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A Review of Optical Communication link design using EDFA

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ABSTRACT

Optical fiber communication offers large bandwidth for data transmission at higher rates. However, the fiber channel is capable of transmitting data at the rate of terabits-per-second. For point to point communication, adding more and more fibers to the system for increasing data throughput is uneconomical. Erbium-Doped Fiber Amplifiers (EDFA) are by far the most important fiber amplifiers for long-range optical fiber communication networks. EDFA can efficiently amplify light at 1.3 to 1.7 µm wavelength region. In case of multi-wavelength signals, if the EDFA has enough pump energy available to it, it can amplify the multiplexed optical signals falling into its amplification band. These properties of EDFAs have enabled us to use Wave Length Division Multiplexing (WDM), Dense WDM (DWDM) technique, which uses denser channel spacing in order to achieve even higher bit rates for long haul communication link. EDFA also increases the operation flexibility by reducing different types of losses in optical fiber communication system. In this present paper, performance analysis of optical link using EDFA has been explored in details. Also it focusses on different technologies used for analyzing the performance of EDFA with respect to various wavelengths and data rates. This will help the researcher to get the information related to EDFA at a single platform and help them to continue their work in area of interest.

Keywords: EDFA, DWDM, WDM Non Return to Zero (NRZ), Return to Zero (RZ)

I. INTRODUCTION

Optical Fiber Communication has grown rapidly in last two decades offering large bandwidth and high speed data transmission capabilities. In long haul point-to-point optical fiber communication links, the signal suffers from various losses i.e. fiber tap losses, fiber splice losses, fiber attenuation etc. Due to these losses, the signal strength reduces drastically and it is difficult to detect the original signal at the receiver side. So in order to transmit signal over a long distances in a fiber, it is necessary to compensate all losses in the fiber. The introduction of optical amplifiers allowed the signal amplification in optical domain. With optical amplifiers, there is no need to convert the optical signal to electrical signal. So, optical amplifiers revolutionized the optical fiber communication field [1]. There are mainly two types of optical amplifiers: semiconductor optical amplifier and fiber amplifiers. Fiber amplifiers are generally classified as EDFA, Raman amplifier and Brillouin amplifier [2].

II. EDFA

Optical fiber amplifiers provide in-line amplification of optical signals by effecting stimulated emission of photons by rare earth ions implanted in the core of the optical fiber. Erbium is the preferred rare earth element for this purpose though amplifiers using Praseodymium are also in use. EDFA is an optical repeater device utilized to boost the intensity of optical signals being carried through optical fiber communication system. It is made of silica fiber doped with erbium (Er^{+3}) ions for long–haul telecommunication applications [3, 4]. Erbium uses its pink colored Er^{+3} ions, which have optical fluorescent properties suitable for optical amplification. EDFAs are used to provide amplification in the long wavelength window near 1550 nm.

The principle of rare earth doped fiber amplifier is the same as that of lasers except that such amplifiers do not require a cavity as shown in Figure 1 below. Where as an external cavity is required for laser oscillation.

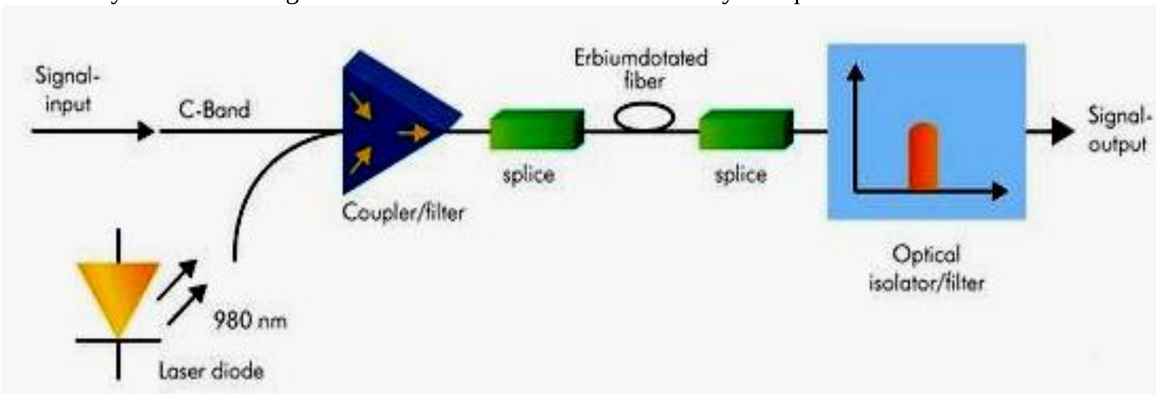

Figure 1: Block diagram of EDFA [5]

A particular attraction of EDFAs is its large gain bandwidth, which is typically tens of nanometers. This is more than enough to amplify data channels with the highest data rates without introducing any effects of gain reduction. The advent of EDFA has enabled the optical signals in an optical fiber to be amplified directly in high bit rate systems even beyond Terabits. For long distance communication, EDFAs with high pumping power and larger link length are available these days. So, more and more researchers are exploiting use of EDFAs in WDM systems in order to improve their performance.

Principle of EDFA: The rare-earth ions for doping of optical fiber are Erbium (Er), Ytterbium (Yb), Thulium (Th), Praseodymium (Pr), and Neodymium (Nd). Each one of these is used at certain wavelength band. Energy levels of Er^{+3} doped system is shown in the figure 2. An optical fiber is doped with this rare earth element Erbium, so that the glass fiber can absorb light at one frequency and emit light at another frequency. Erbium ions are optically pumped at around 980 or 1480nm. This action excites the erbium atoms.

It may be noted that the energy levels form three groups of energy levels marked with their spectroscopic notations. For simplicity, these three groups of energy levels have been denoted by **u, m** and **g** representing the upper, the metastable and the ground states respectively [6, 7]. EDFA uses a pump laser (980 or 1480nm) to bring up electrons to a higher energy level, thereby providing signal amplification by emitted photons using stimulated emission.

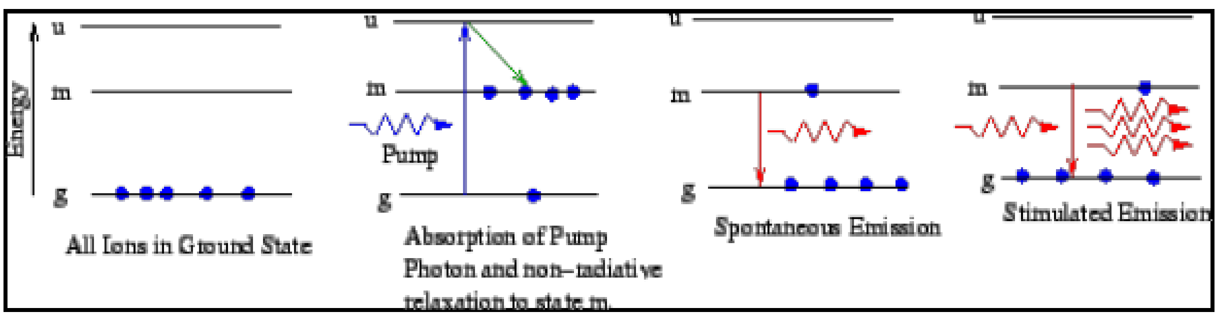

Figure 2: Energy levels and working principle of EDFA [5]

EDFA can be used to amplify signal in two bands of wavelengths in the third transmission window. The wavelength range **1525 nm to 1565 nm** is known as the **C-band** or the conventional band and the second band from **1568 nm to 1610 nm** is known as the **L-band** or the long band.

III. EDFA OPERATION IN DIFFERENT WAVELENGTH REGIONS

(1) 1527nm-1552nm: In this wavelength region, the simulation of a 32-channel DWDM system using NRZ modulation format results in an output power of 21.255dBm for a fiber length of 5m and 250mW pump power. Varying concentration of erbium ions changed the gain and the best performance is obtained for a concentration of

1000ppm-wt and pump power of 250mW at which Q-factor of 9.02413 and BER of 10^{-20}. The optimal values of gain are obtained for a value of -25dBm. These values are taken at 70km fiber length [8].

(2) 1530nm-1562nm: In this wavelength region for 64-channel WDM system, different pumping techniques are used for EDFA length (4m-10m) at input power of -26dBm and pump power of 200mW. With co-pumping, received power decreases with increase in length of EDFA and BER lies in e-20 to e-22. With counter pumping, received power increases with increase in length and BER lies in e-17 to e-21, but transmission is acceptable up to 8m EDFA length. For bidirectional pumping, power decreases but provides more power as compared to other configurations and BER between e-20 to e-21 for 100mW pump lasers. Q-factor for different pumping techniques lies between 8.5 and 9.7. Higher Q-factor is recorded for bidirectional pumping technique [9].

(3) 1546nm -1556nm: In this wavelength region, the 16-channel WDM system using NRZ modulation format is simulated with length of erbium doped fiber varying from 2 to 50m and pump power ranging 100-800mW at a constant input power which is set at -26dBm. The maximum output power of 26dBm is obtained with 800mW of pump power at 10m length of amplifier. At pump power of 800mW the gain is about 44dB which is very high but at the same time noise figure is high for this pump power. So the best value of pump power is 500mW where high gain and low noise figure are achieved. Also the suitable value of erbium ions is 500ppm-wt. BER is less at more pump power. It is minimum at 1546nm and maximum at 1552nm [10].

(4)1546nm-1568n: In this wavelength region, the system for 32-channel amplification using NRZ modulation type is designed with 27 dB intrinsically gain flatness. The optimum fiber length is 5m whereas the optimum pump power is 23mW. The output power of 8.408 dBm and an average noise figure of 6dB are obtained from simulation. This WDM system has a BER which lies from 10^{-21} to 10^{-42} and Q-factor which is in the range of 9 to 13 [11].

(5) 1552nm-1565nm: In this wavelength region, the system for 16-channel amplification using RZ modulation format is analyzed with gain flatness. The fiber length of 10km and 50 mW pump power and an average noise figure of 0.5dB are obtained. This DWDM system provides a Q-factor of 29.84 and a BER which is in the range of 10^{-175} to 10^{-196}. The optimal values of gain and noise figure are obtained for a value of -14dBm [12].

(6)1552.2nm-1582.2nm: In this wavelength region, the system for 16-channel amplification using NRZ modulation format is analyzed. Using different pump powers, it is concluded that the pump power of 0.75W gives better results. A maximum gain of 61.04dBm and noise figure of 3.91 is recorded. The minimum bit error rate is recorded to be 8.442e-7 and maximum Q-factor of 4.77422 [13].

IV. EDFA OPERATION WITH DIFFERENT DATA FORMATS

The two different modulation schemes are- NRZ and RZ as shown in figure 3. NRZ and RZ modulation formats are used to avoid intersymbol interference (ISI) on an optical carrier wave for transmission over optical fiber. Each modulation method has its own advantages and disadvantages for the particular channel conditions.

(1) NRZ. In the NRZ format, throughout the bit slot the pulse remains on and its amplitude does not return to zero between two or more successive bits. As a result, pulse width varies depending on the bit pattern. In the early days NRZ was used in fiber-optical communication due to (i) requires a relatively low electrical bandwidth for transmitters and receivers when compared with RZ (ii) provides simplest configuration of transmitter and receiver at low cost. Unfortunately, NRZ modulation type is not appropriate for high bit rate and long distance optical communication system [14, 15]. NRZ modulation may be better in case of large number of channels.

(2) RZ. In the RZ format each pulse that represents bit 1 is shorter than the bit slot, and its amplitude drops to zero before the bit duration is over and pulse width remains the same. RZ is used in far away communication signals in which the signal drops to zero between each pulse. This takes place even if a number of consecutive “0” or “1” occurs in the signal. The RZ pulse code modulation signal is self-clocking [16]. Therefore, it does not require separate clocks to be sent alongside the signal, but suffers from using twice the bandwidth to obtain the same data-rate as compared to NRZ format. The main characteristic of RZ modulated signals is a relatively broad optical spectrum, resulting in a reduced dispersion tolerance and a reduced spectral efficiency [14]. RZ pulse enables an increased fairness to fiber nonlinear effects [15].

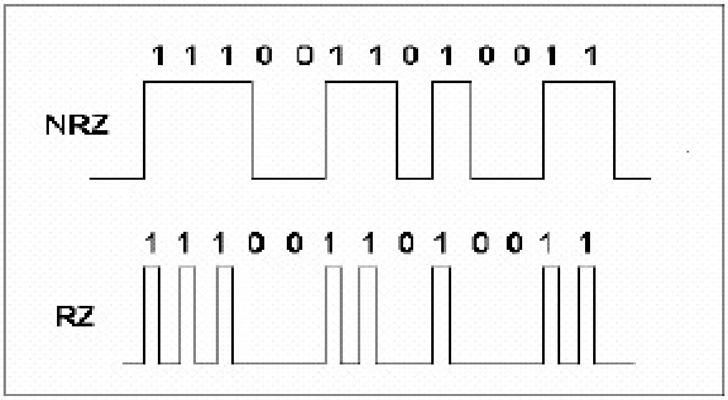

Figure 3: NRZ and RZ Modulation Format

V. APPLICATION AREAS OF EDFA

EDFA has the following areas of application:

(1) WDM and DWDM Systems. EDFA can be employed in wavelength-division multiplexing (WDM) system, especially DWDM system. WDM is a technique of sending signals of several different wavelengths of light into the Fiber simultaneously [5]. In optic fiber communications, WDM is a technology which multiplexes a number of optical carrier signals onto a single optical fiber by using different wavelengths (colors) of laser light. This technique enables bidirectional communications over one strand of fiber, as well as multiplication of capacity. A WDM system uses a multiplexer at the transmitter and a demultiplexer at the receiver to split them apart. WDM systems are divided into three different wavelength patterns –**normal** (WDM), **coarse** (CWDM) and **dense** (DWDM).

CWDM provides up to 16 channels across multiple transmission windows of silica fibers. **DWDM** is an optical multiplexing technology used to increase bandwidth over existing fiber networks. DWDM uses the same 3rd transmission window (C-band) but with denser channel spacing. Common channel plans of DWDM vary, but a typical system would use 40 channels at 100 GHz spacing or 80 channels with 50 GHz spacing at distances of several thousand kilometers with amplification and regeneration along such a route [17]. DWDM refers originally to optical signals multiplexed within the 1550-nm band to leverage the capabilities (and cost) of Erbium Doped Fiber Amplifiers (EDFAs), which are effective for wavelengths between approximately 1525 nm – 1565 nm (C band), or 1570 nm - 1610 nm (L band). Utilization of EDFA in WDM system enables us to solve problems of insertion loss and generally reduce the influences of chromatic dispersion.

(2) Optical Fiber Subscriber Access Network System. For long transmission distances, EDFA functions as a line amplifier to compensate for transmission losses of lines, thereby greatly increasing the number of subscribers. As a substitute for Optical-Electrical-Optical (OEO) repeater, EDFA can directly amplify the optical signals transmitted in lines.

(3) High Speed Optical Communication System. EDFA can be employed in high- capacity and high -speed optical communication system. This application tends to be very constructive to deal with the problems of low sensitivity of receivers and short transmission distances due to lack of OEO repeater.

(4) Community Antenna Television (CATV) System. EDFA functions as a booster amplifier in CATV system to greatly improve the input power of an optical transmitter. Compensating for the insertion loss of optical power splitters using EDFA can significantly enlarge the scale of distribution network and increase the number of subscribers.

VI. EDFA MODELLING USING NUMERICAL METHOD

The RUNGE-KUTTA method with fourth order accuracy is the numerical method used to calculate the input pump power and gain for EDFA. To analyze the optical parameter, we use the dynamics of EDFA with the numerical method based on RUNGE-KUTTA method with fourth order accuracy. The EDFA is modeled with a set of three differential equations as a three level laser system.

The fourth order RK-method is

$$\mathbf{y_{i+1} = y_i + \frac{1}{6}(k_1+2k_2+2k_3+k_4)}$$

where

$$\mathbf{k_1=hf(x_i, y_i)}$$

$$\mathbf{k_2=hf(x_i+\frac{h}{2}, y_i+\frac{k_1}{2})}$$

$$\mathbf{k_3=hf(x_i+\frac{h}{2}, y_i+\frac{k_2}{2})}$$

$$\mathbf{k_4=hf(x_i + h, y_i + k_3)}$$

These differential equations from EDFA can be modeled with a numerical model, which describe the EDFA dynamics and require to determine the gain and loss spectra [18].

CONCLUSION

This paper presents different methods for analyzing the performance of optical link using EDFA. In the wavelength region of 1552nm-1565nm, the best results are obtained using RZ modulation format. RZ data has higher spectral content compared to NRZ. The performance comparison of both modulation schemes show that RZ modulation type is the best for the long distance optical communication system due to its low value of jitter and BER at high bit rate with high input power. It provides a maximum Q-factor of 29.84 and an average noise figure of 0.5db.The system provides a good performance of BER which is in the range of 10^{-175} to 10^{-196}. Also the RUNGA-KUTTA numerical method provides the best solution for the differential equations form EDFA due to low errors.

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