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Gain Flattening of L-band EDFA -Raman Hybrid Amplifier

Avneet Kour
M.Tech Student
Department of Electronics and Communication
PEC University of Technology
Chandigarh, India

Neena Gupta, PhD
Professor
Department of Electronics and Communication
PEC University of Technology
Chandigarh, India

ABSTRACT
A design of L-band EDFA cascaded with distributed Raman amplifier has been optimized so as to improve the gain, noise figure and gain variation. Firstly, the L- band EDFA system has been designed and the effect of change in input power, change in the length of the doped fiber and the use of various pumps on EDFA has been examined. It has been observed that gain obtained is maximum with a low noise figure at 1480nm pump with the length of doped fiber of 150m. Secondly, this system is then cascaded with distributed Raman amplifier (DRA) to form a hybrid optical amplifier (HOA) so as to further improve the gain, noise figure and gain flatness. The HOA system has the best flat gain spectrum of ±0.73dB over the bandwidth of 42nm with the gain of 29.43dB and the noise figure of 4.403dB.

Keywords
EDFA (Erbium doped fiber amplifier), L-band, Gain, Noise figure (NF), Hybrid optical amplifier (HOA), Distributed Raman amplifier (DRA), Gain flatness.

1. INTRODUCTION
Erbium doped fiber amplifier (EDFA) is the most commonly used amplifier in optical communication system. But, with the growth of data traffic and ever increasing demand of internet, there is the need of extending the operating band from C-band (1525nm-1565nm) to L-band (1565-1610nm) [1]. The C-band has been of great importance to optical communication because it provides efficient optical amplification with low losses [2] but the L-band is a region of even lower losses [3]. EDFA is less efficient in the L-band so different techniques are used for better amplification. Earlier, the L-band EDFA was used in combination with optical filters [4-5], Raman amplifier, wavelength dependent splitters. But optical filters and wavelength dependent splitters introduce losses and flexibility issues. L-band EDFA with distributed Raman amplifier (Hybrid optical amplifier) [6] can provide wide gain in the required wavelength but till now, gain obtained of hybrid optical amplifier (HOA) is small with low noise figure and more gain variation.

2. SYSTEM DESIGN
The HOA system is simulated in VPI PHOTONICS version 9.0. In proposed HOA-WDM system, 100 channels with emission frequency of 184e12 Hz and channel spacing of 0.8 nm has been investigated. The HOA-WDM system consists of EDFA section cascaded with distributed Raman amplifier section. The first stage (Erbium doped fiber amplifier section) is forward pumped by 1480 nm pump with pump power of 100 mw with the length of doped fiber=150m. The second stage (distributed Raman amplifier) is pumped by counter pumping scheme. The effect of various pumps on gain, noise figure and gain variation has been analyzed in the counter pumping scheme.

The first stage is excited by WDM combination. The optical coupler combines the input signal and pump signal and is propagated by Erbium doped fiber amplifier. TESTSETAMPLIFIER module is used around the first stage amplifier system. Isolator is used to prevent the back propagation of the signals which causes the reflections resulting in unstability of the whole system. The signal amplified by the first stage is then propagated by the second stage consisting of distributed Raman amplifier which is pumped by counter propagation technique with multiple pumps. TestSetAmplifier modules are used in the second stage amplifier system 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.

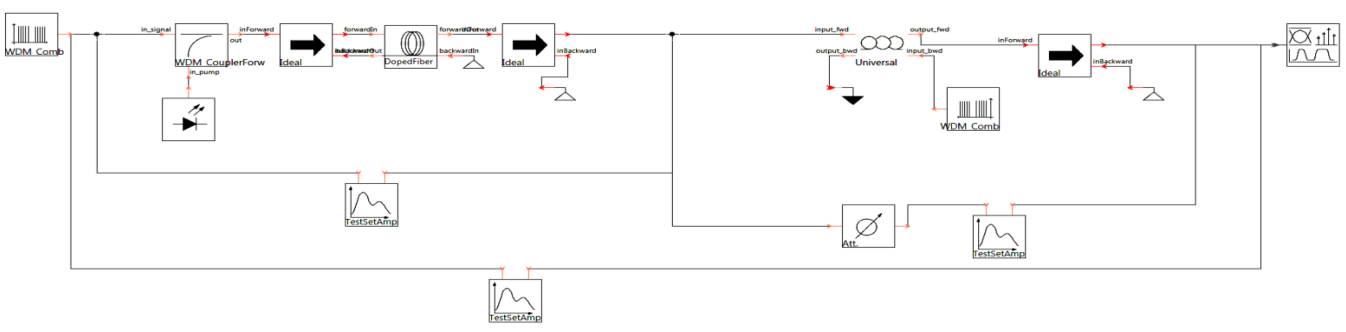

Figure 1: Block diagram of HOA system with multiple pumps in counter pumping technique

3. RESULTS

After simulating setup, the results have been plotted and tabulated with different parameter values of simulation results i.e. gain, noise figure with counter pumping technique. Also, different components use the different operational parameters.

To find out the channel spacing, the linewidth conversion formula [7] is used:

$$\Delta f = \frac{c}{\lambda^2}\Delta\lambda \quad (1)$$

Where c is the velocity of light, Δf is the laser linewidth in frequency domain, Δλ is the laser line width in spectral domain.

Figure 1 shows the schematic of hybrid amplifier. Individual test sets are used to assess the performance of EDFA stage and Raman stage. The stages are:

- A forward pumped EDFA stage
- A multiple backward pumped Raman stage with dedicated fiber

The pumps of Raman amplifier are distributed in wavelength to provide the gain over a wide range.The WDM parameters are shown in table 1.

Table 1: WDM_COMB Parameters

Emission frequency	184e12Hz
Channel spacing	100e9Hz
Channel power	1e-6W
No. of channels	100

In the first stage (Erbium doped fiber amplifier section), the gain obtained is best at 1480nm pump so here 1480nm pump is used in spite of 980nm pump as it has higher optical conversion efficiency. The length of doped fiber is chosen as 150 m as the operating band is L- band which requires long length of the doped fiber. The EDFA parameters used in simulation setup is shown in table 2.

Table 2: EDFA Parameters

Model Type	Er two level
Pump wavelength	1480nm
Average pump power	100e-3 W
Length of doped fiber	150m

In the second stage (Raman amplifier section), Raman amplifier is backward pumped with dedicated universal fiber. The length of universal fiber is chosen as 45km.TestSetAmplifier is placed across this section which displays On/Off gain and lumped equivalent noise figure simultaneously. An attenuator is placed before the Preinput of TestSetAmplifier and set its attenuation to that of the fiber when the pump is off (45km*0.1e-03 dB/km). Thus, the TestSetAmplifier is fooled into thinking that it is measuring a lumped amplifier at the end of an attenuating fiber. The Raman fiber parameters used in simulation setup is shown in table 3.

Table 3: Raman Fiber Parameter

Length of Raman fiber	45km
Attenuation	0.1e-3dB/km
Raman scattering	On
Pump power	100mW

Table 4: Effect of various pump wavelengths of Raman on gain and noise figure of hybrid amplifier

S. No	Pump wavelengths (nm)				Gain (dB)	Noise figure (dB)	Gain variation (dB)
1.	1448	1450	1452	1454	20.63	4.4053	3.58
2.	1462	1464	1466	1468	23.73	4.4066	5.96
3.	1470	1472	1474	1476	26.25	4.4058	6.49
4.	1482	1484	1486	1488	28.84	4.4039	4.77
5.	1492	1494	1496	1498	30.18	4.4023	1.44
6.	1502	1504	1506	1508	29.43	4.4035	0.73
7.	1512	1514	1516	1518	27.53	4.4065	0.86
8.	1522	1524	1526	1528	26.24	4.4088	0.87

As seen from Table 4, when Raman amplifier is backward pumped with 1502,1504,1506,1508 nm, the gain obtained is 29.43dB with the noise figure of 4.403dB. The system has the best flat gain spectrum of ± 0.73dB over the bandwidth of 42nm.However, in all the cases, the noise figure approximately remains constant.

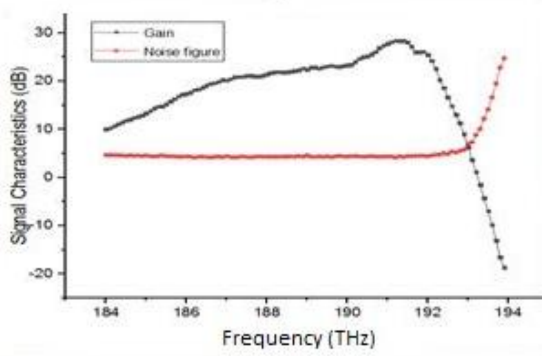

Figure 2: Gain and noise figure analysis of L- band EDFA

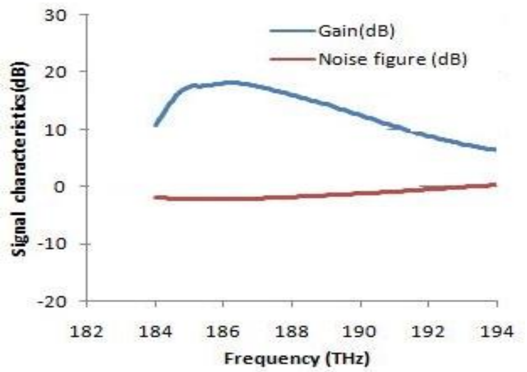

Figure 3: Gain and noise figure of Raman amplifier pumped at 1502, 1504, 1506, 1508nm

The above figure shows the gain and noise figure of multi-pump Raman amplifier as measured by TestSetAmplifier. An attenuator with the equivalent attenuation of the unpumped fiber is used to obtain the (pump) on-off gain and equivalent lumped amplifier noise figure.

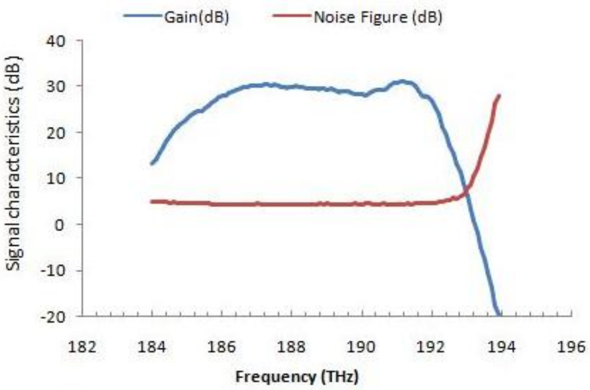

Figure 4: Overall gain and NF of HOA pumped at 1502, 1504, 1506, 1508nm

The above figure shows the overall gain of 29.43dB and noise figure of 4.403dB with the gain variation of ±0.73dB.

4. CONCLUSION

A Hybrid amplifier has been proposed using EDFA- Raman amplifier. The length of the doped fiber is 150m with input channel power of 1e-6W. When backward pumped with 1502, 1504, 1506, 1508nm in counter pumping scheme, the gain of HOA is 29.43 dB with the noise figure of 4.403dB. The system has a flat gain spectrum of ±0.73dB over the bandwidth of 42 nm. A low gain variation with better gain and better noise figure is obtained without using any costly gain flattening techniques. This work can be further extended to hybrid optical amplifiers combined with other gain media including combination of Raman amplifiers with fibers doped with different rare earth media (e.g., Nd and Yb).

5. REFERENCES

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