ISSN: 2278 – 7798
International Journal of Science, Engineering and Technology Research (IJSETR)
Volume 5, Issue 12, December 2016

GAIN FLATTENING OF ERBIUM DOPED FIBER AMPLIFIER - A REVIEW

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***Abstract* - There is an increasing demand of transmission bandwidth for long haul wavelength division multiplexed optical fiber communication systems. Bandwidth can be well utilized by using wideband and gain flattened amplifiers. Wideband amplification can be done by combining several amplifiers having different gain bandwidths. Different gain flattening techniques are available for gain flattening purposes to reduce gain variation such as gain flattening filters as fiber bragg gratings, optimization of material composition of fiber amplifiers, using rare earth doped ions, hybrid amplifiers, wavelength splitters. Different gain flattening techniques have been discussed in this paper so as to utilize the bandwidth of optical communication system to the maximum.**

***Index terms* – Erbium doped fiber amplifier (EDFA), gain flatness, hybrid amplifier, optical fiber communication systems, Raman amplifier, wavelength division multiplexed system (WDM)**

I. INTRODUCTION

Optical communication system is seen one of the fast growing communication technologies to achieve consumer needs. The basic principle of optical communication system is that light can carry information over long distances. Optical fiber communication systems provides us with the large bandwidth but still bandwidth cannot be fully utilized because of requirement of too many sources for sending many signals and problem of multiplexing. The development of wavelength division multiplexed systems (WDM) has overcome this problem upto a certain extent by utilizing the bandwidth of optical communication systems. WDM is a potential technology in which multiple optical carriers with different wavelengths are modulated by electrical bit streams and are then transmitted over the fiber. In optical fiber communication systems, amplifiers are vital for regenerating, amplifying and retransmitting the optical signals. Amplifiers are needed to prevent the seriously attenuated optical signals. Erbium doped fiber amplifiers (EDFA) are generally used as compared to other amplifiers because of merits of high gain, better performance, polarization insensitivity, low pump powers, low noise figure.The main disadvantage of using EDFA in implementing WDM is that gain spectrum depends on wavelength so it doesn't essentially amplify wavelengths of all the channels equally. Gain spectrum of EDFA is non uniform and dynamic i.e. each channel input experiences a different gain. When EDFAs are cascaded, due to dependency of gain on wavelength, imbalance of power occurs in transmitted channels and signal to noise ratio increases as signals propagate along the fiber. Gain spectrum of EDFA isn't flat which means deviation of power for amplified signals. Therefore, gain is needed to be flat in EDFA so various gain flattening techniques are available for this purpose.

There is an increasing demand of transmission bandwidth in optical communication systems due to growth of network traffic. Due to this ,the operating band of EDFA has to be extended from C- band (1520-1570 nm) to S-band (1450-1500 nm) and L–and (1570-1620 nm) [1].Because of practical issues, L-band EDFA has gained more interest in terms of gain flatness and enhancement. So as to utilize the transmission bandwidth, EDFA can be cascaded with other amplifiers such as Raman amplifier, thulium doped fiber amplifier, ytterbium doped fiber amplifier, neodymium doped fiber amplifier etc. having different gain bandwidths so as to obtain a wideband amplification.

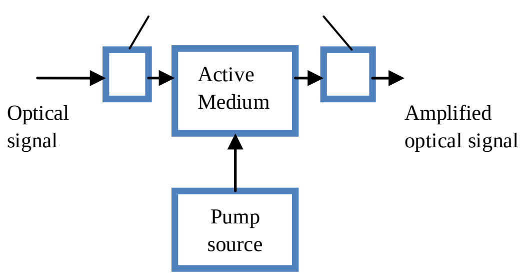

Fig.1: Block diagram of EDFA

II. Techniques of Gain Flattening

The gain of optical fiber amplifiers is wavelength dependent due to which imbalance of power occurs in the transmitted channels. Therefore, various gain flattening techniques are applied to overcome this problem:

- For rare doped earth fibers, the gain spectrum can be flattened by adjusting the inversion level of doped ions. This can be achieved by changing the pump power and length of the active fiber.
- Another technique is to optimize the material composition of the optical fiber core e.g. fluoride co-doped EDFA has a flat gain spectrum as compared to silicon based EDFA, bismuth co-doped EDFA has a wider emission bandwidth than silica based EDFA fibers [2].
- Another method is to use several amplifiers combined together to form a wideband hybrid amplifier.
- Gain flattening filters can be used for flattening the gain spectrum of amplifiers but this method cause higher losses in wavelength regions where gain is higher e.g. fiber bragg gratings.
- Another approach is to use a wavelength dependent splitter i.e. it distributes the signal over different optical amplifiers and wavelength dependent coupler recombines the spectral components.

III. Literature Review

Wideband and gain flattened optical amplifiers are crucial for long haul optical communication systems. Gain flattening of EDFA can be done by various techniques. In first approach, two stages of EDFA are used. A short fiber length C-band EDFA produces ASE which, in turn, with pump power enters the second stage to increase the output gain in long length L-band EDFA. Two fiber bragg gratings (FBG) are placed in the second section at both ends of long fiber to form Fabry perot cavity. The gain in L-band is flattened by the compressed gain under the matched wavelength of FBG [1].

In another approach, hybrid amplifiers are used .The advantage of hybrid amplifiers is that one amplifier can work independently of others and required number of amplifiers can be added according to the demand. A double pass assembly of EDFA with hybrid gain medium- silicon and zirconia is used in parallel configuration. A chirp fiber bragg grating is used in both stages to attain the required gain in C-band and L- band regions [2]. It causes the double propagation of the signal resulting in overall increased gain but noise figure also increases which is the major problem.

Another hybrid amplifier is EDFA–Raman amplifier. Raman amplifier can be distributed and discrete. The discrete Raman amplifier can be used in spite of type of transmission fiber [3] and its main purpose is to expand the usable bandwidth of the fiber. Then again, the distributed Raman amplifier (DRA) improves the reach of fiber span . The overall effect of DRA is that it decreases the noise as well as the non linearities. EDFA + DRA can be used to increase the overall gain as well as decrease the noise figure. EDFA has a larger gain variation with respect to the wavelength. Raman amplifier has a smaller gain variation in comparison to EDFA. This property can be used to form a hybrid optical amplifier (HOA). By increasing the number of pumps, the gain of HOA can be increased [4]. But there is a limit to the increase in number of pumps otherwise gain will decrease. By adjusting the pump wavelengths, pump power and length of fiber, amplification and gain flattening can be done in different wavelength regions [5].

Erbium and Ytterbium co-doped phosphate (Er/ Yb –EDFA) and Raman phosphate fiber amplifier can be used as hybrid amplifier and has the advantage of higher transmission capacity than silicon based fiber amplifiers. Phosphate glass has larger phonon energy, greater solubility to rare earth ions, large emission cross section and higher energy transfer efficiency [6]. This hybrid amplifier can be used for higher transmission capacity on dense wavelength division multiplexed systems.

In another technique, Erbium doped waveguide amplifier (EDWA) and Erbium doped fiber amplifier is connected in series to achieve the gain flatness in the C- band [7]. EDWA is less efficient than EDFA due to higher erbium concentration. Higher erbium concentration requires more pumping power .There is loss of waveguide in the fiber. EDWA provides high gain in short optical path. High gain and gain flatness is obtained by this method but wideband amplification cannot be obtained.

Table 1: Findings of papers reviewed

S.NO.	TECHNIQUES	PARAMETERS	FINDINGS
1.	EDFAs (C+L Band) in series with Fiber bragg grating at both ends of L- EDFA	• Operating wavelength of tunable laser source (TLS) = 1570-1610 nm • Dynamic range of input power (TLS) = -40dBm to 0dBm • Length of C- EDFA= 11m	• Gain flatness = ± 0.44dB at central wavelength of 1553.4 nm in the 40nm range

		• Length of L – EDFA= 40m • Pumps = 974 nm with 30 mw output power for C-EDFA • Pumps = 1478 nm with 70 mw output power for L-EDFA • Central wavelength of FBGs= 1530 – 1560 nm • Reflectivities of FBGs= 99%	• Gain = 20.2 dB • Fluctuation of gain = ± 0.1 dB for each channel.
2.	EDFA(C+ L band) with hybrid gain medium(Zr and Si) and chirp fiber bragg grating	• Operating wavelength of tunable laser source(TLS) =1530-1605nm • Input signal power of TLS = -30 dBm to 0 dBm • Length of Zr-EDFA = 2m forward pumped by 980 nm • Length of Si- EDFA= 9m forward pumped by 1480 nm • Pump power =160 mw-280mw • Insertion loss of WDM coupler = 0.9 and 1.8 dB in C-and L- band respectively.	• Flat gain = 15 dB at input signal power of 0dBm at pump power of 220 mw • Gain variation < 0.5dB • Noise figure = 6.2 to 10.8 dB .
3.	Hybrid amplifiers (fluoride based EDFA + Discrete Raman amplifier)	• Operating wavelength= 1530 - 1605nm • Input signal power = -20dBm • Length of fluoride based EDFA= 3.3m forward pumped by 1465 nm laser diode(LD) • Two Raman fibers =8.0 km and 8.3 km respectively • Four LD pumps for Raman fibers=1471.5nm,1495.1nm,1502.5nm, 1503.0nm	• Bandwidths = 3.0dB bandwidth of 80 nm, 1.3dB bandwidth of 76 nm,1.0 dB bandwidth of 69 nm • Relative gain flatness = 11.3,4.7, 3.7% respectively

			• Peak gains > 26 dB • Noise figure < 6.0 dB
4.	Hybrid amplifiers (Si – EDFA + distributed Raman amplifier)	• Operating wavelength = 1570-1604 nm • No. of channels =160 • Channel spacing = 25 GHz • Input power per channel = 3mw • Input laser powers = 3,5 15 mw • Fixed gain of EDFA= 25 dB • Noise figure of EDFA= 4 dB • Two Raman pumps with pump frequency = 207THz, 201 THZ respectively • Pump power = 650 ,250 mw respectively	• Input signal power = 3mw • Flat gain > 10 dB • Gain variation < 4.5dB
5.	Hybrid amplifier(Er/Yb co-doped phosphate EDFA + phosphate doped Raman amplifier)	• Operating wavelength = 1515-1610 nm • Input signal power = - 40 dBm to -10dBm • Two 980nm pumps with pump power of 27dBm • Length of Er-Yb co-doped EDFA = 1m • Length of Raman amplifier = 25 km	• Gain = 40.33 dB at 1530 nm and input signal power = -30dBm

IV. Conclusion

Different techniques have been studied for gain flattening of EDFA. Every technique has its own merits and demerits. EDFA in C-band (1520-1570 nm) has a higher gain than EDFA in L-band (1570-1620 nm). Raman amplifier has a lower noise figure, wide gain bandwidth and flexibility on choice of gain medium. A C+ L band EDFA and Raman amplifier (hybrid amplifier) can be used to increase the overall gain and reduce the noise figure simultaneously. Hybrid amplifier is the best technique as it reduces the non linearities, increases the overall gain, reduces the noise figure, cost effective and doesn't have any flexibility issues. By using hybrid amplifiers, wideband amplification can be done in specific wavelength regions.

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