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Some Studies on Gain Spectra Optimization of Multi Pumped Th3+ - Er3+ (Thulium Erbium) Doped Hybrid Optical Amplifier

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Abstract:

In Optical fiber communication signal degradation occur hence we use Optical Amplifiers which have advantages over regenerators as it does not require to do any reshaping, retiming, retransmitting or any costly O-E-O conversions. Limitation of Optical Amplifiers arises when non-linear effects occur. So, there is demand of optical amplifiers which provide better performance (in term of transient performance, gain flatness, larger gain bandwidth etc.) for DWDM systems. To minimize the impairments due to fiber nonlinearities and to enhance the gain bandwidth and/or gain flatnesshybrid optical amplifier is a promising technique for future DWDM multi-terabit systems. In this paper many hybrid optical amplifications like EDFA, TDFA, FOPA, OPCPA, TDFA-FOPA and TDFA-RAMAN are surveyed to carry work on TDFA-EDFA hybrid amplifier. Methods of implementing hybrid amplifiers and types of hybrid models that are available for use are surveyed. Comprehensive gain characteristics of TDFA, EDFA and hybrid amplifiers (TDFA-EDFA) connected in cascaded and parallel configurations are reported. TDFA and EDFA are simulated using multiple pumping scheme at variable lengths in order to optimise the gain spectra.

Keywords — **Thulium Doped Fiber Amplifier (TDFA), Hybrid Optical Amplifier (HOA), Erbium Doped Fiber Amplifier (EDFA),Dense Wavelength Division Multiplexing (DWDM).**

I. INTRODUCTION

The optical fiber is a propitious technology used in almost all the trunk lines of present networks. Optical amplifiers improved signals without going through the costly conversions from optical to electrical signal and vice versa. But due to the various non-linear effects and phase noise present in the optical amplifier, its use is restricted to limited applications in optical communications [12]. So, there is demand of optical amplifiers which provide better performance (in term of transient performance, power crosstalk, gain flatness, larger gain bandwidth etc.) for DWDM systems. In order to achieve these goals it is more important to design, characterize and investigate an appropriate optical amplifier for high capacity DWDM systems [1]. As such, new ways to extend the bandwidth, improve the noise and dynamic properties of present day amplifiers are constantly pursued. This paper facilitates this process by tracking several system level challenges while acknowledging the limitations of existing devices. The hybrid optical amplifier is an enabling and promising technique for future DWDM multi-terabit systems to minimize the impairments due to fiber nonlinearities and to enhance the gain bandwidth and/or gain flatness [13]. This paper mainly design, characterize and optimize the new hybrid optical amplifiers for DWDM system and further various important aspects has been addressed, such as gain flatness; gain bandwidth product; transient phenomena (Adding/Dropping of channels in the network can cause power variations in the system)

[2] etc. We have characterized this TDFA-EDFA scheme in Cascaded TDFA-EDFA and in parallel configuration to achieve better gain characteristics without using any other costly components like a gain equalizer [3].

II. LITERATURE SURVEY

A comprehensive literature review of the work reported in the paper is presented briefly describing the specific aspects of hybrid amplifier in Fiber-Optic communication networks.

S. Singh and R.S.Kaler (2014) [2]: Adding/Dropping of channels in DRA-EDFA HOA system cause power transient.EDFA has the fastest response time therefore response of the HOA is mainly determined by the transients of the EDFA. Channels in the system undergoes power excursion. To mitigate this effect EDFA pump power and length is changed, this reduces the power excursion.

S. Aozasa, et al. (2016) [14]: Gain characteristics of a TDFA are obtained with different lengths of TDF and different pump ratios. It is significant to make the best of these parameters to obtain high TDFA gain. A TDFA with WDM signals achieved gains exceeding 20 dB and an NF of less than 6 dB from 1453 to 1483 nm (30 nm bandwidth) with a total pump power of 300 mW for WDM signals input at a total power of-7 dBm. Pump power of 300W had 10% power conversion efficiency.

S. Olonkins, et al. (2016) [15]: EDFA has produced more amplified signal impairments than the LRA (Lumped Raman amp), it is a fact that it requires by far less pumping power to ensure a certain level of amplification, it is a more preferable solution for WDM transmission systems, when used as a preamplifier.

S. R. Luthi, et al. (2016) [16]: Combining TDFA-FOPA hybrid amplifier for simultaneous S-band amplification and S-to-C, S-to-L band wavelength conversion. It makes use of the overlapping gain bands of the TDFA and FOPA, signal amplification from 1450 to 1530 nm, and wavelength conversion into the1540-1630 nm range are demonstrated. The noise Fig. is normally in the range of 6-12 dB.

R. Singh and M. L. Singh (2016) [5, 17]: The gain of TDFA has been obtained for diverse fiber length and doping concentration. As the TDFA length increases, gain increase for the lower wavelengths (up to 1490nm), gain increases with the increase in the doping concentrations.

It has been observed from the study of available literature that very little progress has been made in enhancement of gain spectra of TDFA-EDFA hybrid amplifiers for WDM applications. So, this research work is aimed at obtaining overall flat gain using TDFA-EDFA hybrid amplifier (cascade/parallel) to increase the overall bandwidth of the system. Further these amplifiers are characterized in specific wavelength regions and their gain characteristic havebeen optimized. TDFA followed by EDFA connected in series and in parallel configuration has been analysed in S+C+L band.Thulium doped fiber amplifier (TDFA) provides inadequate gain at low pump powers whereas Erbium doped fiber amplifier (EDFA) provides higher gains for same pump powers.

In this paper work being presented is split into six sections. These sections comprise study and simulation of research problem as: Section I presents a brief overview hybrid optical amplifier with large number of benefits as compared to traditional communication systems. It also focuses on various HOA advantages and disadvantages. Section II covered the literature survey from various research papers with main focus on Hybrid Optical Amplifiers. Section III illustrates the results and performance analysis of TDFA with multiple pumping scheme for TDF lengths 5m and 10m. Section IV illustrates the results and performance of EDFA with single, double and triple pump frequencies at 10, 20 and 30 dBm of pump power for 5m and 10m EDF length. Section V illustrates the combined performance of TDFAEDFA connected in cascaded and parallel configuration. Section VI concentrates on the conclusion made from this work and future recommendations to enhance the performance of hybrid TDFAEDFA system.

III. GAIN CHARACTERISTICS OF TDFA

TDFA is becoming a key component in various lightwave systems, principally in short distance communication distribution systems in the first telecommunications window around 820 nm [6], Previously pumping schemes like 1040 nm [7], 690 nm, 1050 nm or 1400 nm[9],1050 nm , 1550 + 980 nm, 1047 + 980 [9], 1064 nm [9], 1050 nm + 800 nm [7], 1410 nm and 1047 nm [7], 1050 nm,1400 nm, 800 nm [6], have been reported by the researchers [10]. The carefully worked-out model of thulium doped fiber amplifier in the silica host was presented by P. Peterka et al. [8]. This paper is based on model presented by P. Peterka et al. [8] but compares gain for 5m, 10m TDFA length in TDFA with 1040 nm + 1400nm + 790 nm pumping schemes.

A. Simulation Setup for TDFA characterization

As shown in Fig. 1 WDM transmitter capacitise 125 channels in the wavelength region 1400-1500 nm with 0.8 nm channel spacing. These signals are multiplexed into TDFA. Here we use pumps for amplification and TDFA is used so we obtain its characteristics by using a dual port WDM analyzer. The amplified signals are then demultiplexed in 1400-1500 nm region and received by optical receiver.First, we calculated the gain characteristics of the TDFAs with changing TDF lengths and pump powers. Fig. 2, 3 shows the variation of gain spectra on TDF lengths, when WDM signals were input at the power of −20 dBm/Ch.

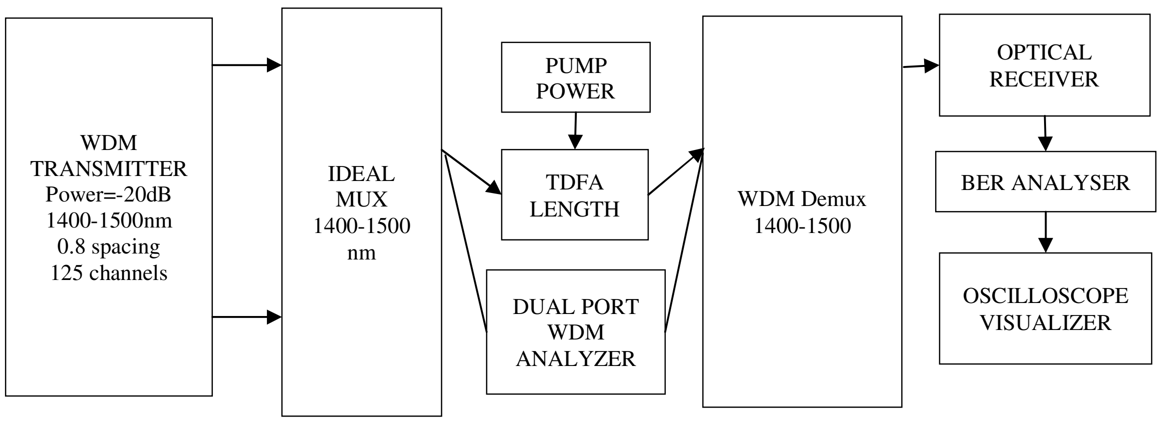

FIG. 1 Simulation setup deployed for chracterization of TDFAs

B. Results

Fig 2 shows the gain analyse of TDFA with double pump at pump frequencies 1040 nm, 1400 nm and pump power 30 dBm gives us 8.68 dBm gain for 5m TDFA length whereas fig 3 displays 10m TDFA length with same pump frequencies and pump power gives us 13.20 dBm gain.Gain enhancement of TDFA with 1050nm+1400nm+790nm,pump power 30dBm gives us 9.86 dBm gain as shown in Fig.4 it is for 5m tdf length and for 10m TDFA length 14.73 dBm gain(Fig.5). TDFA pumped with 10 dBm pump power at this 1040nm pump frequency does not gives adequate gain. TDFA provides low gain hence is useful in short band S-band region for 1400 nm range. High gain is obtained in 1460-1480 nm region for TDFA[10], [11].

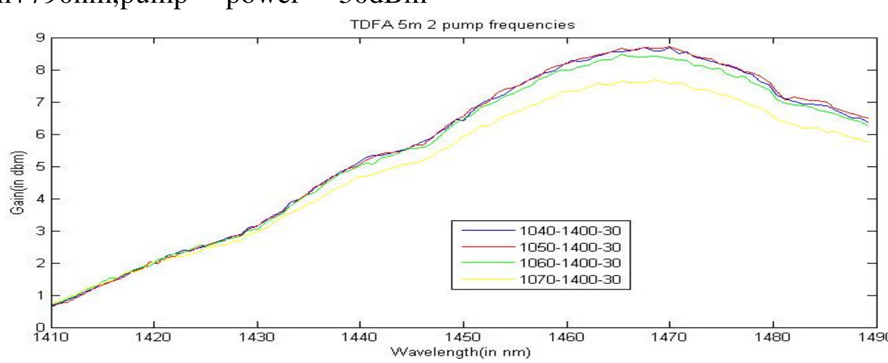

Fig 2 TDFA 5m with Two pumps

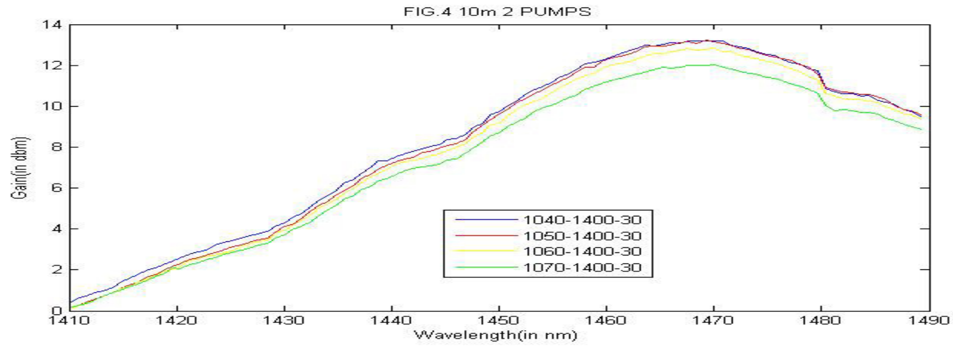

Fig 3 TDFA 10m with Two pumps

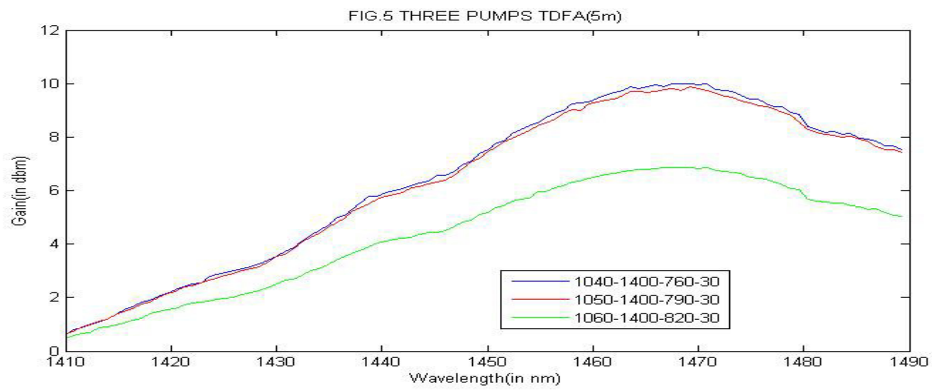

Fig 4 TDFA 5m with Three pumps

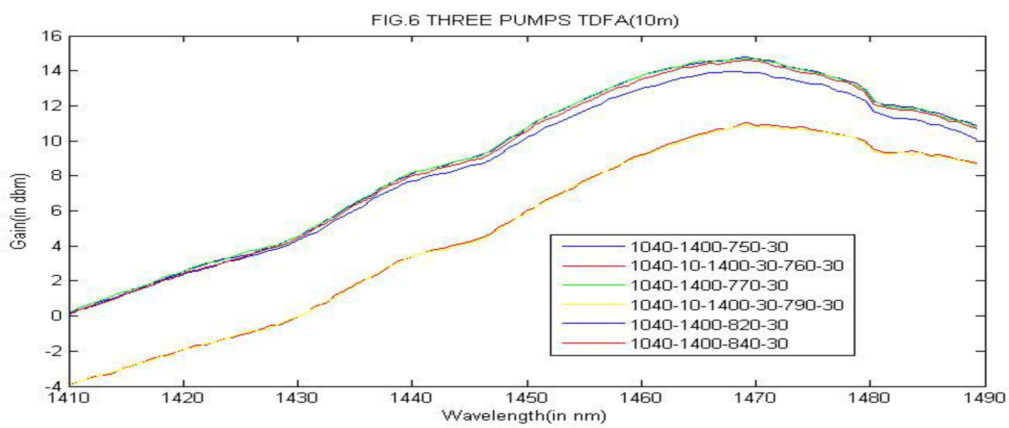

Fig 5 TDFA 10m with Three pumps

IV. GAIN CHARACTERISTICS OF EDFA

Er-doped fibers gives us an amplified output around 1530-1550nm. The EDFA is one of the key devices used for dense wavelength division multiplexed (DWDM) transmission systems. Some of the advantages offered by EDFAs are: High gain (~40 dBm), High output power, Low noise Fig., Less gain variation, Wide bandwidth of operating suiting DWDM, Inherent compatibility to transmission fiber with low insertion loss, Cross talk immunity in multichannel systems etc. [4]. EDFA in wavelength band 1470-1570 nm having lengths 5m and 10m respectively is examined.

A. Simulation setup for EDFA characterization

As shown in Fig. 6 WDM transmitter capacitise 125 channels in the wavelength region 1470-1570 nm with 0.8 nm channel spacing. These signals are multiplexed into EDFA.

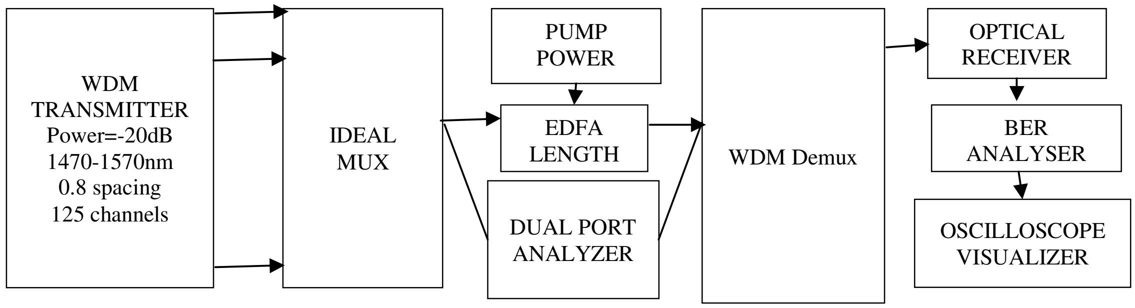

FIG 6 Simulation setup deployed for chracterization of EDFAs

B. Results

Gain analyses of EDFA for 890 nm+1420 nm+1450 nm pumping frequencies , pump power 30dBm gives us 38.46 dBm gain as shown in Fig.7 for 5m EDFA length whereas for 10 m EDFA with same pump frequencies and pump power gives us 39.23 dBm gain(Fig.8). Gain amplificaton is shown at 10 dBm of pump power.Gain provided by TDFAis low but EDFA provides us high gain. EDFAgives us an amplified output around 1530-1550nm with maximum gain of 39.23 dBm is achieved. EDFAs are therefore apt for long haul transmissions (C and L band).EDFA required by far less pumping power in order to ensure the required level of amplification than TDFA.

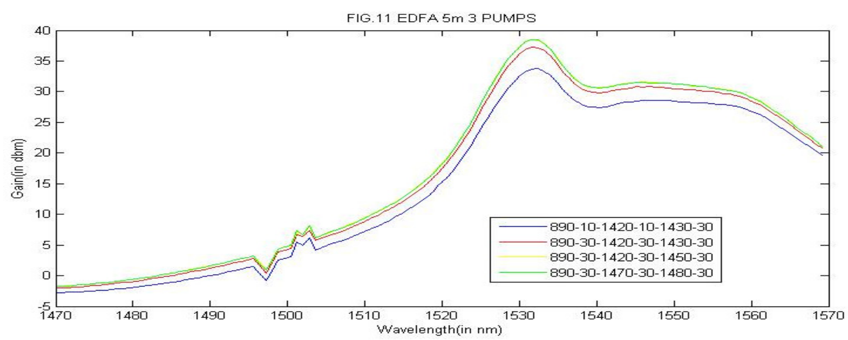

Fig 7EDFA 5m with Three pumps

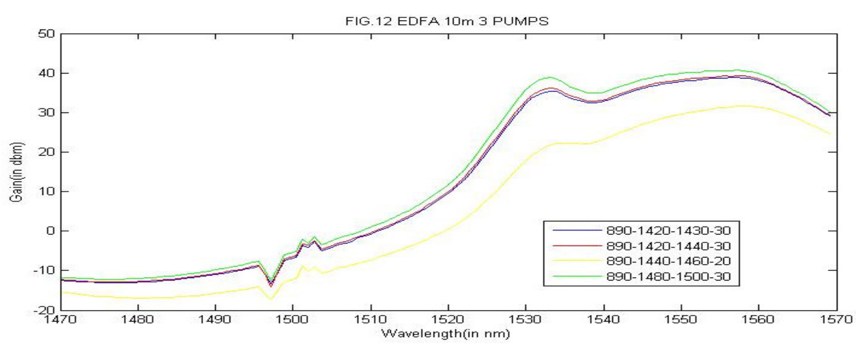

Fig 8EDFA 10m with Three pump

V. GAIN CHARACTERISTICS OF TDFA EDFA HYBRID AMPLIFIERS

A.TDFA EDFA Series Configuration

As shown in Fig. 9 WDM signals were input at the power of −20 dBm/ch in entire wavelength region 1400-1570 nm region including 212 channels where TDFA and EDFA are connected in series (Fig. 9) [3]. These signals are multiplexed into hybrid fiber . Here we used single pump 1040nm for amplification of TDFA and 1460 nm pump frequency for amplification of EDFA with both having 5m lengths each.

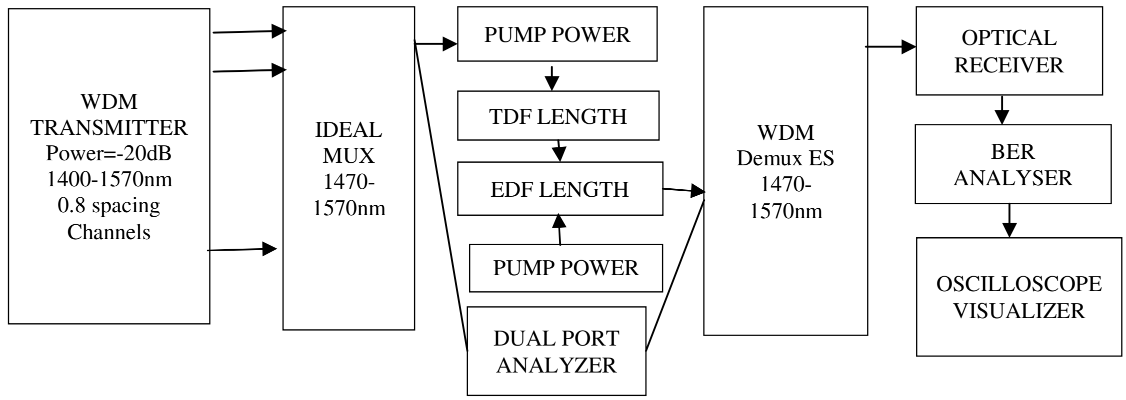

FIG 9 Block Diagram for Hybrid Amplifier Cascaded Configuration

B.TDFA EDFA in Parallel Configuration

In Fig. 10, two WDM transmitters transmitted signals at the power of −20 dBm/ch in separate wavelength regions (1400-1500)-(1470-1550) nm region. Here TDFA and EDFA are connected in parallel configuration. Here we used single pump 1040nm for amplification of TDFA and 1460 nm pump frequency for amplification of EDFA.

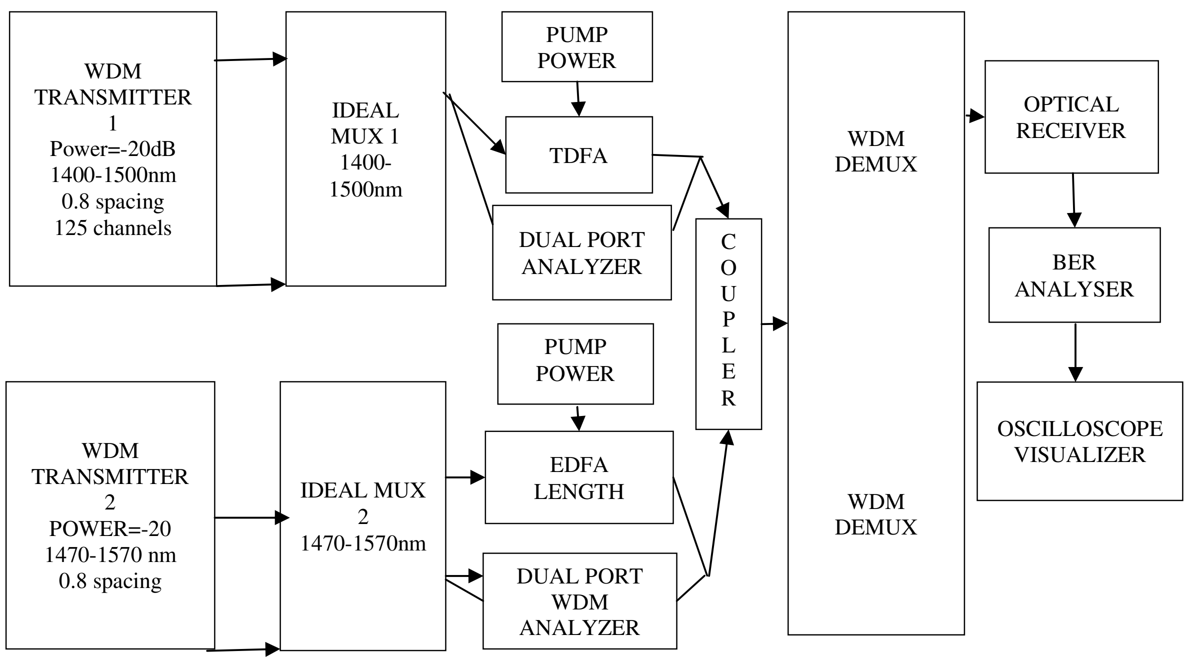

FIG 10 Block Diagram for Hybrid Amplifier Parallel Configuration

C. Results

In Fig. 10 TDFAEDFA are connected in parallel configuration with pump frequency 1040nm for TDFA and 1460nm for EDFA having lengths 5m for TDF and EDF. A uniform gain along the entire region 1400-1550 nm is obtained. 10 dBm gain in TDFA region and 37.5 dBm gain in EDFA region(Fig 12). Here coupling is used hence we got a little narrow range gain.

Gain plot in serial configuration is wider as no coupling is used (Fig 11). A higher gain is achieved in parallel configuration for EDFA region of about 37.5 dBm near 1535 nm region as shown in Fig. 12. High gain achieved in TDFA is 10 dBm around the region (1460-1480) nm.

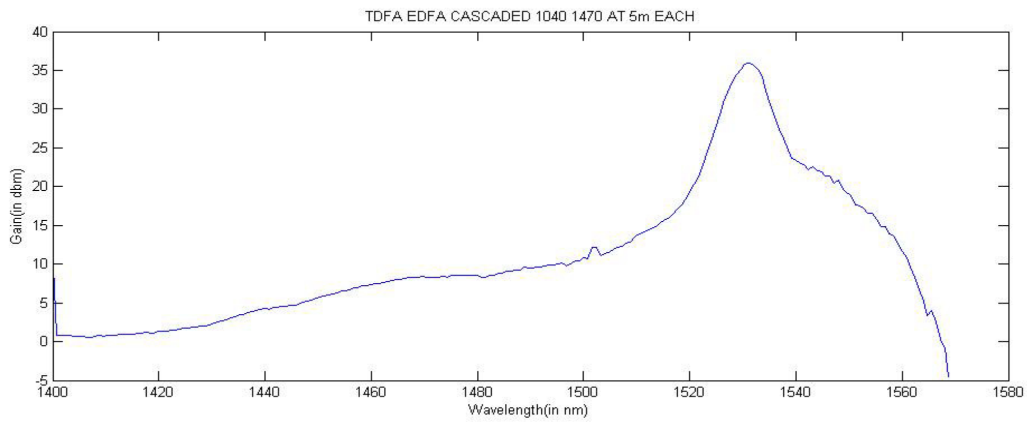

Fig. 11 TDFA EDFA cascaded, connected in series with pump frequency 1040nm for TDFA and 1460nm for EDFA having lengths 5m for TDF and EDF

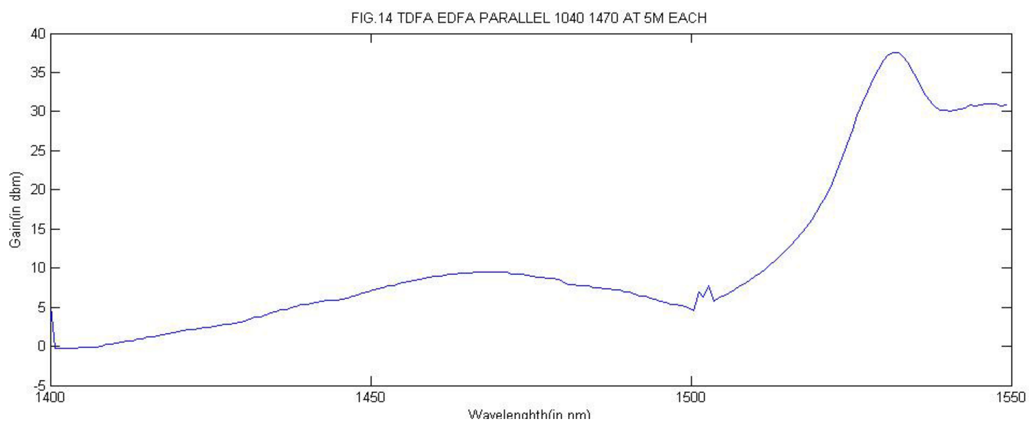

FIG. 12 TDFA EDFA are connected in parallel configuration with pump frequency 1040nm for TDFA and 1460nm for EDFA having lengths 5m for TDF and EDF

VI. CONCLUSIONS AND FUTURE SCOPE

In this paper, we have reviewed some of the progress attained in the field of hybrid optical amplifiers (HOA) in the form of a literature survey.We have described the gain characteristics of TDFA and EDFA individually for their respective wavelength regions and then together for the entire wavelength region (1400-1570) nm wide. Multiple pumping scheme is employed (single, double and triple pump) with varying pump power 10, 20 and 30 dBm, Thulium Doped Fiber length and Erbium Doped Fiber length. We have obtained a high gain of 14.73 dBm in wavelength region 1460-1480 nm in case of TDFA pumping with 1050nm, 1400nm and 790nm (TDF=10m). Although TDFA does not show adequate gain for lower pump powers at 1040nm frequency. For EDFA highest gain obtained is 39.23 dBm in wavelength region 1530-1560 nm pumping with

890nm, 1420nm and 1450nm (EDF=10m). EDFAs are therefore apt for long haul transmissions (C and L band). EDFA required by far less pumping power in order to ensure the required level of amplification than TDFA.At last variation in graphs of cascaded TDFAEDFA and when connected in parallel are shown. Gain plot in serial configuration is wider as no coupling is used. A higher gain is achieved in parallel configuration for EDFA region. It has been learnt that these hybrid amplification techniques have apt ability to display various desirable characteristics like attainment of better gain, flattens of overall gain and foremost reducing the Noise Fig. (NF). Attenuation is present in fiber optic communication hence these amplifiers plays a pivotal role for better transmission. A lot of work can be done to accomplish better gains with different amplifiers. Thus, there is a scope in development of strategies for the minimising signal degradation problem in hybrid optical amplifier optical communications systems.

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