Erbium Doped Fiber Amplifiers: State Of Art

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Abstract: The field of optics has a drastic impact in the field of electronics and communication. With the rising need for higher data transfer rate, optical advancements have served this purpose. Optical amplifiers play a crucial role in the amplification of signal at regular intervals to avoid loss of data. Erbium doped fiber amplifiers (Erbium Doped Fiber Amplifier) carry out the amplification by stimulated emission and spontaneous emission and are known to provide a higher gain when compared to other optical amplifiers in this domain. This paper throws light on state of art results of the EDFA based on several experiments to measure their gain and noise figure. It is found that it provides better results for amplification of optical signals.

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INTRODUCTION

The advancement in the field of optical fiber communications has been increasing with every passing day as a result of new optoelectronic technologies that aim at utilizing the wide bandwidth of optical fiber. When setting up a Fiber Optic link, certain parameters like Power budget, Sensitivity of the receiver, link quality & path loss are to be considered for effective error free communication between the transmitter and the receiver. To establish a communication link of several kilometers repeaters are added at regular distances to amplify the signal to overcome the path loss and other associated losses. The conventional method employed for these types of repeaters are Optical to Electrical Converters (O/E Converters). These O/E Converters introduce noise in the signal level and consume more power. Hence this process of O/E and E/O is best suited for low to moderate speed signals of single wavelength. To overcome the problem associated with the above, Optical amplification was introduced. In Optical amplification, the optical signal will be amplified in the same optical domain itself without doing any conversion and hence it is simpler. The introduction of noise in the signal will be eliminated by this optical amplification. There are several different physical mechanisms that can be used to amplify a light signal, which correspond to the major types of optical amplifiers. In doped fiber amplifiers and bulk lasers, stimulated emission in the amplifier's gain medium causes amplification of incoming light.

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In semiconductor optical amplifiers (SOAs), electron-hole recombination occurs. In Raman amplifiers, Raman scattering of incoming light with phonons in the lattice of the gain medium produces photons coherent with the incoming photons. Parametric amplifiers use parametric amplification. There are two popular types of optical amplifiers viz. Semiconductor Optical Amplifier (SOA) and Erbium Doped Fiber Amplifier (EDFA). The SOAs are based on a semiconductor gain medium. They consume less power and have fewer components than EDFA and are very compact. But the disadvantages of SOA are higher noise, lower gain, polarization dependant and highly nonlinear for a high speed signals. Doped fiber amplifiers use a doped optical fiber as a gain medium as opposed to semiconductor in SOA. Amplification of the input signal is carried out by the stimulated emission of the photons from the dopant ions in the doped fiber and an external pump sources is used to get the stimulated emission of the doped fiber. This stimulated emission is responsible for the amplification of the input signal. These amplifiers can be doped by small amount of any rare earth element like Erbium, neodymium, ytterbium, thulium or praseodymium into the optical fiber, the optical amplification is achieved.

Why EDFA?

Erbium is generally preferred because of the inherent properties associated with it. Erbium ions have quantum levels that can be stimulated to emit in the least power loss 1540nm band. This property of Erbium ions made it suitable to construct good quality high gain amplifier. Moreover the property of Erbium is that its quantum levels allow it to get excited by a 800nm or a 980nm signal which is carried by the glass fiber without much loss and which does not lie near the signal wavelength. Another important property of Erbium is its solubility with silica which will make it easier to get doped into mixtures for making glass fibers. Amplification is achieved by stimulated emission of photons from dopant ions in the doped fiber. The pump laser excites ions into a higher energy from where they can decay via stimulated emission of a photon at the signal wavelength back to a lower energy level. The excited ions can also decay spontaneously (spontaneous emission) or even through nonradiative processes involving interactions with phonons of the glass matrix. These last two decay mechanisms compete with stimulated emission reducing the efficiency of light amplification. The amplification window of an optical amplifier is the range of optical wavelengths for which the amplifier gives the amount of usable gain which does not include noise. The spectroscopic properties of the dopant ions, the glass structure of the optical fiber, and the wavelength and power of the pump laser determine the As we all know about the electronic transitions of an isolated ion. When the ions are incorporated into the glass of the optical fiber, broadening of energy levels occur and thus the amplification window is also widened, meaning that the broadening is homogeneous (i.e.) all ions exhibit the same broadened spectrum and inhomogeneous (different ions in different glass locations exhibit different spectra). Homogeneous broadening arises from the interactions with phonons of the glass, while inhomogeneous broadening is caused by differences in the glass sites where different ions are hosted. Different sites expose ions to different local electric fields, which shifts the energy levels via the Stark effect. In addition, the Stark effect also removes the degeneracy of energy states having the same total angular momentum (specified by the quantum number J). Thus, for example, the trivalent erbium ion (Er^{+3}) has a ground state with $J = 15/2$, and in the presence of an electric field splits into $J + 1/2 = 8$ sublevels with slightly different energies. The first excited state has $J = 13/2$ and therefore a Stark manifold with 7 sublevels. Transitions from the $J = 13/2$ excited state to the $J= 15/2$ ground state are responsible for the gain at 1.5 µm wavelength. The gain spectrum of the EDFA has several peaks that are smeared by the above broadening mechanisms. The net result is a very broad spectrum (30 nm in silica, typically). The broad gain-bandwidth of fiber amplifiers make them unique and useful in wavelength-division multiplexed communications systems as a single amplifier can be utilized to amplify all signals being carried on a fiber and whose wavelengths fall within the gain window.

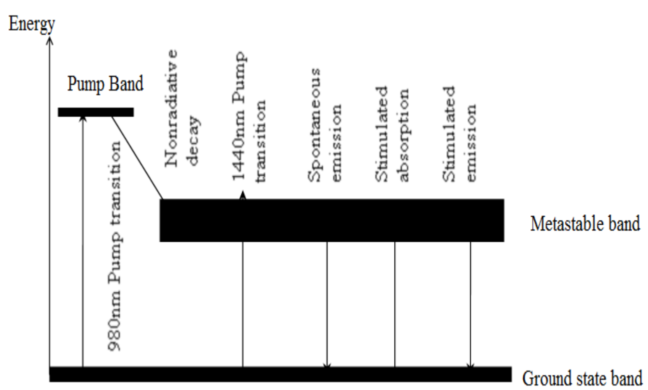


Fig: 1 Energy level diagram of Erbium ion
(Source: Optical Fiber Communication Gerd Keiser)

In the EDFA, pump laser photon of 980nm wavelength is used to excite the erbium ions from the ground state to the Pump band. These excited ions will soon decay very fast to the metastable state. When a signal photon of wavelength equivalent to the band-gap energy between the Ground state and the metastable state is passing through the fiber doped with erbium, two types of transitions occur. First a small portion of the ions in the ground state absorb this signal photon and raise to the metastable state known as stimulated absorption. The ions in the metastable band on absorbing the energy from the signal photon can undergo stimulated emission and drop to the ground level, thereby emitting a new photon of the same wavelength and same polarization that of the signal photon. Erbium ions can also be excited by a pump wavelength of 1480nm but is not desirable because the pump and the signal wavelengths are almost nearer and hence the interactions between these wavelengths will lower the efficiency of the device and increase the amplifier noise. The 980nm Pump source has a higher absorption cross-section and hence will be used where the EDFA design demands low noise. Hence we have used a 980nm pump laser and an EDFA kit designed for C-Band operation.

GAIN

The gain of an amplifier is considered as the performance metric for it as it is the ratio of the output voltage to output power. Hence we have taken into consideration the gain of EDFA and conducted the experiment under several parameters such as varying the length of the erbium doped fiber and different pumping schemes. Erbium Doped Fiber Amplifier has three different possible pumping configurations namely co directional pumping, counter directional pumping and dual pumping. The only difference in these three configurations is the direction of the pump power propagation. If the pump power co-propagates with the signal power then the configuration is known as Forward or co-directional pumping as shown in figure 2.

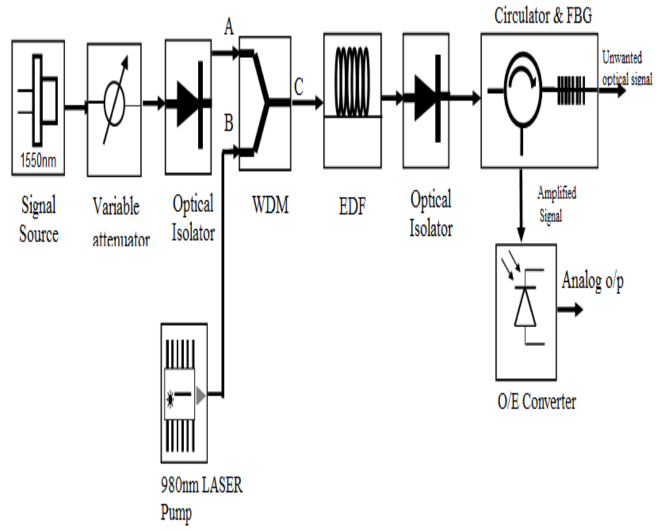


Fig 2: Co directional pumping scheme

Instead, if the pump power propagates in the opposite direction relative to the signal power then the configuration is known as Backward or counter-directional pumping as shown in figure 3. Further, if the pump power is applied in both the directions and hence propagates in both the directions of the signal power then the configuration is said to be dual pumping. The forward pumping provides lower gain and better noise performance than backward pumping. So the forward pumping scheme is generally used in pre-amplifier. The backward pumping scheme is used in power amplifier due to higher gain. Dual pumping scheme is used wherever higher gain is required.

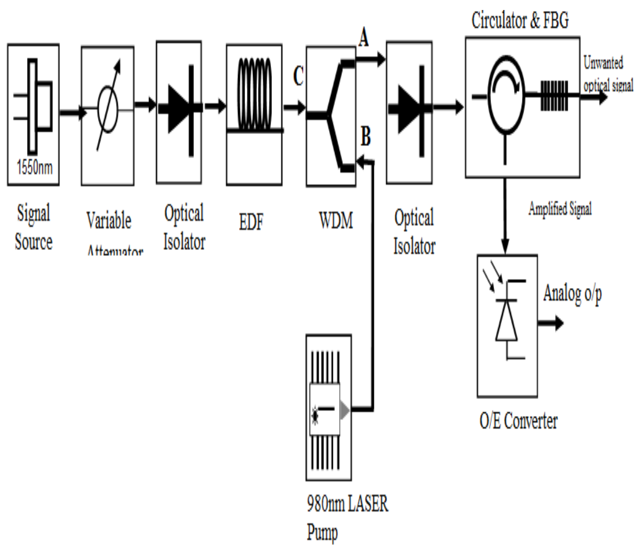
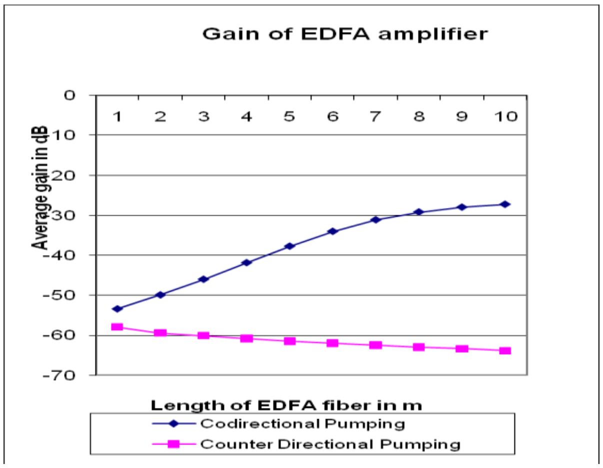


Fig 3: Counter directional pumping

Table I Gain of EDFA amplifier

Length of fiber (m)	Average gain(db)	
	Co-directional pumping	Counter directional pumping
1	-53.416	-57.95
2	-49.917	-59.413
3	-46.014	-60.062
4	-41.876	-60.801
5	-37.758	-61.426
6	-34.053	-61.977
7	-31.168	-62.479
8	-29.214	-62.947
9	-28.008	-63.389
10	-27.301	-63.812

Fig 4: Gain of EDFA amplifier



From the above experiments that have been simulated using GainMaster simulation tool we can come to conclusion that the gain of amplifier increases as length of fiber increases in co directional pumping. However in counter directional pumping it remains almost constant.

Noise

The principal source of noise in DFAs is Amplified Spontaneous Emission (ASE), which has a spectrum approximately the same as the gain spectrum of the amplifier. Noise figure in an ideal DFA is 3 dB, while practical amplifiers can have noise figure as large as 6–8 dB. The origin of ASE is the Spontaneous recombination of electrons and holes in the amplifier medium. When the erbium ions are excited pump power the ions which are sitting at the metastable state level can decay back to the ground state in the absence of an externally stimulated photon flux (1550 nm signal or signal input wavelength). This decay phenomenon is known as Spontaneous emission. This gives rise to a broad spectral background of photons. Photons are emitted spontaneously in all directions, but a proportion of those will be emitted in a direction that falls within the numerical aperture of the fiber and are thus captured and guided by the fiber. Those photons captured may then interact with other dopant ions, and are thus amplified by stimulated emission. The initial spontaneous emission is therefore amplified in the same manner as the signals, hence the term ***Amplified Spontaneous Emission***. ASE is emitted by the amplifier in both the forward and reverse directions, but only the forward ASE is a direct concern to system performance since that noise will co-propagate with the signal to the receiver where it degrades system performance. Counter-propagating ASE can, however, lead to degradation of the amplifier's performance since the ASE can deplete the inversion level and thereby reduce the gain of the amplifier.

Noise figure

On performing many experiments on gain, we cannot come to a conclusion that the gain in the signal is not fully filled with the strength of the signal; it will also consist of some form of distortion in the output signal. An experiment is being conducted on the noise that is seen to be present on the signal when it is pssed through the amplifier.The experiment consists of a few components as shown in the figure 5 signal source is used here to generate a input signal that is to pass through the amplifier.The signal is then sent through a variable attenuator.Then to an optical isolator which does not allow any sort of back current to fall back.A laser pump which produces a 980nm laser is sent to one of the inputs of the WDM and its output is sent to the Erbium Doped Fiber Amplifier which amplifies the signal and then its output is again sent throug the optical isolator to prevent the back current.Then a converter is used to convert the signal into an analog output.

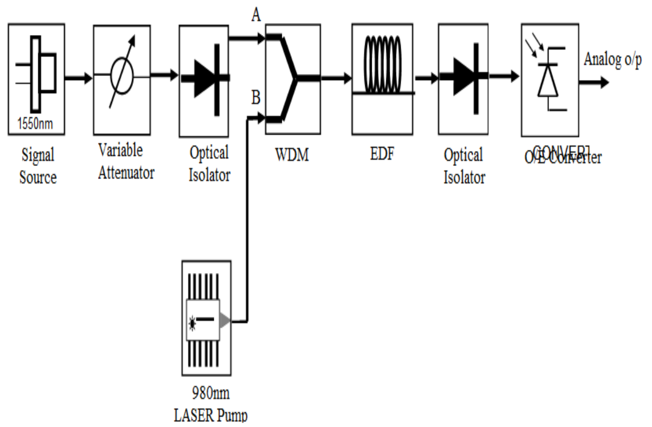


Fig 5: Noise Figure measurement

After giving the connections as shown in figure 5, the experiment is performed by varying the length of the amplifier i.e 3m,5m,7m.The experiment is conducted and the noise figure spectrum is obtained from the values obtained through the experiment.

Table II Noise figure Vs Length of EDFA fiber

Length of the fiber (m)	Noise Figure(dB)
1	3.3
2	3.7
3	3.8
4	3.82
5	3.85
6	3.9
7	4
8	4.25
9	4.4
10	4.7

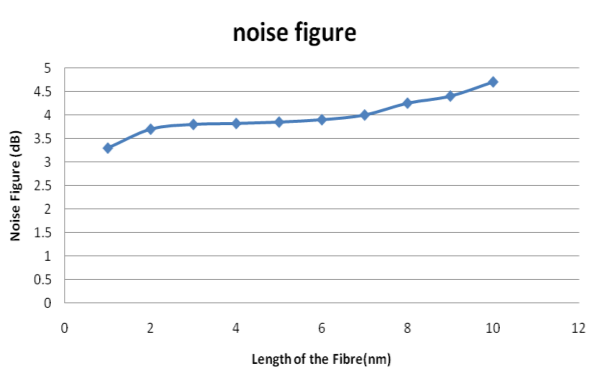


Fig 6: Noise Figure

From the above observation, we can come to a conclusion that Erbium Doped Fiber Amplifier can be used for amplifying signals efficiently and the noise figure of the EDFA is found to be relatively increasing as the length of the fiber increases.

CONCLUSION

It can be inferred from the results that Erbium doped fiber amplifiers have higher gain and low noise figure. Hence EDFA greatly enhances the system performance and hence can be used in long- haul, high data rate fiber optic communication systems. Since long–haul communication uses long length of cable, EDFA is preferred. The EDFA is used here to amplify the signal as its gain remains high as length of fiber increases. Also CATV applications usually need to split a signal to several fibers and hence EDFA finds its use here to boost the signal before and after the signal splitting between fibers. Thus EDFAs can be used as Power amplifier or booster amplifier, in-line amplifier, preamplifier and for loss compensation in optical networks.

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