than half of the ions must be in the excited states. High pump power are needed to perform the inversion since any portion of the fiber that remains uninverted will act as an absorber at the signal wavelength. In the case of $Er^{3+}$, the fast non-radiative decay to the level allows this system to be treated like a two-level system.

At level 2, the erbium ions have a long lifetime and this is one of the advantage in optical amplifier system. Level 2 is an amplification of transition, and Level 1 is the lowest energy level (ground state). Three-level system is expected to illustrate parts of the structure of energy levels $Er^{3+}$ relevant to the amplification process. Amplification in the EDFA can occur if there is a population inversion between level 1 and level 2, and at least half of the whole population erbium ions must be excited at level 2 and there is need for a pump power threshold for the occurrence of amplification.

In Fig. 1 $W_s$ or ($\sigma_s\ \phi_s$) and $W_p$ or ($\sigma_p\ \phi_p$) are the rates for the stimulated transitions while $\Gamma_{32}$ and $\Gamma_{21}$ are the rates for the spontaeous emissions. $\Gamma_{32}$ is assumed to be essentially nonradiative and $\Gamma_{21}$ essentially radiative.[7]

Fig. 2 illustrate absorption and emission cross-section of erbium in wavelength range about 1500 nm to 1640 nm. In this final project, the author using L-Band range, which range between 1560 nm to 1640 nm. It can be seen that this cross-section decays monotonically with the increase of wavelength when it is greater than 1560nm. This in turns means that the gain of the EDFA also decreases accordingly in the L-band

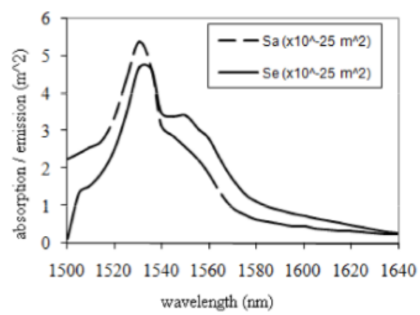


Fig. 2. Absorbtion and emission cross section EDFA[2]

To get more practical formulation we consider the intrinsic background loss that may occur in the Erbium Doped Fiber (may caused by the imperfect material of fiber, the contamination of other material, etc)[6]. The signal and pump field propagation in term of power light field are defined as

$$\frac{dP_s}{dz} = \left(N_2\sigma_s^{(e)} - N_1\sigma_s^{(a)}\right)\Gamma_s P_s - \alpha_s P_s \qquad (1)$$

$$\frac{dP_p}{dz} = \left(N_2\sigma_p^{(e)} - N_1\sigma_p^{(a)}\right)\Gamma_p P_p - \alpha_p P_p \qquad (2)$$

Where:

$\sigma_s$ = signal emission cross section ($m^2$).

$\sigma_p$ = pump absorbtion cross section ($m^2$).

$N_1$ = population of erbium ions at Level 1 ($m^{-3}$)

$N_2$ = population of erbium ions at Level 2 ($m^{-3}$)

$\Gamma_s$ = spontaneous transition rate from signal

$\Gamma_p$ = spontaneous transition rate from pump

$P_s$ = signal power

$P_p$ = pump power

$\alpha_s$ = losses from signal

$\alpha_p$ = losses from pump

The value of gain is expressed in the equation below

$$G(\text{dB}) = 10\,log_{10}\frac{Ps_{out}}{Ps_{in}} \qquad (3)$$

Where:

G = gain (dB)

$P_{s\ out}$ = signal output power (watt)

$P_{s\ in}$ = signal input power (watt)

## 3. RESULTS AND DISCUSSIONS

Purpose of this section is to evaluate the gain characteristic to the input pump power and input signal power from the variation of signal power and pump power with 30 meters amplifier length. Measurements and calculations obtained at a wavelength of a predetermined input signal is 1570,4 nm

### Gain To Input Pump Power

Characteristic of the EDFA at a wavelength of 1570.4 nm for the variation of the input signal power respectively -20 dBm (0.010 mW), -15 dBm (0.032 mW), -10 dBm (0.100 mW) and -5 dBm (0.316 mW) with 30 meters emplifier length. The gain characteric results are shown in Fig 3.

Fig.3 as the solution of the Eq.(2) and Eq.(3). It shows that if we using more input pump power we will get higher gain. And for variant signal input power, we will see that we get higher gain if we using the smaller signal input power, because it has entered the saturation region. This effect is known as gain saturation as the signal level increases, the amplifier saturates and cannot produce any more output power, and therefore the gain reduces[4]. Saturation is also commonly known as gain compression.

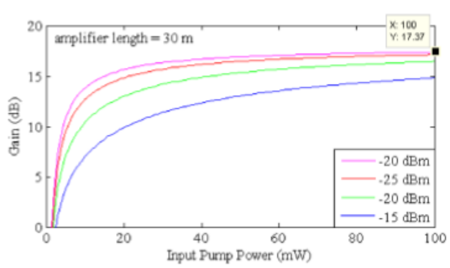


Fig. 3. characteristic of gain EDFA, variations of signal power

We can see when the fiber length 30 meters, we get 17,37 dB gain for the 100 mW input pump power. we can also see that there is a significant increase in gain before entering the saturation region is about 5 mW input pump power.

### Gain To Input Signal Power

This figure below is show the gain characteristic to the input signal power from the variation of pump power with a constant length. The variation of the input pump power respectively 60 mW, 50 mW, 40 mW, and 30 mW with 30 meters amplifier length. The gain characteristic results are shown in the fig. 4.

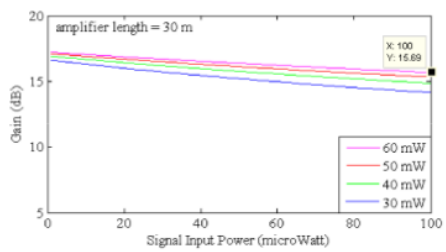


Fig. 4. The gain characteristic of EDFA, variations of pump power

Fig.4 as the solution of the Eq.(1) and Eq.(3). It shows that if we are using more signal input power we will get smaller gain. This can happen because there is more number of photons that excited to the upper state if we give more pump power.

The gain increase after reach the threshold power, minimum pump power required to make the inversion. The increasing is exponentially with pump power, but the increasing become much smaller after trough the saturation regime of pump power. We can see when the fiber length 30 meters, we get 15,69 dB gain for the 100 µW input signal power.

### Gain L-Band With Different Power Signal

Characteristic of the EDFA at a range signal wavelength of 1560 nm to 1640 nm for the variation of the input signal power respectively -20 dBm (0.010 mW), -15 dBm (0.032 mW), -10 dBm (0.100 mW) and -5 dBm (0.316 mW). The gain characteristic results are shown in Fig 5.

In this figure we can be seen that the gain characteristic follows the characteristic of emission and absorption cross section in Fig. 2 for the range of L-Band signal wavelength 1560 nm to 1640 nm.

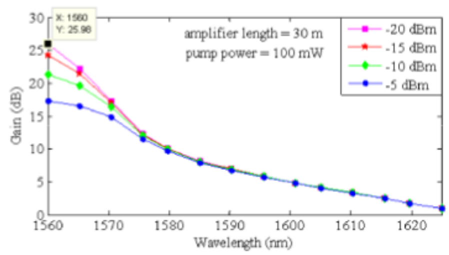


Fig. 5. The gain characteristic of EDFA, variations of signal power with 30 meters length and 100 mW pump power

Fig. 5. Shows the measured gain spectrum of the L-band amplifier. We define the measured gain by the equation (3). Where $P_{out}$ is the output power measured from the doped core of the dual-core fiber with pump laser operating at 980nm and $P_{in}$ is the input power[3]. We can be seen also that there was a significant difference between 1560 nm to 1570 nm. After that, there is no significant difference occurred until at 1640 nm signal wavelength. It also shows that if we using more input pump power we will get higher gain. The figure also shows that we get higher gain if we using the smaller signal input power.

The best gain with different signal power in range of L-Band is reach if we use signal wavelength at 1560 nm. When using -20 dBm or 0.010 mW for signal input power and 100 mW pump power and 30 meters fiber amplifier length.

**Gain L-Band With Different Pump Power**

Characteristic of the EDFA at a range signal wavelength of 1560 nm to 1640 nm for the variation of the length respectively 60 mW, 50 mW, 40 mW, 30 mW. The gain characteristic results are shown in the Fig. 6.

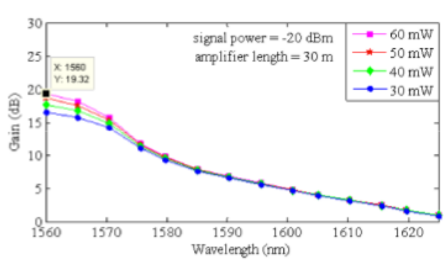


Fig. 6. The gain characteristic of EDFA, variations of signal power with 30 meters length and -20 dB signal power

It shows the measured gain characteristic of the L-band amplifier for different pump power settings with a fiber length of 30 meters. It can be seen that if the pump power decreases, the gain also decreases. Rate of stimulated absorption of the signal $\sigma_s^{(a)}$ is greater than the rate of absorption of the pump $\sigma_p^{(a)}$, ion population resulted in the level2 decreased with increasing photon flux signal $\square_s$. photon flux signal $\square_s$ is directly proportional to the signal power $P_s$. Increase in signal power $P_s$ with a fixed pump power resulted in decreased gain.[3]

We can be seen also that there was a significant difference between 1560 nm to 1570 nm. After that, there is no significant difference occurred until at 1640 nm signal wavelength. In this figure we can be seen that the gain characteristic follows the characteristic of emission and absorption cross section in Fig. 2 for the range of L-Band signal wavelength 1560 nm to 1640 nm.

The best gain with different pump power in range of L-Band is reach if we using signal wavelength at 1560 nm. When using -20 dBm or 0.010 mW for signal input power and 60 mW pump power and 30 meters fiber amplifier length.

## 4. CONCLUSION

The simulation is based on the three level atomic system theory to investigate the amplification process in EDFA. Based on the simulation and analysis. We can conclude that:

EDFA have higher gain if using more input pump power and smaller signal input power. From the simulation, the best gain at 1570,4 nm is about 17,37 dBm. With 30 meters optical amplifier, 100 mW pump power, -20 dBm power signal.

In range L-Band, the optimum gain at 1560 nm signal wavelength is 25,98 dB. With 30 meters optical amplifier, 100 mW Pp, -20 dBm Ps.

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