CHAPTER 3

ANALYSIS OF ERBIUM AND ERBIUM-YTTERBIUM CO-DOPED OPTICAL AMPLIFIER

3.1 INTRODUCTION

An Erbium Doped Fiber Amplifier (EDFA) amplifies signal in third window of fiber optic communication, is very often a handy device for optical communication systems in 1530 nm wave length band. The proposed work is a simulative study on Erbium doped fiber amplifier. One of the significant and interesting advantages of EDFA is its use in modern optical transmission system which use WDM. The theoretical study of the temperature dependent gain was carried out and simulative study of EDFA’s at pump wavelength of 980nm and 1480nm was also carried out with different lengths. The long distance transmission using EDFA is not free from losses and other dispersion of optical signals. Hence dispersion compensation is needed more for long distance transmission of signals with good quality. Simulative study on dispersion compensated and uncompensated system performance is done for dispersionless transmission using Large Effective Area Fiber (LEAF) with suitable length of Dispersion Compensated Fiber (DCF). In addition to this an optical amplifier with erbium co-doped with Ytterbium is simulated with their parameter varied in terms of pump power, doping concentration and the result concludes that EDFA requires half the amount of pump power than that required for YDFA. Further Erbium-Ytterbium co-doped amplifier helps extend EDFA from C-band (1530-1565)nm to L-band (1565-1625)nm.
3.2 THEORETICAL MODEL OF EDFA

The EDFA are optical repeaters used for boosting the intensity of optical signals carried through fiber optic communication system. The major component of these amplifiers is Erbium which is an important constituent of signal repeaters in long distance telephone cables.

The heart of EDFA technology is Erbium Doped Fiber (EDF), which is a silica fiber doped with erbium. A long lifetime intermediate state is achieved when erbium is illuminated at a particular wavelength of 980nm or 1480nm. Signal amplification occurs when the pump wavelength and signal wavelength simultaneously pass through the EDF, thereby resulting in energy transfer.

The design of EDFA consists of a laser pump and a Wavelength Division Multiplexing (WDM) component. The most common EDFA pumping configuration is the forward pumping configuration with 980nm pump energy where the pump energy and the signal propagate in the same direction.

A single stage EDFA consists of three major components such as EDF, pump and WDM combiner. The signal initially enters the amplifier through an input port and then passes through a tap, which sends a small quantity of the signal to the input detector. The signal then passes through an isolator and moves to a pump combiner which is combined with 980nm pump energy and then passes to the EDF where the signal is amplified. The amplified signal again passes through an isolator. The purpose of the isolators is to allow the signal to propagate in only one direction. From the isolator the
signal then passes on to a Gain Flattening Filter (GFF) which flattens the gain spectrum. The output port also consists of a tap and an output detector as in input.

The dynamic behavior of EDFAs can be explained in a three-layered process which consists of ground, stable and upper levels. The process of amplification is dependent on the population inversion of the doping ions and its lifetime of fluorescence in its excited state through the amplification medium. The fiber doped with ER$^{3+}$ ions or with rare earth elements can be operated as an active amplification medium that can be triggered by the direct absorption of light from the pump source at either 980 or 1480nm. The rate equations for the system are,

\[
\frac{\partial M_3}{\partial t} = P_r(M_1 - M_3) - \alpha_{32}M_3 \tag{3.1}
\]

\[
\frac{\partial M_2}{\partial t} = S_{21}M_2 + S_{21}M_1 - \alpha_2M_2 + \alpha_{32}M_3 \tag{3.2}
\]

\[
\frac{\partial M_1}{\partial t} = S_{21}M_2 + S_{21}M_1 - \alpha_2M_2 + \alpha_{32}M_3 \tag{3.3}
\]

\[
\frac{\partial M_1}{\partial t} = -P_r(M_1 - M_3) + \alpha_2M_2 - S_{12}M_1 + S_{12}M_2 \tag{3.4}
\]

Where $S_{12}$, $S_{21}$ denotes the stimulated absorption and emission rates associated with the signal between the first and second meta stable level, $P_r$ refers to the rate of pumping from the first to the third level and the stimulated emission rate between them. $M_1$, $M_2$ and $M_3$ are components of ER$^{3+}$ ions in the first, second and the third place respectively. $\alpha_2$ being the sum of spontaneous radiative and non radiative transmission probabilities from the meta-stable to the ground level.
The relation between the mean numbers of atoms in the two levels, placed closely of a system being at thermal equilibrium are given by Boltzmann’s distribution as,

\[ \beta = \frac{M_3}{M_2} = \frac{n_3}{n_2} \exp(-\Delta E_3 / k_B T) \]  

(3.5)

Where \( \Delta E_3 = E_3 - E_2 \) is the energy difference between the third and the second level \( \beta \) is the Boltzmann population factor and \( k_B \) is the Boltzmann’s constant (\( k_B = 1.38 \times 10^{-23} \text{ J/K} \))

The relative population difference \( (\Delta M / M = (M_2-M_1) / M) \) for 1470 nm pumping configuration can be obtained from Equations. (3.6) - (3.8) as,

\[ \Delta M = \frac{R_p \tau (1-\beta) + S_{12} \tau (1-) - 1}{R_p \tau (1+2\beta) + S_{12} \tau (1+\beta+n) + 1} M \]  

(3.6)

\[ M_1 = \frac{\beta R_p \tau (1-\beta) + S_{12} \tau f i l l - 1}{R_p \tau (1+2\beta) + S_{12} \tau (1+\beta+n) + 1} M \]  

(3.7)

\[ M_2 = \frac{R_p \tau + S_{12} \tau}{R_p \tau (1+2\beta) + S_{12} \tau (1+\beta+n) + 1} M \]  

(3.8)

And

\[ \eta = \frac{S_{21}}{S_{12}} \]  

(3.9)

Where, it is assumed that \( M_3=\beta M_2 \) because, of \( M_2 \) and \( M_3 \) levels of \( \text{Er}^{3+} \) ion pumped at 1470 nm wavelength are spaced closely and the fast relaxation process. Thus, the \( \beta \) parameter is inserted into the rate equations for the case of 1470 nm pumping.
The relative population difference for 980 nm pumping configuration is also obtained from the rate equations as,

\[
\frac{\Delta M}{M} = \frac{R_p \tau + S_{12} \tau (1-\eta)-1}{R_p \tau + S_{12} \tau (1+\eta)+1}
\]  
(3.10)

With

\[
M_1 = \frac{S_{12} \tau f_{ill} + 1}{R_p \tau + S_{12} \tau (1+f_{ill})+1} M
\]  
(3.11)

\[
M_2 = \frac{R_p \tau + S_{12} \tau}{R_p \tau + S_{12} \tau (1+f_{ill})+1} M
\]  
(3.12)

When \(\alpha_{32}\) is large compared to the pumping rate into level 3, the population \(M_3\) is very close to zero, so the total population equals \(M_1\) plus \(M_2 \Delta M\). That is given by Eq. (3.6) for 1470 nm pumping and by Eq. (3.10) for 980 nm pumping, is a very important factor, because the gain of EDFAs depends firmly on the relative population inversions. If the excitations for both pumping configurations are very strong, then it can be written from Equation,

\[
R_p(1470) > 1 - S_{12} \tau (1 - \eta_{(1470)})
\]  
(3.13)

\[
R_p(980) > 1 - S_{12} \tau (1 - \eta_{(980)})
\]  
(3.14)

When the pumping rates or the pumping powers required for the excitation are extremely strong, the population differences in Equations. (3.6) and (3.10) becomes,

\[
\lim_{R_p(1470) \to \infty} \Delta M = \left(\frac{1-\beta}{1+2\beta}\right) M
\]  
(3.15)

\[
\lim_{R_p(980) \to \infty} \Delta M = M
\]  
(3.16)
These two equations when verified yielded same results as $M_3$ is negligible. In the given conditions, with the greater population inversion stronger amplification is obtained as expected. When the pumping is small the various transitions to the upper levels can be seen which is called the Excited State Absorption (ESA). There is no ESA for 980 and 1470 nm pump wavelengths whereas it occurs for 510, 532, 665, 810 nm pumping wavelengths and reduces the efficiency of EDFAs. Hence EDFAs pumped at the wave lengths used here show not only the higher gain per unit pump power, but also the higher signal output power and the lower amount (a few decibels) of amplified spontaneous emission (ASE) noise.

### 3.2.1 Amplified Spontaneous Noise

A photon in its excited state is not stimulated within 10 ms of its lifetime thus spontaneously decaying to its ground state producing ASE. When this photon travels through the erbium-doped fiber, it gets amplified, resulting in amplified spontaneous emission. All the ions in the excited state from the upper state to the ground state relax spontaneously by emitting a photon that is not related to the signal photons. This photon emitted spontaneously can be amplified as it travels down the fiber and stimulates the emission of more photons from excited electron. Amplified spontaneous emission can occur at any frequency within the fluorescence spectrum of the amplifier transitions. The dominant source of noise in any EDFA is amplified spontaneous emission. This spontaneous emission reduces the amplifier gain by consuming the photons that would otherwise be used for stimulated emission of the input signal.
3.2.2 Signal Power of an EDFA

The out power signal is calculated as,

\[ P_{out} = P_{in} \times G \]  

(3.17)

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 when a WDM signal is amplified. The amplified output signal power is degraded due to the ASE (Amplified Spontaneous Emission) noise. The output signal power increases as the result of the stimulated emission and this in turn is due to population inversion which is directly related to the pumping power. The gain of the EDFA is limited by the small number of Erbium ions in the core. Increasing the pump power beyond the limit where all the ions are excited does not produce gain because it reaches a saturation point.

3.2.3 Pump Power of an EDFA

Typically, the EDFA configuration by pumping scheme is categorized into three- Forward pumped (co-pumped), Backward-pumped (counter pumped), and Bidirectional-pumped (Dual-pumped). 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.

In forward pumping, the input signal and the pump signal propagate in the same direction within the fiber. The input signal and pump are combined with the use of a pump combiner or wavelength selective coupler. Within the fiber, the pump energy is transferred to the input signal which is amplified at the output of the amplifier. Isolators are used in this
scheme to make sure that the signal travels only in a single direction and there is no occurrence of feedback of signal.

The pump wavelength is determined by the spectroscopic characteristics of the active medium. In the case of the glass system, Er\textsuperscript{3+}: Si used in EDFAs (silica glass doped with trivalent erbium ions), the pump wavelength can be chosen both around 980 nm and around 1480 nm. In the first case, Er\textsuperscript{3+}: Si behaves like a three-level laser system; in the latter, it is a near-two-level system where the amplifier is pumped in the high-frequency tail of the fluorescence band. Both kinds of excitation, 980 and 1480 nm, can be realized by means of semiconductor laser diodes, that is, very compact, powerful, reliable sources.

### 3.3 DISPERSION COMPENSATED FIBER

Dispersion is one of the basic limitations in the modern optical transmission systems. Dispersion leads to pulse broadening due to the non-zero bandwidth of an optical signal and the presence of group delays in the different spectral components. Dispersion compensating optical fibers (DCF) with negative dispersion value and negative dispersion slope (-50 ~ -500 ps/nm\textsuperscript{2}/km) are used for compensating or optimizing the dispersion characteristics of long distance transmission systems. DCF can provide high negative dispersion coefficient which are opposite in sign but larger than the positive chromatic dispersion of conventional single mode fibers at 1550 nm. The technique based on DCF is widely developed in this connection to combat the chromatic dispersion of the fibers.

An important parameter for DCF is the excess loss when DCF is spliced to Standard Single Mode Fiber (SSMF). Commercially available DCF comprises a smaller core with a high refractive index and three or more cladding layers, having a Mode Field Diameter (MFD) of approximately 5.0
at 1550 nm, compared with the approximately 10.5 MFD of SSMF at 1550 nm. The difference in core diameters leads to significant signal loss in splicing process when connecting DCF to SSMF. Efforts are being made to reduce the splicing loss by choosing splicing parameters that allow the core of the DCF to diffuse, thereby causing the MFD of the DCF core changed to taper outwards thereby resulting in MFD mismatch induced decreased signal loss.

3.3.1 Basic Principle of DCF

The positive dispersion of a SSMF is compensated by the DCF encapsulated in a module, which is inserted into the transmission link. The total dispersion ($D_T$) and total attenuation ($\alpha_T$) of the link is given

$$D_T = D_{SMF} L_{SMF} + D_{DCF} L_{DCF}$$

$$\alpha_T = \alpha_{SMF} L_{DCF} + \alpha_{DCF} L_{DCF} + L_{splice}$$

Where $D_{SMF}$ is the dispersion in a single mode fiber, $L_{SMF}$ is the length of the single mode $D_{DCF}$ is the dispersion in DCF. $L_{DCF}$ is the length of DCF, $\alpha_{SMF}$ is the attenuation in single mode fiber, $\alpha_{DCF}$ is the attenuation in DCF and $L_{splice}$ is the splicing loss.

The length of DC chosen is calculated for $D_T=0$. Formula 3.19 illustrates DCF splicing loss induced total attenuation in the transmission link. It is necessary to improve splicing techniques to reduce splicing loss.

In a dispersion compensated link consisting of a standard SMF and a DCF, the input pulses first broaden due to propagation through the SMF and then subsequently recompress to their original shape due to propagation through the DCF, which has the dispersion coefficient parameter of opposite
sign to that of SMF. During the propagation of a pulse through the fiber, the Group Velocity Dispersion (GVD) changes the frequency across the pulse referred to as frequency chirp. The chirp depends on the sign of the dispersion parameter. When the dispersion coefficient parameter of the fiber is negative, the frequency increases across the pulse from the leading to the trailing edge. This is referred to as the positive frequency chirp. On the other hand, when the frequency chirp is negative, i.e., the frequency decreases across the pulse from the leading to the trailing edge. This is known to have positive dispersion coefficient. When the dispersion coefficient parameter is positive, the frequency chirp is also induced by the SPM effect and increases in magnitude with the propagated distance.

Frequency chirping is positive due to the SPM effect irrespective of the sign of the dispersion coefficient parameter. Therefore, the SPM effect leads to an enhanced rate of pulse broadening in the fiber with negative dispersion coefficient parameter compared to that expected from the GVD alone. However, the broadening rate decreases during propagation in the fiber with positive dispersion coefficient parameter, as the two chirp contributions cancel each other. In the dispersion management technique, consider the situation in which each optical pulse propagates through two fiber segments, the second of which is DCF. The condition for perfect dispersion compensation is:

\[ D_1 L_1 + D_2 L_2 = 0 \]  \hspace{1cm} (3.20)

i.e., its length should be chosen to satisfy

\[ L_2 = -(D_1/D_2) \times L_1 \]  \hspace{1cm} (3.21)

where \(D_1\) and \(D_2\) are the fiber dispersions of SMF and DCF respectively. For practical reasons, \(L_2\) should be as small as possible. This is possible only if the DCF has a large negative value of \(D_2\).
3.3.2 Noise Figure

EDFA Noise Figure (NF) quantifies the Signal-to-Noise Ratio (SNR) degradation experienced by an optical signal when it is passed through the amplifier. The NF will always be greater than one since the EDFA adds noise during the amplification process in the form of ASE. So the output SNR is always less than the input SNR. In theory, the best NF achievable by an EDFA is 3 dB.

\[
NF = \frac{SNR_{in}}{SNR_{out}}
\]  

(3.22)

\[
NF (dB) = 10 \log \left( \frac{SNR_{in}}{SNR_{out}} \right)
\]  

(3.23)

Where \( SNR_{in} \) is the signal-to-noise ratio for the EDFA input signal, and \( SNR_{out} \) is the signal-to-noise ratio for the EDFA output signal.

The value of NF depends on the pump frequency. For large SNR values, an approximate expression for NF is given by

\[
NF = \frac{1}{g} \left[ 1 + \frac{2P_{ASE}}{hv\Delta} \right]
\]  

(3.24)

Whereas \( P_{ASE} \) is the noise power of ASE, \( V \) is the pump frequency and \( \Delta \) the bandwidth of EDFA. The noise figure thus depends both on the pump power and EDFA length.

The noise figure of an optical amplifier has a significant role in analog systems. The signal-to-noise ratios of analog systems are often so demanding that noise figures of less than 5 dB must be measured accurately. Another important purpose of the noise figure is to characterize the amount of ASE produced by the amplifier, because the ASE tends to accumulate in the communication system. Theoretically, the noise figure of an optical amplifier
can be measured electrically or optically. Electrical noise figure measurements are considered as being closer to reality. However, they are complicated and usually suffer from lack of accuracy. For Optical performance, optical measurements are often preferred by EDFA manufacturers in view of their higher accuracy.

3.3.3 Gain Saturation

An important consideration in designing amplified systems is the saturation of the EDFA. Gain saturation is the signal power dependent gain compression that an amplifier suffers when the input signal strength becomes large. Depending on the pump power and the amplifier design itself, the output power of the amplifier is limited. As a result, when the input signal power is increased, the amplifier gain drops. This is called gain saturation. This behavior can be captured approximated by the following equation:

\[
G = 1 + \frac{P_{Sat}}{P_{Lin}} \ln \frac{G_{Max}}{G}
\]  

(3.25)

Gain in EDFA is achieved due to population inversion of dopants ions. As there are limited number of dopants ions, increasing pumping power to a level at which all the dopants are excited will not increase the population of the excited level any further and the gain saturation will take place. Further as the input signal power increases, inversion level reduces and there will be no further amplification. The maximum output power beyond where no amplification occurs is called gain saturation.

Their behavior is different from that of electronic amplifiers where the gain curve is linear till saturation occurs. This results in signal distortion for an electronic amplifier that is operated near saturation point.
Here, $G_{max}$ is the unsaturated gain and $G$ the saturated gain of the amplifier, $P_{sat}$ is the internal saturation power of the amplifier, and $P_{in}$ is the input signal power. The saturated gain is less than the unsaturated gain. EDFA gain saturation can degrade the received signal quality and increase the receiver BER.

### 3.3.4 Gain Dispersion in EDFA

Gain dispersion refers to the wavelength dependence of the gain of an EDFA. Since the population density at the various levels within a band is different, the gain of an EDFA becomes a function of the wavelength. When such an EDFA is used in a WDM communication system, different WDM channels undergo different degrees of amplification. The wavelength dependence of gain is referred to as gain dispersion. This is a critical issue in WDM systems with cascaded amplifiers.

One way to improve the flatness of the amplifier gain is to use fluoride glass fiber instead of silica fiber, doped with Erbium. Such amplifiers are called Erbium Doped Fluoride Fiber Amplifiers (EDFFAs). However, there are certain drawbacks while using fluoride glass. The noise performance of EDFFA is poorer than EDFA. Fluoride fiber is difficult to handle. It is brittle, difficult to splice with conventional fiber, and susceptible to moisture. Another approach to flatten the EDFA gain is to use a filter inside the amplifier. Long period fiber gratings and dielectric thin film filters are currently the leading candidates for the task. Most commercially available amplifiers are able to provide gain flatness of less than 1 dB ripple across the nominal band.
3.3.5 Gain Spectrum of an EDFA

EDFA gain spectrum is mainly determined by two characteristics which are emission $\sigma_{21}$ and absorption $\sigma_{12}$ cross section defined as,

$$P_{abs} = \sigma_{12} \times I$$ (3.26)

$$P_{em} = \sigma_{21} \times I$$ (3.27)

Where, $I$ = Intensity of incident light per unit area

$P_{abs}$ = Amount of power absorbed

$P_{em}$ = Amount of power emitted

Here 1 and 2 corresponds to Energy level E1 and E2 between which transition occurs. Total power change can be calculated as,

$$\Delta P = P_{em} - P_{abs} = [N_2\sigma_{21} - N_1\sigma_{12}] \times I$$ (3.28)

$N_1$ and $N_2$ are the population of respective energy levels. The link between the emission and absorption cross section is defined by the Mc Lambert relationship.

$$\sigma_{21}(\nu) = \sigma_{12}(\nu) \times e^{[(E-h\nu)/kT]}$$ (3.29)

Where, $\nu$ = frequency

E = Mean transition energy between two manifolds

$h$ = Planks constant

$k$ = Boltzmann constant

$T$ = absolute Temperature
The spectral dependence of amplifier gain is weighted combination of gain & absorption cross-section where the weighting depends on the population of upper & lower levels

\[ G_{dB}(\lambda) = 4.343\left[N_s\sigma_s(\lambda) + N_a\sigma_a(\lambda)\right] \Gamma_s L \]  

(3.30)

Where, \( \Gamma_s \) Effective overlap factor between signal and ion population

\( N_1 \) Lower level population, \( N_2 \) Upper level population \( L \) Length of Erbium doped Fiber, \( \sigma_s \) is absorption cross-section and \( \sigma_a \) is gain cross-section.

The gain can be calculated directly from the longitudinal area of upper and lower population.

### 3.3.6 Bit Error Rate

Transmission of data through a fiber-optic link unavoidably leads to bit errors due to various effects, the dominant of which are noise from optical amplifiers, fiber nonlinearity, polarization effects, and non-ideal transmitters and receivers. One of the main parameter describing the quality of data link is a Bit Error Rate. With BER it is possible to comapare the quality of different system for data transmission. Bit Error Rate is defined by the following equation,

\[ BER = \frac{n_c}{N_B} \]  

(3.31)

Where \( n_c \) is number of bits received in error and \( N_B \) is the total number bits received in the given time. Calculating the BER (G.Basco et al. 2000) in such a regime or handling the optimal power level requires an accurate model of the nonlinear interactions.
3.3.7 Quality Factor

The Quality factor is a measure of how noisy a pulse is for diagnostic purposes. The eye pattern oscilloscope will typically generate a report that shows what the Q factor number is. The Q factor is defined as the difference of the mean values of the two signal levels (level for a “1” bit and level for a “0” bit) divided by the sum of the noise standard deviations at the two signal levels. A larger number in the result means that the pulse is relatively free from noise.

3.4 Erbium-Ytterbium Co-Doped Fiber Amplifier

Achievement of fine-tuning efficiency of absorption with optimization of the fiber material can be realized by co-doping ytterbium ions into the erbium-doped fiber as a sensitizer and double cladding the fiber structure for enlarging the aperture of the pump light. The corresponding fiber is known as Erbium–Ytterbium Doped Fiber (EYDF). Non-degrading the optical amplification efficiency of the co-doped amplifiers were employed for achieving low non-linearity. The Co-doped amplifiers like the EYDFA use the mechanism of stimulated emission rather than spontaneous emission when compared to EDFA and YDFA. Application includes planar waveguide technologies using sputtered or ion-exchanged waveguides fabricated from high concentration rare-earth doped glasses.

3.4.1 Optimization of Doping Concentration

The rate equation model of the co-doped system was used for finding the optimal Er3+-Yb3+ dopant concentrations and predicting the expected population inversion for a range of Er3+ and Yb3+ concentrations. Hence the need for many samples to be grown with varying dopant concentrations and ratios does not arise. Here, according to the approximations of the researcher, the decay rate of the Yb3+ ions caused by energy transfer to the Er3+ ions are done by an exponential fall-off with
respect to the Er\(^{3+}\) concentration. The up conversion rate increases with Er\(^{3+}\) concentration, and this was approximated by a linear function after the analysis of Er\(^{3+}\), Yb\(^{3+}\)-doped phosphate glasses in which the up conversion rate was constant with respect to the Yb\(^{3+}\) concentration. The dynamics of Er\(^{3+}\), Yb\(^{3+}\)-doped lithium niobate crystals and the lifetime of the Er manifold was not affected by the Yb\(^{3+}\) concentration and so it remains constant in the analysis. Moreover, the lifetime of the Yb\(^{3+}\) manifold increased slightly with increasing Yb\(^{3+}\) concentration.

**Summary**

In recent communication systems, fiber optic components are frequently used. These systems have many properties such as high capacity, wide bandwidth, and fast transmission. However, due to the attenuation of the fiber cable in the transmission line with a length of 100 km, optical repeater must be used in such kind of systems. EDFAs are the most commonly used popular optical repeaters because of its attractive properties such as simple, compact structure, high gain, and low noise figure. They are generally used in C band (1530-1565 nm) but with the increasing demand, it can also be used in L band (1570-1610 nm) region. Therefore, longer transmission lines are necessary in the ultra-long fiber optic communication. Hence, high optical gain, low noise figure, and wide bandwidth are desired for such kind of systems. Thus as a key feature, theoretical model of EDFA containing the rate equations, ASE, Signal power, pump powers has been discussed along with dispersation compensated fiber model with basic principle of DCF, Noise Figure, gain saturation, gain dispersion, BER and Quality factor are also been discussed in this chapter. Consequently, the works related to EDFA performance with respect to temperature changes, Dispersation compensated EDF and Erbium-ytterbium co-doped optical amplifiers performances have been discussed in forth coming chapter.