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Optical Communication link design using EDFA with FBG : Theoretical Review

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Abstract –A larger bandwidth is offered by optical fiber communication for data transmission at higher rates. The fiber channel is capable of transmitting data at the rate of terabits-per-second but for increasing data throughput, addition of extra fibers to the system is uneconomical. Erbium-Doped Fiber Amplifier (EDFA) is the optical amplifier that can amplify the multiplexed optical signals falling into its amplification band for long range optical communication networks. EDFA's operational flexibility is also increased by reducing different losses that occur in optical fiber communication system**.** Besides these losses, optical communication system also suffers from dispersion and nonlinear impairments. For this purpose, Fiber Bragg Grating (FBG) is most widely used**.** In the present paper, performance analysis of optical link using EDFA and FBG has been explored in details. Also it focuses on different pumping techniques used to analyze the performance of EDFA and FBG with respect to various parameters- wavelengths, modulation formats and data rates.

Keywords- EDFA, FBG, Return to Zero (RZ), Single mode fiber (SMF), Continuous wave laser (CW), Refractive index (RI),Non Return to Zero (NRZ), Wavelength Selector Coupler (WSC), Mach-ZehnderModulator (MZM)

I. INTRODUCTION

Optical fiber Communication system offers certain special characteristics and advantages over conventional electrical communication system i.e. small dimension, low losses and imperfections from external environments. From last few decades due to its enormous capacity i.e. large bandwidth, it provides high speed data rate. It can transmit data at the rate of tera bits/sec [1]. Optical Fiber Communication transmission uses three basic steps, these are (i) Generating an optical signal using an optical source such as LASER or LED (ii) Relaying the signal over an optical fiber which act as the medium (iii) Using optical detector for converting optical signal back into original electrical signal. In optical fiber Communication, detection of optical signal at receiver end becomes difficult because of several fiber losses which results in reduction of signal strength. Therefore in order to prevent these losses, we use an optical amplifier with good gain. With the introduction of optical amplifiers, there is no need of optical to electrical conversion [2].

Besides these losses, optical communication system also suffers from dispersion and non-linear impairments. Hence overall performance can be improved by employing dispersion compensating techniques. For this purpose FBG is most widely used.

This paper presents a detailed review of different methods used for studying the performance of optical link using EDFA and FBG with their applications. Section II provides a detailed review of EDFA, its operation, model designing and various techniques used for analyzing its performance. In Section III, FBG along with its working principle, application areas have been explored in details followed by conclusion in section IV.

II. EDFA: DESIGN AND OPERATION

Optical fiber amplifiers provide in-line amplification of optical signals by effecting stimulated emission of photons. Mostly chosen rare earth element for this purpose is Erbium. EDFA is utilized in order to strengthen the optical signals. For long–distance telecommunication

applications it is made by using silica doped erbium (Er+3) ions. Pink colored Er+3 ions, have optical luminous properties which are appropriate for amplification. EDFAs are used to provide amplification in the wide wavelength region of 1550 nm- 1600nm [3].
EDFA's Particular attraction is its large gain with enormous capacity, which is of the order of tens of nanometers. EDFA's with high pump power and longer link lengths are being used for the overall improvement of system performance. Figure 1 shows the Block Diagram of EDFA.

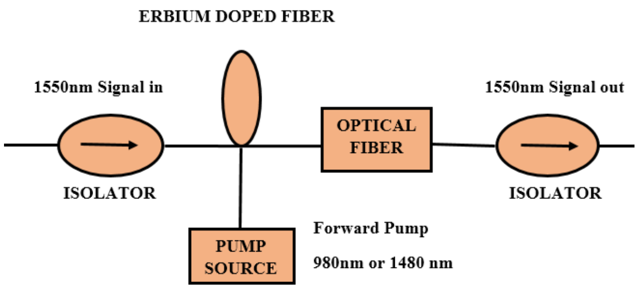

Figure 1. Basic Block Diagram of EDFA

Here EDFA is pumped by using a laser diode source of wavelength 980 or 1480nm. When erbium ions are elevated by using pump source, signal amplification occurs. On both sides of the channel, Isolators are used to prevent the back propagation of signals.

EDFA's basic principle of operation is Stimulated Emission [4]. Erbium ions are basically having the optical luminous properties which makes them suitable for amplification purpose. There are mainly two wavelength bands i.e. C-Band within range of 1530nm to 1560nm while L-Band ranging from 1560nm to 1600nm. EDFA able to amplify an extensive wavelength range of 1500nm to 1600nm. The three level energy diagram showing method of its amplification is shown in figure 2.

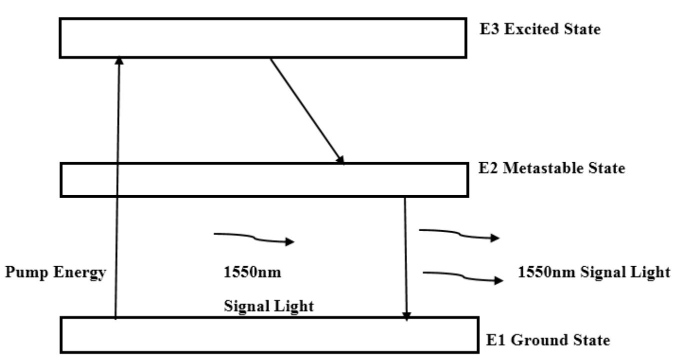

Figure 2. Energy Levels of Erbium ions (Er+3) [5]

E1 is the ground state. When no pump signal is applied, the population of ions at E1 is greater than the population density at E2 which is the metastable state. On application of pump signal, the density of ions get altered and the process is called population inversion.The density of ions at E3 becomes greater than the density at E1.

When the laser source is provided with pump wavelength of 980nm, the Er3+ ions are excited from E1 to the upper state E3. But as the upper state E3 is not stable, ions does not last there for the longer time and return back to the metastable state E2. After a time span of around 10ms, they come back to the ground state E1 and emits photons of certain energy in this process [4, 5].

EDFAs are pumped by using a laser diode source of wavelength 980nm or 1480nm.There are several ways to elevate or pump Erbium ions (Er3+) from the lower states to the higher states. The various pumping techniques used for EDFA are shown in figure 3.

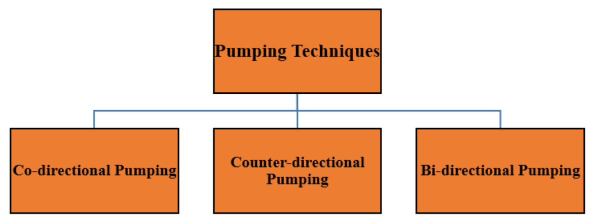

Figure 3. EDFA Pumping Techniques

In Co-directional Pumping, both input signal and pump signal travel in the same direction inside an optical fiberwhile for Counter–directional Pumping technique, the input light signal and the pump signal are opposite to one another [6]. The Wavelength Selector Coupler (WSC) is used to combine the input signal and pump signal. The arrangement used for Co-directional Pumpingis shown in figure 4. The pump laser provides energy to the input signal along the fiber and the signal amplification is done at the output of the amplifier.

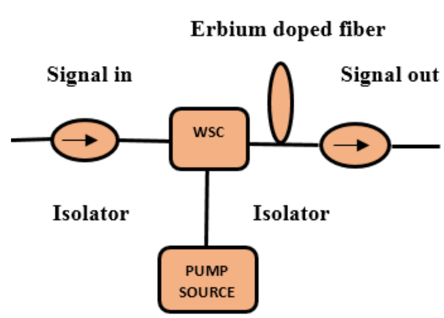

Figure 4. Co-directional pumped EDFA Structure

The arrangement for Counter-directional Pumping is shown in figure 5.

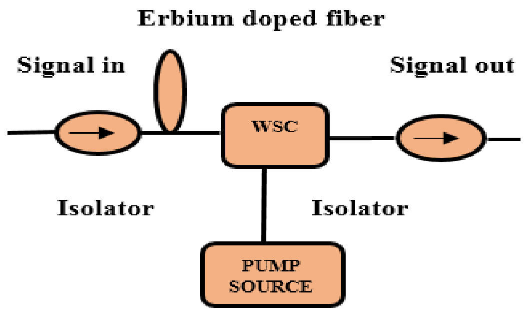

Figure 5. Counter–directional Pumped EDFA Structure

In Bidirectional Pumping, out of two pump signals one signal travels in the same direction as that of input signal whereas another signal travels in the opposite direction[6, 7]. The arrangement for Bi-directional Pumping is shown in figure 6.

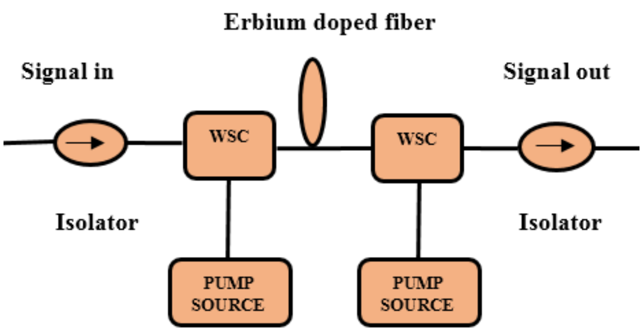

Figure 6. Bidirectional Pumped EDFA Structure

The authors in [8] have explained the use of EDFA in different wavelength regions and with different modulation formats. The best results are obtained in a wavelength band (1552-1565 nm) using RZ modulation format.

The authors in [9] have used different pumping techniques to study the performance of EDFA in terms of Gain and noise figure (NF) values. On implementation, it is found that Co-directional Pumping and Counter–directional pumping technique have an almost equal gain of 27 dB while the bi-directional Pumping technique has higher gain of 32dB.The values of gain obtained at pumping wavelength of 1480nm are higher than at 980nm. The values of noise figure at 1480 nm and 980 are 6dB and 8dB respectively.

Shivani Radha Sharma et al. [10] have presented the gain flattening of EDFA, which means achieving a uniform gain bandwidth.The gain of EDFA is calculated as :

$$G_{EDFA} = Gmax[L, \lambda p, \lambda s] = \exp[L \frac{rp(\lambda p)-r(\lambda p)}{1+rp(\lambda p)}] \ldots\ldots\ldots(1)$$

where and λ_s denotes the pump and signal wavelength respectively, r_p denotes the ratio of pump absorption to the pump emission (σ_{pa}/σ_{pe}) whereas r denotes the ratio of signal absorption and signal emission(σ_{sa}/σ_{se}).

Gain spectra of EDFA fluctuates between wavelength range of 1530 to 1560 nm. This fluctuation range should be minimized as it is not possible to work with an amplifier not having a uniform gain.Hence, different techniques are used for achieving flatness of gain over its entire range of operating wavelength. Gain flattening techniques are mainly categorized as Glass composition, Gain flattening filters and Hybrid optical filters which are further classified as shown in figure 7.

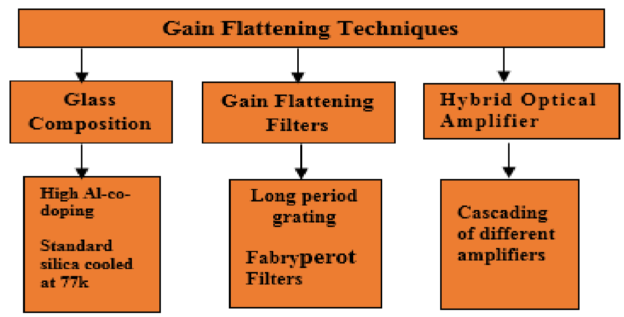

Figure 7. Gain Flattening Techniques

Giridhar Kumar R et al. [11] have designed a four-stage EDFA in WDM arrangement and analyzed the gain and noise figure by using pump powersof 0.1, 0.15 and 0.75Watts. This design of EDFA is employed in booster applications. A relatively flattened maximum gain of 61.04 dBm and a low noise figure is obtained at a pump power of 0.75 W. The authors in [12] provides a study of 32-channel DWDM systemperformance using EDFA in C-band with a flow rate of 10 Gbps. By designing an optical fiber link of variable lengths the performance of RZ and NRZ modulation formats are investigated. Optimal results of BER and Q-factor are found for 60km, 80km and 100km of fiber cable length. Hence the designed system givesmajor improvement and works significantly for RZ modulation format at 100km of fiber length.

Simranjeet Singh et al.[13] have compared Raman-EDFA and EDFA-YDFA optical amplifiers for DWDM communication system and the system performance is measured in terms of Q-factor, BER and Eye diagrams. It is found that Raman-EDFA performs better up to 100km in terms of Q-factor while for 100km onwards, EDFA-YDFA gives good results and shows the immunity towards the

non-linearities. The maximum tolerable repeater-less transmission distance of Raman-EDFA sytem is found to be 170km whereas for EDFA-YDFA system the repeater-less transmission distance is 130km.
G.lvanovset al. [14] have presented the application of EDFA in WDM transmission system. By applying large enough signal power at EDFA input, the produced ASE noise can be reduced. The optical filters have been used during multi amplification stages to keep the ASE noise level low. It is also found that for small length of optical fiber, a portion of EDFA pumping radiation is wasted. Thus, an optimal length of fiber should be used.

III. FBG

FBG is very simple lost cost filter in which Refractive Index (RI) varies periodically along the fiber axis which performs filtering operations with high efficiency and low losses. On doping the core with germanium, phosphrous or boron during fabrication process, a fiber can be made photosensitive. Depending on the pattern spacing and refractive index of medium, FBG selectively transmits some wavelengths and relect others. FBG act as tiny mirror fiber and due to periodic variations in RI of fiber core, it can reflect specific wavelengths. Fundamental principle of operation of FBG is Fresnel Reflection [15]. Here when light travels in between the media of different RI's may both reflect and refract, where the reflected wavelength is called Bragg wavelength(λ_B).On the other hand λ_B is equal to the twice of grating period (Λ) multiplied by (n_e) the effective RI of fiber core, which is called asBragg condition, as shown below :

$$\lambda_B = 2n_e\Lambda \ldots\ldots (2)$$

where $n_e$and $\mathbf{\Lambda}$ denotes the effective RI of grating in the fiber core and period of grating respectively. FBG'sprinciple of operation is shown in the figure 8 given below, which consists of core and cladding with variable RI's denoted by N0,N1,N2 and N3.

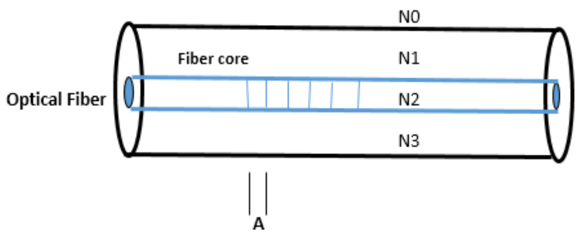

Figure 8. Principle of FBG

Marcelo M. Werneck in [16] stated that the sensitivity of the Bragg wavelength (λ_B) can be calculated with respect to temperature and strain by using equation (2) and it is foundthat the sensitivity of $\lambda_B$with temperature (T) is the partial derivative with respect to temperature as shown in equation (3)

$$\frac{\Delta\lambda B}{\Delta T} = 2neff\frac{\partial\wedge}{\partial T} + 2\wedge\frac{\partial neff}{\partial T} \quad \ldots\ldots\ldots\ldots\ldots (3)$$

Substituting equation (2) in equation (3), we obtain

$$\frac{\Delta\lambda B}{\Delta T} = \frac{1}{\wedge}\frac{\partial\wedge}{\partial T}\lambda B + \frac{1}{neff}\frac{\partial neff}{\partial T}\lambda B$$

After rearranging,

$$\frac{\Delta\lambda B}{\lambda B} = \frac{1}{\wedge}\frac{\partial\wedge}{\partial T}\Delta T + \frac{1}{neff}\frac{\partial neff}{\partial T}\Delta T \ldots\ldots\ldots (4)$$

In equation (4) the first term and second term can be replaced by (α) and (η) respectively then we obtain,

$$\frac{\Delta\lambda B}{\lambda B} = (\alpha + \eta)\Delta T \ldots\ldots\ldots\ldots\ldots\ldots\ldots (5)$$

where the term (α) denotes the silica's thermal expansion (α) and term (η) denotes the thermo-optic coefficient which represents the RI (dn/dT) temperature dependence.

On the other hand, sensitivity with strain is the partial derivative of (2) with respect to displacement (L) as shown in equation 6 :

$$\frac{\Delta\lambda B}{\Delta L} = 2neff\frac{\partial\wedge}{\partial L} + 2\wedge\frac{\partial neff}{\partial L} \ldots\ldots\ldots\ldots\ldots (6)$$

Substituting equation (2) in equation 6, we obtain

$$\frac{\Delta\lambda B}{\lambda B} = \frac{1}{\wedge}\frac{\partial\wedge}{\partial L}\Delta L + \frac{1}{neff}\frac{\partial neff}{\partial L}\Delta L \ldots\ldots\ldots\ldots (7)$$

In Eq. (7), first term denotes the grating period strain due to the extension of the fiber whereas second term denotes the photo-elastic coefficient (ρe) which is the variant of RI with respect to strain. Therefore Eq.(7) can be written as

$$\frac{\Delta\lambda B}{\lambda B} = (1 - \rho e)(\varepsilon_z) \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (8)$$

(ε_z) denotes the longitudinal strain of grating
Combining equation no. (5) and (8) finally came up with sensitivity of λ_B with respect to both temperature and strain and results in equation no. (9).

$$\frac{\Delta\lambda B}{\lambda B} = (1 - \rho e)(\varepsilon z) + (\alpha + \eta)\Delta T \ldots\ldots (9)$$

FBG Sensors can be used in a number of applications [17].FBG sensors provides a direct method of temperature measurement that can be used in Overhead Transmission Lines. These sensors are electrically passive,compact size, low weight and are insensitive to electromagnetic interferences which are some of the advantages of these sensors[18]. FBG sensors are also used in development of wearable physiologic monitoring system. These sensors have the ability of sensing temperature, strain, and movements and are thus suitable for wireless and long haul physiologic monitoring [19]. FBGs can be widely used in several microwave photonics applications due to its unique flexible spectral response,low losses and compatibility to other fiber-optic components [20]. Earlier, intrusion detection methods were used for homeland security like electrical pressure mats, reed switches and perimeter fence sensors that are extensively replaced by FBG sensorsnowadays. In addition to this, FBGs can be used as in-ground acoustic sensors establishing a network for real-time observing of prospective intruders [21].Similarly Optical fiber sensors also find an application as both biomedical sensors and long distance sensors. In case of biomedical sensing breathing rate measurements includes the use of microbend fiber sensors. Whereas in case of long distance sensing, 150-km long FBG temperature and vibration sensor system is demonstrated [22].

The authors in [23] have used two different modulation formats-NRZ and RZ at 10Gb/s rate in order to avoid intersymbol interference (ISI). In this work continuous wave laser (CW) is used with 1550nm wavelength and 5dBm power. EDFA has been used for amplification purpose while dispersion is compensated by using loop control mechanism.The operation of FBG with NRZ performs better as compared to RZ modulation format for transmission over single channel using SMF.Aashima Bhardwaj et al. in [24] has launched a 20 Gb/s NRZ signal over a 50 km long standard (SMF) single mode fiber. For various optical fiber cable (OFC) lengths their corresponding Q-factor values are noted as, for OFC cable length of 10, 20, 30, 40 and 50 km their Q-factor values are 23.8289, 19.819, 12.7887, 8.66328, 7.21557. It is concluded that, with increase in data rate and fiber cable length, the Q-factor goes on reducing.

The authors in [25] have used FBG to compensate chromatic dispersion with variable grating lengths and Apodization functions. CW laser is used with frequency of 193.1 THz and O/P power of 15 dBm which is modualted by NRZ modulation format externally at a rate of 10 Gb/s. The grating length used in this model is 80 mm whereas SMF length used for transmission is 210 km. Uniform, Gaussian and Tanh are the various apodization functions used and the values of Q-factor obtained are 8.22db,10.59db,8.6db respectively.These values of Q-factor concluded that Gaussian and Tanh functions provides good results than Uniform function.

IV.CONCLUSION

This paper presents a detailed review of different methods used for analyzing the performance of optical link using EDFA and FBG along with their application areas.The operation of EDFA is revised with different pumping configurations. Among all pumping techniques, the bi-directional pumping arrangement provides flat gain and low noise figure. The techniques used for gain flattening of fibers are also explored in details. EDFA provides better results using RZ modulation format in wavelength band ranging from 1552nm-1565nm. FBG lessens dispersion using loop control mechanism and performs better with NRZ modulation format. During optical transmission system, as the length of optical fiber cable and data rate increases, its corresponding Q-factor reduces.Hence, System Performance is a measure of Q-factor.

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