Performance Analysis of EDFA Gain using FBG for WDM Transmission

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***Abstract*— The paper demonstrates a gain-flattening performance characteristics of Erbium-Doped Fiber Amplifier (EDFA) for C-band application ranges from 1525 nm to 1565 nm. This technique was modeled with eight channel transmissions associated with Wavelength Division Multiplexing that comprises of gain uniformity. Signal amplification process at the input was accomplished of Erbium doped fiber with Non-Uniform Fiber Bragg Grating (FBG) and Amplified Spontaneous Emission (ASE). These results showed that the stimulated emission was associated with the least flat amplification and inversely proportional relationship between output signal power and the space separating the gratings in Fiber Bragg Grating. The performance analysis also resembled the dependency of gain on the Doping Concentration, Input Powers, Length of Fibers, Doping Profile of the Erbium Doped Fiber and Windows Wavelength of input signal, which in turn increases the input and output signal power. However, after a reduction in the resultant gain, low noise power of about -60 dBm existed. Lastly, a comparison of different methods for gain flattening was conducted and the results showed high gain modeled with EDFA using FBG. The simulator Optisystem 14.0 was also used to investigate the characteristics of the C-band EDFA using FBG.**

***Index Terms*— EDFA, FBG, Gain Flattening, WDM, ASE, Optisystem 14.0.**

I. INTRODUCTION

Design topology of Wavelength division multiplexing plays a significant role in optical systems for transmission that concerns with the application of high speed and high capacity. Optical Amplifier has the ability to reduce the effects of attenuation and dispersion, which improves the performance of long-haul optical systems. Optical communication network is basically associated with signals covering long distance along fibers without significant loss.

The transition of signals at long distance is compulsory to be amplified. Optical fiber amplifiers that use effective Stimulated Emission of photons associated with earth ions embedded to optical fiber core provides an in-line amplified input optical signals. In optical fiber network, these amplifiers are used for regenerating, amplifying and then retransmitting the optical signal. For long distance optical transmission, many amplifiers are required to prevent the attenuation of output signal. The increased space between the amplifiers reduces the number of amplifiers to be used, leading to cost reduction. The gained spectrum of EDFA is not essentially flat. Although there is no problem with the gain variation for single channel systems, problems in transmission may arise in optical fiber network when there is an increase in the number of channels [1, 2].

The gain flatness is important for EDFA's Wavelength Division Multiplexing (WDM), and it is a major technique for long distance optical transmission link system. A significant problem with EDFA is that the Stimulated Emission generates Amplified Spontaneous Emission (ASE) during the amplification of input signals. The ASE is considered as the background noise and when passed through another amplifier, it amplifies the noise signal with input signal [3, 4]. The output signal power is inversely proportional to EDFA's spacing, and it increases with a decrease in spacing. Optimization technique of output signal power is possible by increasing the gain. By maximizing the gain, the output signal power can be optimized [5]. The gain is dependent on the doping level concentrations, input powers, length of fibers, erbium doped fiber's doping profile, windows wavelength of input signal, pump power [6, 7]. It is challenging to increase in the number of channels that can be transmitted with reduced channel spacing. Thus, a continuous effort using different methods, such as co-doping concentration and multiple pumping schemes by various researchers in the respective field has shown good results[8-12].

In this paper, a new design topology is proposed. This design applied the Fiber Bragg Grating in order to input the signal gain flattening of Wavelength Division Multiplexing that allows a reduction in ASE. A simulation software, Optisystem14.0 was used for the characterization of Erbium-Doped Fiber Amplifier in C-band.

II. ERBIUM DOPED FIBER AMPLIFIER

Silicon Fibers acts as a gain medium when they are doped with Ions such as Erbium (Er^{3+}). These ions are associated with fluorescence property and exhibits amplification in optical communications. It is constituted primarily of two wavelength windows: C-Band and L-Band. EDFA amplifies wavelength ranges from 1500 nm-1600 nm, simultaneously it also provides amplification in WDM. EDFA basically states that "when an optical signal such as 1550 nm wavelength signal enters the EDFA from input, the signal is combined with a 980 nm or 1480 nm pump laser through a Wavelength Division Multiplexer device. The input signal and pump laser signal pass through fiber doped with Erbium ions. And the 1550 nm signal is amplified through the interaction with doped Erbium is also in use". EDFA can also be used in amplification of large distance associated optical communications with lesser loss of 0.2dB/km and thus, amplification in wavelength near 1550 nm is achieved. Rare earth Doped Fiber Amplifier is similar in principle as that for lasers, as there is no need of cavity in such amplifiers because according to usual standards, a cavity is associated with laser oscillation.

Advantages of EDFA:

- In-line amplification possibility of signal without the use of electronics, which is entirely an optical amplification i.e., the signal is converted to electrical signal only after amplification;
- The amplification does not depend on data rate;
- The pump to signal power that transfer efficiency is high;
- A relatively flat gain helps in cascading for long distance use; and
- Large devices, gain saturation and the presence of amplified spontaneous emission (ASE).

Principle of EDFA:

Figure 1 shows the Energy levels of Erbium Doped System. As shown in Figure1, there are three groups of energy levels, marked with their spectroscopic. The modified groups of energy levels are modeled by three sharp levels of energy, represented as the upper, meta-stable and ground state.

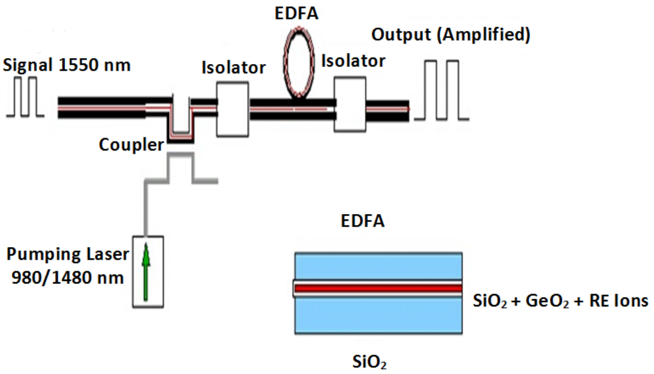

Figure 1: Configuration of EDFA system.

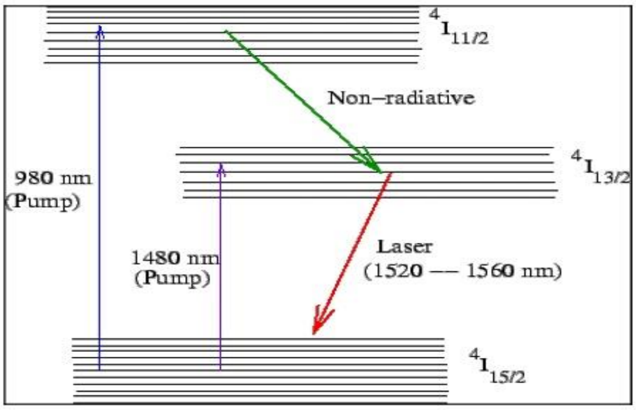

Figure 2: Laser phenomenon

A light beam with associated frequency incident on the system as the ions moved through excitation to a higher level. The resulted radiation is known as pump radiation at 980 nm; a continuation of excitation of ions to the required level continued. The ions in the level are associated with approximate lifetime and they are readily decay to meta-stable state without any radiative transition. The ions are excited directly to meta stable state with the application of laser Pump at 1480 nm. In this condition, rapid relaxation occurs at its lowest sub-level to perform a laser action within levels. 1480 nm pumping are preferred over 980 nm pumping.

Moreover, the separation of wavelength concerning to pumping and laser are widened. 980 nanometer pumping is the least messy with reference to vibrations. The transitions of excited ions transited to the ground state are done either by spontaneous emission, stimulated emission or amplified window, as described below.

A. Spontaneous Emission:

Spontaneous photon emission has no phase relationship with the subsequent levels. It covers the overall bandwidth of transition and has a possibility of backward travelling. As a result, noises are generated in the channel. Minuscule part photons that are spontaneously emitted in a way of direction within the numerical aperture associated with fiber that are captured and streamlined. Rare earth ions may interact with these photons and can be amplified. A prime source of noise in the system is the Amplified Spontaneous Emission (ASE). For signal associated with low power, Amplified Spontaneous Emission is nearly not dependent on signal except signals associated with high power. Population inversion are reduced to much lower extent with the application of amplified stimulated emission when compared to pumping rate.

B. Stimulated Emission:

Stimulated emission is feasible for wavelength range of 1520 nm – 1560 nm, if a data signal is provided as input into the fiber with the corresponding wavelength. As the newly generated photons through stimulated emission travels along the fiber, signal amplifies. Thus, it is clear that the population inversion is not possible in two-level system. Population inversion is also noticed when 1480 nm pumping is directed at meta-stable levels, in cases when Erbium levels are tightly spaced.

C. Amplification Window:

EDFA amplified signals are distributed in two sets of bands associated with wavelength of third transmission window. The C-band is notified when the conventional band has a wavelength ranges of 1525 - 1565 nanometers. The L-band is notified when the second band or long band has a wavelength ranges of 1568 - 1610 nanometers. Specified term “long band” is denoted for doped section applicable in longer range.

III. FIBER BRAGG GRATING

In the year 1978, Ken Hill firstly established the Fiber Bragg grating. A visible laser was used along the fiber core to manufacture the gratings. Figure 1 shows the principle of FBG. In optical fiber, with the help of Fiber Bragg grating some particular wavelength of light were reflected while all other were transmitted. This can be achieved by making a change in refractive index of core, since the formation of dielectric mirror is associated with significant wavelength. FBGs were initially conceived when excessive ions of argon are doped with Germanium that gives a laser radiation.

According to Fiber Bragg wavelength, the selectivity associated with grating shows the propagation of light in fiber and is given by:

$$\lambda_B = 2n_e \Lambda \quad (1)$$

where, n and Λ symbolizes the respective core refractive index and grating period. The principle of operation of Fiber Bragg Grating is shown in Figure 1. Fiber grating is a significant parameter that allows the dispersion compensation.

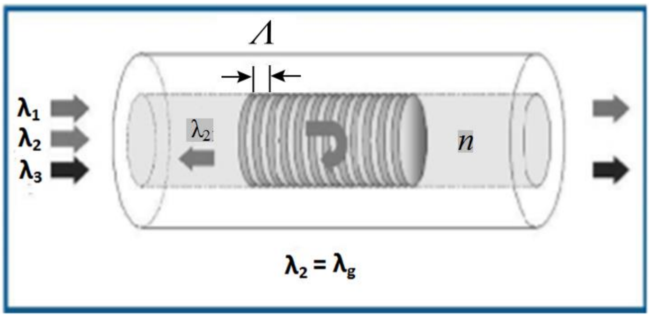

Figure 3: Fiber grating.

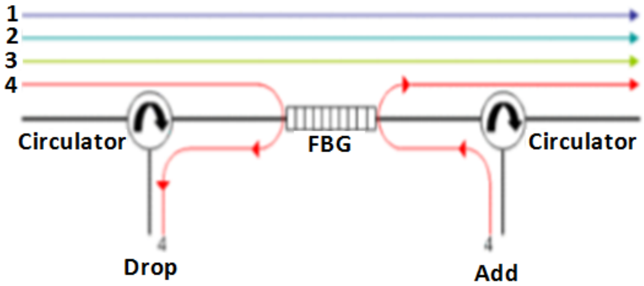

Figure 4: Optical add/drop multiplexer.

IV. SIMULATION MODEL

The transmitter section consists of a Wavelength Division Multiplexer (WDM) transmitter, used as a data source, provides input power, frequency spacing and bit rate and has a modulator type Non-Return to Zero (NRZ). Multiple optical signals transmitted by transmitter were multiplexed with WDM. The multiplexed signal was subsequently passed through the optical amplifier (EDFA), and then the Fiber Bragg Grating. Fiber Bragg Grating output was then sent to the detector. Output spectrum analyzer was connected to the output of the FBG, which will measure the gain and its characteristics. In the detector section, Application of de-multiplexer at the transmitter side was used for different optical signals with its respective wavelengths. At receiver section, the optical signal photo-detector was used for detection. Then, the Low pass filter and Bit Error Rate (BER) analyzer were used for measuring Q-factor.

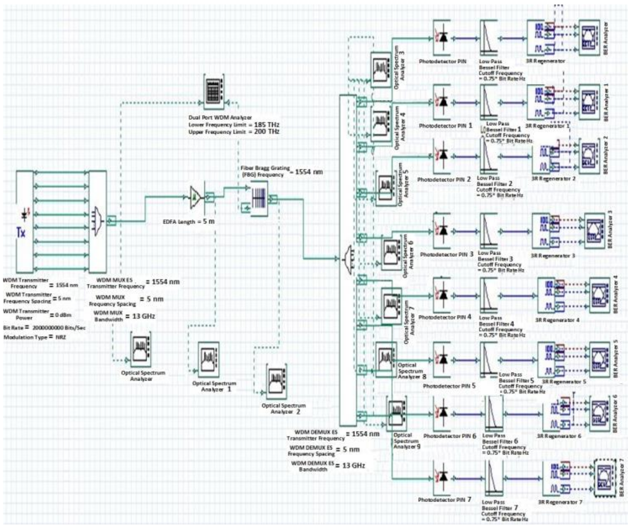

Figure 5: Simulation model

Table 1
Gain Flattening Parameter of EDFA Associated with Fiber

S.No.	Parameters	Values
1	Bit Rate	10 Gbps
2	Times window	1.28e-0.08 s
3	Sampling rates	64GHz
4	Sequencial length	128 bits
5	Samples per bit	64
6	Number of samples	8192

Table 2
Transmission Link Associated Component Values for Gain Flattening of Edge using GFF

S.No.	Component	Values
1	Wavelength Division Multiplexer Transmitter Frequency	1554 nm
2	Wavelength Division Multiplexer Transmitter Frequency Spacing	5nm
3	Wavelength Division Multiplexer Transmitter Power	0dBm
4	Wavelength Division Multiplexer Bandwidth	13 GHz
5	Erbium-Doped Fiber Amplifier Length	5m
6	WDM demux Bandwidth	13GHz
7	WDM demux frequency spacing	5nm

V. SIMULATION RESULT

The gain flattening characteristics of the EDFA using FBG is shown in Figure.6. The ASE spectrum shows that the noise power is too low i.e. -60dBm. The gain obtained is about 13 dBm in the C-band. Figure 3 also shows that the gain is flattened for a particular frequency band. Figure 7 represents the Eye Diagram associated with output signal that clears low bit error rate.

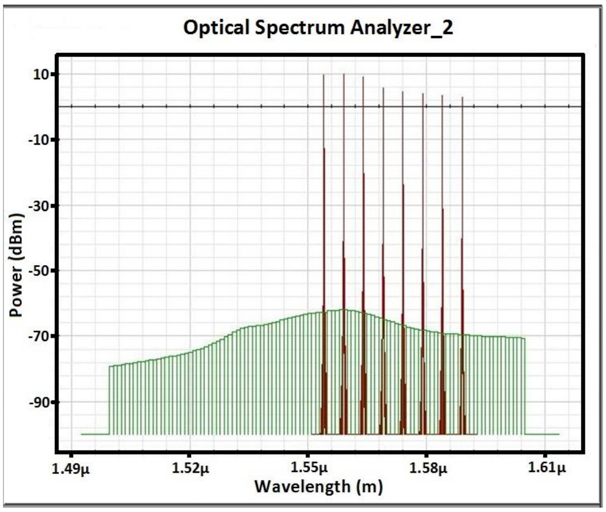

Figure 6: Gain characteristics of EDFA using FBG.

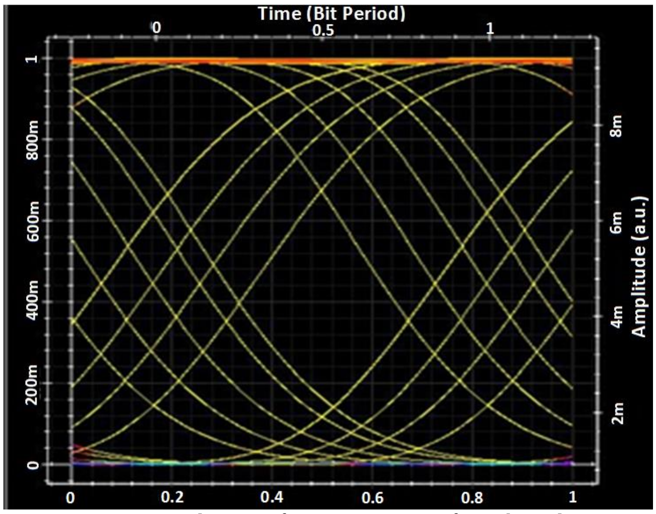

Figure 7: Eye diagram of EDFA using FBG for 8 channels.

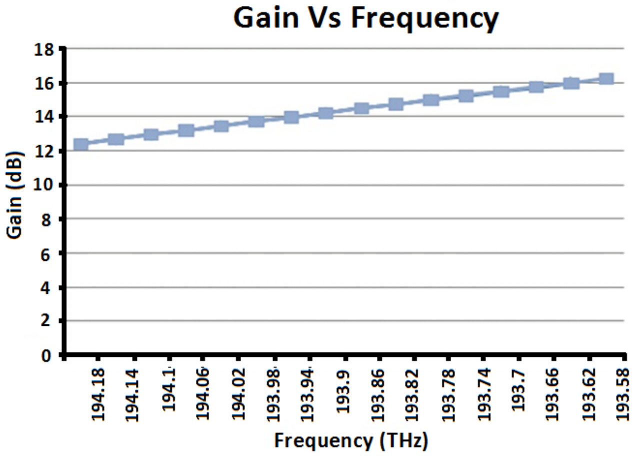

Figure 8: Gain Response.

Finally, the design modeled in this paper was compared with its level of gain flatness to the previous design that was modeled to have better performance, see Table 3.

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Table 3
Comparison of the Techniques used for Gain Flattening

S. No.	Ref. No.	Gain Flattening Technique	Gain Variation (Maximum value – Minimum value)
1	12	Hybrid EDFA-RFA	(35.7555 dB – 33.2946 dB) = 2.4609 dB
2	*12*	Optimized Gain Flattening Filter	(18.9039dB – 18.9024dB) = 0.0015 dB
3	*This Work*	EDFA-FBG	(16.21dB – 12.41dB) = 3.8 dB

The comparative table shows the different methods adopted to achieve gain flattening technique. It was found that EDFA with FBG has the higher gain when compared to others. The EDFA with FBG studied in this paper has an increasing gain from 12.41dB to 16.21dB and a decrease in frequency ranged from 194.18 THz to 193.58 THz, see Figure 8. The gain is represented as a function of frequency. The increase in gain has a fruitful significance of application in C-band at wavelength division multiplexing with good performance showing reduced noise in the Amplified Spontaneous Emission spectrum for transmission over long distance optical communication systems

VI. Conclusion

The erbium doped fiber amplifier has very high gain and can be made suitable for optical communications systems for long-haul communications by employing appropriate gain flattening technique. By applying FBG gain flattening technique, the amplifier has a gain of 13dBm, while the ASE spectrum shows that the noise is obtained about -60 dBm by giving the input power of 0dBm. The amplified gain is flattened in the C-band. The proposed model uses 8-channels for transmission with good performance.

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