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Gain Flattened L-Band EDFA -Raman Hybrid Amplifier by Bidirectional Pumping technique

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ABSTRACT

In this paper, gain flattening of L-band EDFA-Raman hybrid amplifier is done by using bidirectional pumping scheme i.e. forward and backward pumping simultaneously. L-band EDFA is connected in series with Raman amplifier to form the hybrid amplifier. L-band EDFA is forward pumped at 1480 nm with the length of doped fiber of 150 m. The effect of various pumps on the performance of hybrid optical amplifier has been analyzed. It has been observed that when the Raman amplifier is forward and backward pumped with 1500 nm and 1502 nm respectively, the system has a flat gain spectrum of ±1.51 dB over 42 nm bandwidth with the gain of 20.74 dB having the noise figure of 4.377 dB.

Keywords: Erbium doped fiber amplifier (EDFA), Raman amplifier, gain flatness, noise figure, gain, L-band, Hybrid amplifier (HA)

I. INTRODUCTION

There is an ever-increasing demand of transmission bandwidth for optical 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 [1]. Gain flattening techniques such as gain flattening filters as fiber bragg gratings, optimization of material composition of fiber amplifiers , using rare earth doped ions, hybrid amplifiers can be used to reduce the gain variation.

EDFA has been of great importance in optical communication system due to its advantages like high gain, low noise figure, polarization insensitivity and it works well in the C-band [2]. The main problem with EDFA is that the gain is not uniform and the wavelength of each channel is not amplified equally [3]. So, different techniques such as optical filters, optimization of core of optical fiber, hybrid amplifiers are used for better amplification. But the techniques like fiber bragg gratings and optimization of material composition introduce losses and flexibility issues. Also, with the increasing number of internet users, a need is being felt to extend the C- band (1525-1565 nm) to L-band (1565-1610 nm) [4, 5]. Although, L-band is a region of very low losses as compared to C-band but EDFA is not as much as efficient with L-band as it is with C-band. So, Raman amplifier can be used with L-band EDFA to compensate for this problem. So, hybrid amplifier technique is much more preferable. Here, L-band EDFA is cascaded with distributed Raman amplifier by bidirectional pumping scheme to obtain the hybrid optical amplifier which results in wide bandwidth and gain flattening of EDFA.

II. GAIN ANALYSIS

EDFA is a lumped amplifier and is a three level system and the gain is as follows:

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$$G_{max}(L, \lambda p, \lambda s) = \exp\left[L \frac{rp(\lambda p) - r(\lambda s)}{1 + rp(\lambda p)}\right] \quad (1)$$

where the G_{max} depends on λ_p(pump wavelength), λ_s (signal wavelength), cross section ratios $r_p = \sigma_{pa}/\sigma_{pe}$ (pump absorption/pump emission); $r = \sigma_{sa}/\sigma_{se}$ (signal absorption/signal emission), $L = (L_{amp} \cdot \Gamma_s \cdot \sigma_{se} \cdot \lambda_s \cdot N_T)$ where Γ_s is the signal to core overlap and L_{amp} is the physical length of the amplifier [3].

In the Raman amplifier, the distribution of power of optical signal is affected by Rayleigh back scattering, double Rayleigh back scattering, Raman pumping [3]. The most important parameter is the Raman gain coefficient g_r. It explains how the Stokes power increase as pump power is transmitted to it through Stimulated Raman scattering. The Raman gain is characterized as:

$$\frac{dP_s}{dz} = g_r P_p P_s - \alpha_s P_s \quad (2)$$

$$\zeta \frac{dP_p}{dz} = \frac{\omega_p}{\omega_s} g_r P_p P_s - \alpha_p P_s \quad (3)$$

where α_s and α_p determine fiber losses at the stokes and pump wavelength respectively. ω_p and ω_s are the pump and signal frequencies respectively. The parameter ζ has values ±1 depending on whether it is forward pumped or backward pumped.

III. SIMULATION SETUP

HOA is simulated in VPI PHOTONICS version 9.0. The proposed hybrid optical amplifier system consists of two sections:

- L-band EDFA forward pumped
- Raman amplifier forward and backward pumped simultaneously

In first section, a single stage WDM source of emission frequency 184 THz, channel spacing of 100 GHz with varying input signal power is used. 100 channels are transmitted from WDM source. L-band EDFA is forward pumped at 1480 nm with the length of doped fiber of 150 m. The amplifier is excited by WDM combination. The optical coupler combines the input signal and pump signal and is propagated by Erbium doped fiber amplifier. The second stage consists of distributed Raman amplifier forward and backward pumped simultaneously. Distributed Raman amplifier is used in spite of discrete Raman amplifier as discrete Raman amplifier is placed into the transmission fiber to provide gain, where all the pump power is limited to the lumped element whereas, in a distributed amplifier the pump power expands into the transmission fiber, using it as the gain medium [6]. Distributed amplification, retain the optical signal level over a long distance along the transmission line and maintains the SNR

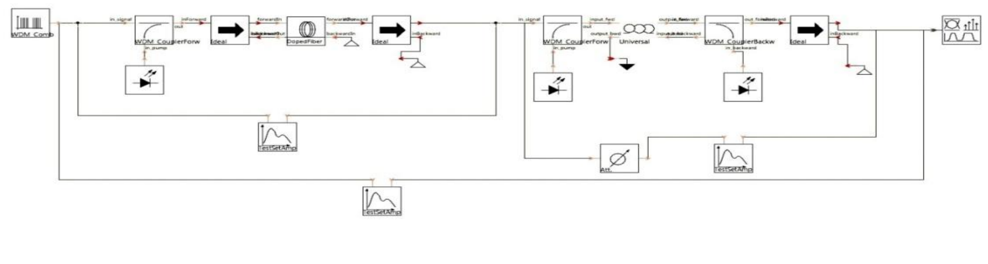

Figure 1: Block diagram of HOA system by co-counter pumping scheme

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The length of universal fiber is chosen as 45 km with the attenuation of 0.1e-3 dB/km. An attenuator is placed before the Preinput of TestSetAmplifier and set its attenuation to that of the fiber when the pump is off (45 km*0.1e-03 dB/km).The signal amplified by the first stage is then propagated by the second stage consisting of distributed Raman amplifier. TestSetAmplifier modules are used around the EDFA section, Raman section and the whole amplifier system. In the end, the combined signal is fed into the optical spectrum analyzer to analyze the performance of optical spectrum.

IV. RESULTS

After simulating setup, the results have been plotted.The effect of channel power on gain and noise figure of EDFA has been examined keeping the length of doped fiber of 150 m. As the operating band is L-band, the length of doped fiber is chosen as 150 m i.e. the length of doped fiber has to be long enough resulting in better optical efficiency. The gain of EDFA is best at 1480 nm pump with channel power of 1e-6 W having the gain variation of 2.37 dB in the range of 186-191 THz. As the input power increases from 1e-6 to 1e-4 W, the gain starts decreasing from 22.09 dB to 7.06 dB at 1480 nm pump and noise figure increases from 4.33 dB to 5.84 dB. This is due to local inversion along the length of the fiber induced by pump power.

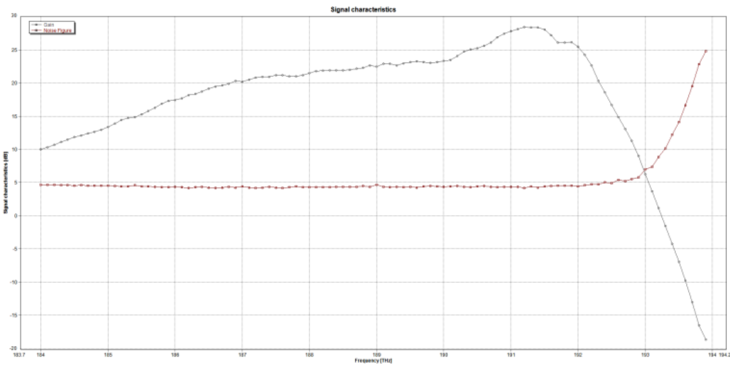

Figure 2: Gain and noise figure of EDFA at 1480nm for channel power of 1e-6 W

L-band EDFA forward pumped at 1480 nm with the channel power of 1e-6 W having the length of doped fiber of 150 m is cascaded with distributed Raman amplifier to form HOA system. The effect of various pumps on gain and noise figure of HOA has been plotted and tabulated. When the HOA is forward and backward pumped simultaneously, the effect on gain variation, gain and noise figure has been observed.

Table 1: Effect of various pumps on Gain and Noise figure of HOA

S.No.	Forward pump wavelength (nm)	Backward pump wave length (nm)	Gain (dB)	Noise Figure (dB)	Gain variation(dB)
1.	1460	1462	17.44	4.421	3.81
2.	1464	1466	18.02	4.420	4.06
3.	1468	1470	18.49	4.382	4.28
4.	1480	1482	20.04	4.379	3.97
5.	1490	1492	20.97	4.371	2.40
6.	1500	1502	20.74	4.377	1.51
7.	1510	1512	19.97	4.380	1.26

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8.	1520	1525	18.91	4.383	1.28
9.	1530	1535	18.05	4.387	1.43
10.	1540	1542	17.46	4.390	1.63

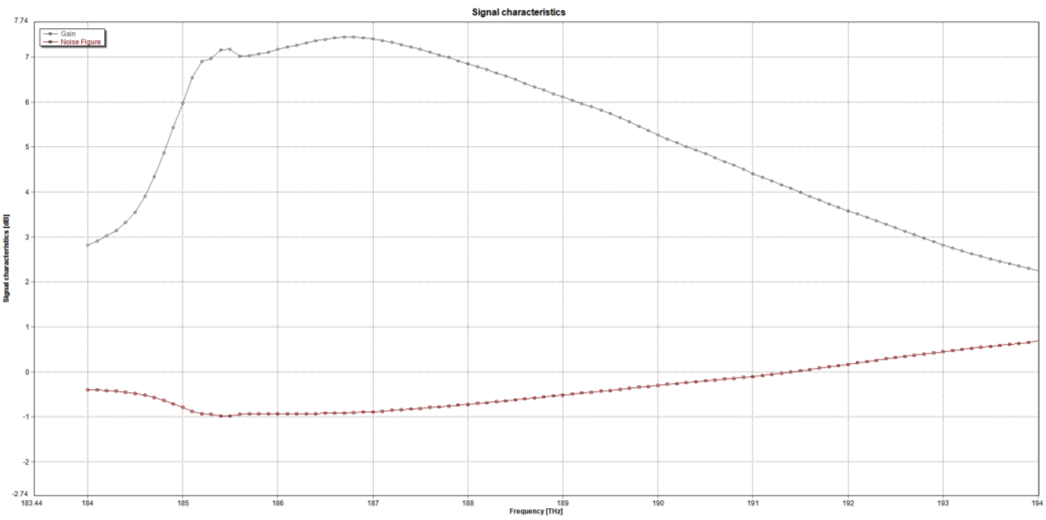

Figure 3: Gain and NF of Raman amplifier when co-counter pumped with 1500 nm and 1502 nm respectively

The above figure shows the gain and noise figure of Raman amplifier.These are not on-off gains and equivalent lumped amplifier measures, as the fiber is not contributing to the transmission span distance. The gain peaks around 1614 nm with a low noise figure at this wavelength.

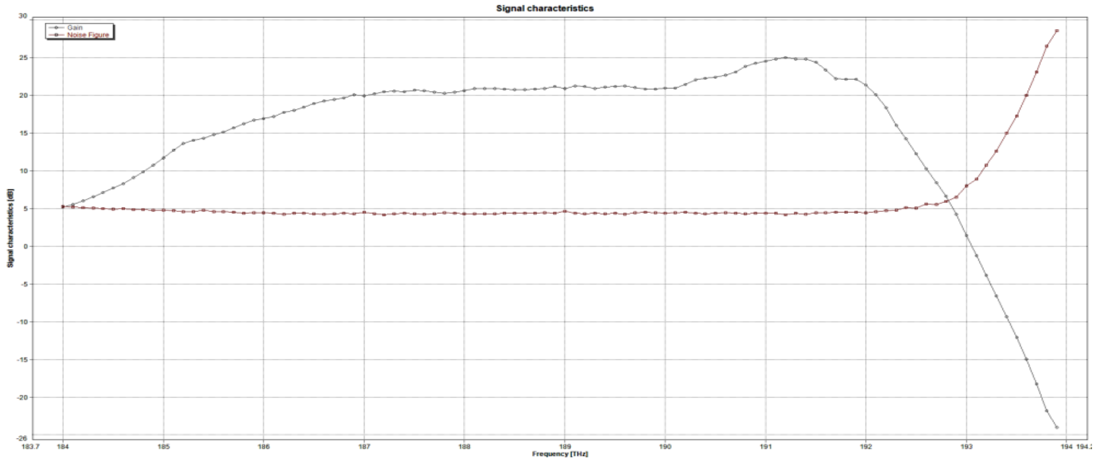

Figure 4: Overall Gain and NF of HOA when co-counter pumped with 1500 nm and 1502 nm respectively

The system has a flat gain spectrum of ± 1.51 dB over the bandwidth of 42 nm in case 6. The gain of overall system is lower as compared to gain of L-band EDFA but there is improvement in gain variation of overall HOA system. The gain value can be further increased by cascading more EDFA stages. As seen from Table 1, case 7 has a less gain variation than case 6 but the gain value also gets decreased. So, the best case is 6 with the overall gain of 20.74 dB and the noise figure of 4.377 dB .

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V. CONCLUSION

A EDFA-DRA Hybrid optical amplifier system has been proposed by bidirectional pumping scheme.When Raman amplifier is forward and backward pumped with 1500 nm and 1502 nm respectively, the system has a flat gain spectrum of ±1.51dB over 42 nm bandwidth with the gain of 20.74dB having the noise figure of 4.377 dB.

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