

Study Of Single and Multi Wavelength(WDM) EDFA Gain Control Methods

Prateeksha Sharma^{1#}, Bipan Kaushal^{2#}, Shrija Jain³

[#]E&EC Department, PEC University
Sec-12, Chandigarh -160012

⁴ECE Department, PCET Lalru Mandi , Punjab

Abstract— The purpose of this paper is to provide an introduction to EDFA and discussing various gain flattening techniques. EDFA is widely used amplifier due to its transient suppression, wide band variable gain operation. An amplifier should be dynamically configured over a wide range to support different span lengths. We focus on building dynamic reconfigurable optical layers to facilitate explosive growth in IP traffic. Wavelength selective switch devices provides dynamic configurability as we can add or drop the wavelengths at the nodes thus increasing network flexibility, improving bandwidth utilization and reducing complexity. Electronic feed-back control is designed for achieving flat gain at the top of required gain range. The paper begins with the basics of technology and then goes on to discuss gain fluctuation and various techniques for gain flattening for single and multi-wavelength system.

Keyword-- EDFA, Pumping, Isolator, WDM, ASE, Optical Fiber Communications

I. Introduction

Huge signal bandwidth of optical fiber is not fully deployed due to use of electronic devices. A way to overcome this limitation is all optical transmission. Various amplifiers like RFA(Raman Fiber Amplifiers),SLA(Semiconductor Laser Amplifiers),Doped Amplifiers are used in all optical communication. The RFA is based on the nonlinear effect of stimulated Raman Scattering and Gain of the SLA [1] is polarisation dependent so it suffers from large inter-modulation distortion and cross-talk. The Performance of an Optical Communication system can be improved by the use of EDFAs as an Optical Amplifier. The erbium-doped fiber amplifier (EDFA) is the most deployed fiber amplifier as its amplification window coincides with the third transmission window of silica-based optical fiber. EDFAs are reliable for transmitting data through long distance because of their wide bandwidth and optimum bit error rate. But major problem with EDFA is gain fluctuation as its gain is wavelength dependent. In the past several control strategies have been proposed to fix the EDFA gain at a given operating point. The ability [2] to pump the devices at different wavelengths and low coupling losses are the main features of an EDFA. These

features are also used in gain flattening. Different pumping schemes are used as forward, backward and bi-directional. Gain flattening filters(GFF), Fiber bragg gratings are used for more optimization. The main advantages of EDFA are high gain and low noise figure. The performance of EDFA is highly affected by temperature and Concentration of Erbium ions. If we operate EDFA at 77 degree Kelvin we can optimize the best solution but this is not practically feasible. Further, we can change the doping concentration. Multi-stage EDFA are also used for gain optimization. Hybrid amplifiers are best alternative for broadening and flattening of the gain. But these solution are not feasible in case of multi-wavelength system. Erbium doped fiber amplifier (EDFA) is an important element in WDM networks but the gain of signals fluctuates due to channel add/drop networks. In future transparent automatically switched optical networks switches can initiate adds and drops with rise and fall times in the order of milliseconds and power changes of more than 10 dB. Moreover, due to faults such as fiber cuts or subband component failures a sudden loss of many WDM channels may occur. In both cases the remaining traffic should be maintained without exceeding the given BER margins. All-optical gain control scheme has been proposed. Furthermore, electronic pump-power control suggested [2] is widely used, which is based on a feed forward/-back signal taken from a photodiode before or after the amplifier. Also a combination of optical and electrical control schemes is possible [3].

II. EDFA GAIN-CLAMPED AMPLIFIER FOR SINGLE WAVELENGTH SYSTEM

Erbium-Doped Fibre Amplifiers (Edfa's) Are Realized To Apply In A Wide Range Of Applications Like Metro-DWDM Networks. These Applications Require The Edfa To Provide Maximum Output Power Level And Low Noise Figure. To Get Such An Ideal Amplifier Selection Of Several Parameters Such As Erbium Concentration[4] In The Composite Core Glass, Length Of Fibre, Pump Power And Input Signal Is Very Important Different Pump Configurations, Like Co-, Counter And Bidirectional In Varying Concentrations Of

Erbium Doped Fibres (EDF) Have Been Studied After Optimizing The Fibre-Length. It Was Observed That Output Power Is High Both In Counter And Bidirectional Pumping Scheme Than That Of Co-Directional Pumping. But The Output Snr Is High, I.E., Noise Figure (NF) [5]. Is Low In Co-Directional Pumping Compared To Other Two directions. Various pumping schemes are shown in Fig 1.

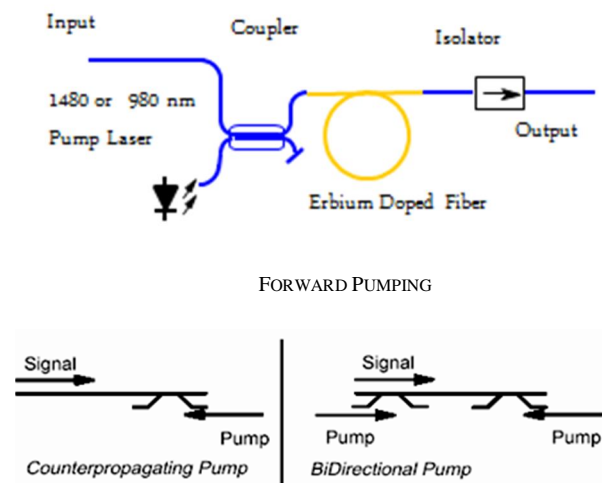


FIG.1 VARIOUS PUMPING SCHEMES

The effects of fibre length and the pumping configuration were studied for 980 nm pumped EDFA . For a given pump power, to obtain the maximum gain / output saturation power for a given erbium concentration in the fibre core, the fibre length should be optimized. Optimum fibre length increases with pump power and decreases with the signal power. Result

I/P Signal wavelength= 1550 nm, I/P Signal power= +0 dbm, Pump Wavelength= 980nm , Pump Power= 60 mw		
Pumping Direction	O/P signal Power	Noise Figure
Co dirctional	13.3	4.8
Counter directional	14.4	8.5
Bi- directional	14.0	5.4

TABLE 1 SHOWS DIFFERENT PUMPING MECHSNISMS

studied of such experiment are shown in Table 1

For improving the output power and SNR we can use different GEF(gain equalization filter). They are Used to reduce variation in amplifier gain.it is Designed to have

approximately the opposite spectral response to that of an EDFA as shown in fig2.

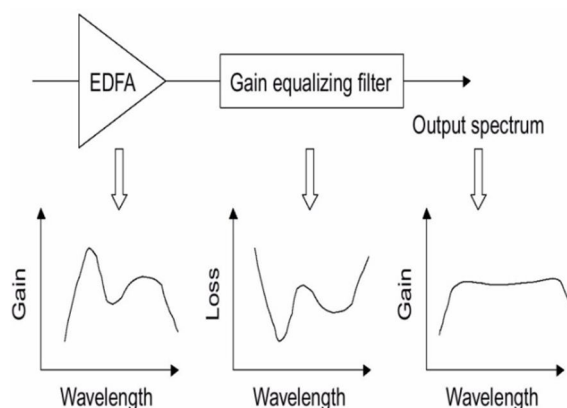


Fig2. Methodology of GEF

The gain equalisation is realised by inserting tapered long period gratings within the erbium doped fibre core. We can also use Fiber bragg grating (as shown in fig 3). Fig. 3(a) shows the structure reported in [5], in which a portion of the backward ASE is reflected. Fig. 3(b) corresponds to the case, in which a portion of the forward ASE is reflected. The structures using backward pumping are shown in Figs. 3(c) and (d). Fig. 3(c) corresponds to the case, in which a portion of the backward ASE is reflected. Fig. 3(d) corresponds to the case, in which a portion of forward ASE is reflected.

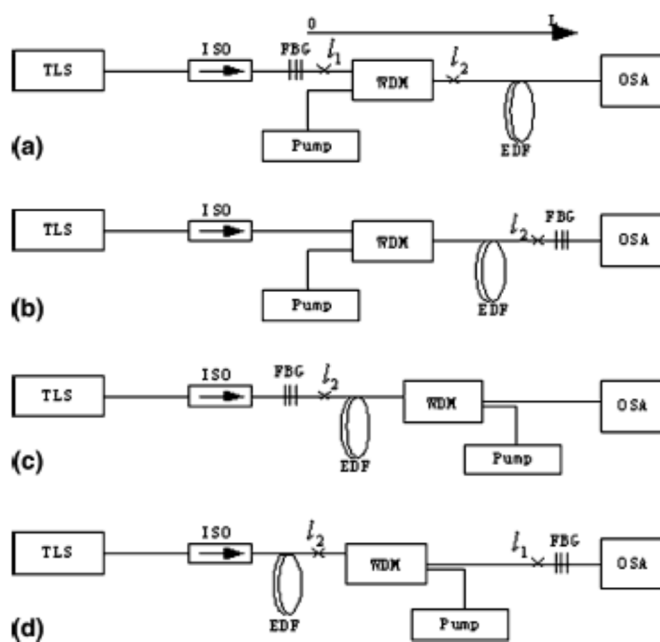


Fig3. Various possible configurations for a gain-clamped EDFA with a single fiber Bragg grating

Some new EDFA designs concatenate two or even the three amplifier stages. An amplifier stage is to considered to consist

of any unbroken section of erbium doped fiber. By using such systems we can increase the output power while retaining low noise figure. Here, pump power will split in a ratio different from 50-50 as shown in Fig4

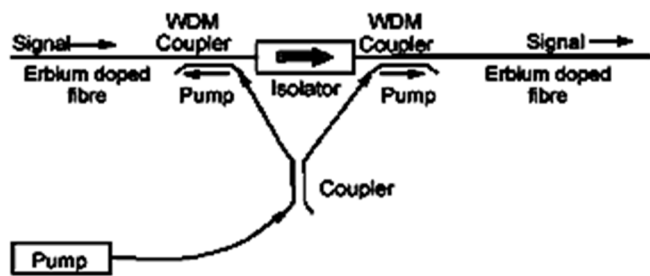


Fig 4. Two-stage EDFA line amplifier with shared pump

Introducing other dopant material such as (Al or Yb) [6] can also help in improving the system parameters. By varying the combinations of amplifier length, pump power or signal power we can get optimized results. Manipulation the shape of fiber is another important factor.

III. EDFA GAIN-CLAMPED AMPLIFIER FOR MULTI-WAVELENGTH SYSTEM

EDFA is very important parameter of wdm system. In wavelength-division-multiplexed (WDM) transparent optical transmission systems amplifiers can experience changes in channel count either due to channel reconfiguration or component failures. Transparent automatically switched optical networks switches can initiate adds and drops. There are various switching techniques like using MEMs[6], WSS using LCOS etc. One of switching schemes experimental set as shown in Fig 5

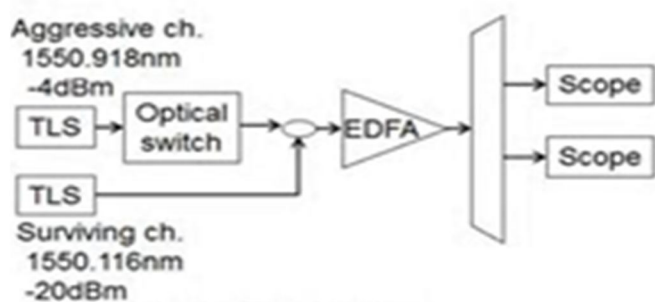


Fig5. Experimental setup

We input two wavelength to the AGC EDFA at 1550.116nm and 1550.918 nm. Here, 1550.16nm is a continuous input so we call it surviving channel and 1550.918 is added or dropped

using fast optical switches and it is called aggressive channel. Input power dynamic range is set to 16 dB that corresponds to sudden add/drop of 39 channels in a 40 channel system. We investigate that faster optical switches provides larger transients. We can further improve the system performance by using cascaded system in combination with variable optical attenuator (VOA)[7] at the output. For some applications, it is necessary to introduce some feedback control laws in order to avoid the generation of transients that could create impairments in the system. We have all optical as well as electrical control loop method. We found electrical feed back control method is more economical than all-optical approach. Electronic pump-power control suggested in [2] is widely used, which is based on a feed forward/-back signal taken from a photodiode before or after the amplifier. Also a combination of optical and electrical control schemes is possible as shown in Fig 6.

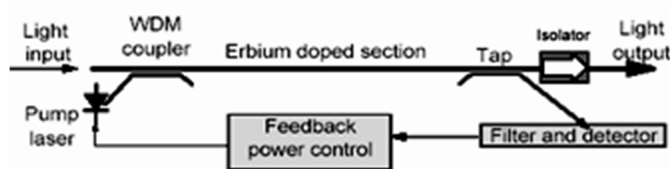


Fig 6. Feedback power control method

There are various feedback controller as PI, PD[8] or PID controllers which we can use according to system requirement. PI controller is better than PD controller as former type is less sensitive to power fluctuations induced by noise or even low-frequency components of the modulation spectrum. The principle of most of these control methods can be explained using Fig 7. Basically the EDFA gain increases as the pump power increases. When the EDFA gain is below 0 dB the gain increases as the signal power increases, whereas the gain decreases as the signal power increases[8] when the gain is above 0 dB. The value of the threshold pump power, P_{th} , does not change when the signal power changes. To keep the gain at G_c [9] when the signal power changes the control can be implemented through the variation of the pump power in way to oppose the gain variation. In this case if the signal power increases, then the gain tends to decrease, but if the pump power is increased by a certain amount of power it will compensate the higher signal power. Other way to compensate changes in the gain is introducing a signal probe [10] that would compensate the signal power variation.

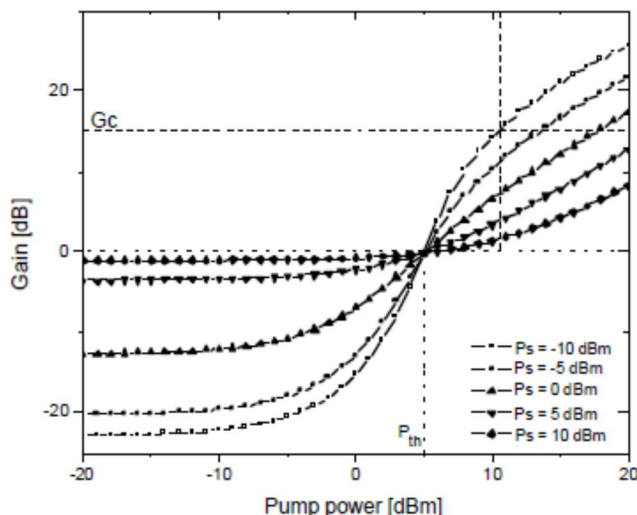


Fig7. Gain as function the pump power and signal power

For further improvement of the system we can use the combination of both optical [9] as well as electrical feed-back control.

REFERENCES

- [1] M. Zirngibl, "Gain Control in Erbium-Doped Fiber Amplifiers by an All-Optical Feedback Loop", *Electron. Lett.* **27**, 560-561 (1991)
- [2] K. Motoshima, et al, "Dynamic compensation of transient gain saturation in erbium-doped fiber amplifiers by pump feedback control," *Photon. Technol. Lett.* **5**, 1423-1426 (1993).
- [3] S.W. Harun, S.K. Low, P. Poopalan, et al., *IEEE Photon. Technol. Lett.* **14** (3) (2002) 293. E. Desurvire, *IEEE Photonic. Technol. Lett.* **1** (1989) 196.
- [4] H. Hatayama, C. Hirose, K. Koyama, N. Akasaka, M. Nishimura, *Opt. Fiber Commun. Conf.* **2** (2000) 142.
- [5] C.R. Doerr, R. Pafchek, L.W. Stulz, *IEEE Photonic. Technol. Lett.* **14** (2002) 334.
- [6] Chinlon Lin, *Broadband Optical Access Networks and Fiber-to-the-Home: Systems Technologies and Deployment Strategies*, Wiley, 2006.
- [7] I. Day, I. Evans, A. Knights, F. Hopper, S. Roberts, J. Johnston, S. Day, J. Luff, H. Tsang, M. Asghari, *Opt. Fiber Commun. Conf.* (2003) 249.
- [8] .M. Dignonet, editor, "Selected Papers on Rare-Earth-Doped Fibre Laser Sources and Amplifiers", SPIE vol. MS37, 1992.
- [9] A. Yariv, *Quantum Electronics*, 3rd ed. (John Wiley & Sons, 1989), Section 21. 1, p.572.
- [10] A. Cavaciuti, B. Sordo, "Noise measurements in EDFAs", *Conference on Optcal Fiber Communications, OFC'94 Technical Digest*, paper WM9, 163 (1994).

EDFA technology is most advanced technology in the optical communication system and consequently the vast majority of optical amplifiers deployed to date are based on this technology. Various single wavelength gain flattening techniques are suggested and their results are also compared. It is important to understand the desired range of wavelength used in EDFA which provides efficient results. Along with source wavelength if other parameters like length, pump power ,signal power are changed , than optimized values of gain and noise figure are obtained. Today it is possible to build broad band WDM EDFA's which provide flat gain over a large dynamic gain range, low noise, high saturation output power, and stable operation with excellent transient suppression. Gain Switched VG EDFA provides an excellent solution. Electronic feed-back control loop can better optimize the result.