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Flat Gainon C-band using Raman-EDFA Hybrid Optical Amplifier for DWDM System

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Abstract
An efficient optical link which provides flat gain over C-band has been designed using a raman fibre amplifier and an Erbium doped fibre amplifier (EDFA) in a hybrid configuration for dense wave division multiplexing system (DWDM). With an input power of 3 mW, gain of > 40 dB is obtained across the range of 1530 nm to 1565 nm with a gain variation of <1.2 dB without using any gain flattening techniques.

Keywords: *EDFA, Optical amplifier, Raman Amplifier*

INTRODUCTION

Considerable efforts have been devoted to the realization of gain-flattened amplifiers over a wide spectral range of optical communication systems. It is of prime importance to flatten the gain spectrum of optical amplifiers for various applications like dense wavelength division multiplexing (DWDM) and all- optical self-routed wavelength addressable networks. Several approaches have been proposed for achieving a flat gain such as changing to new fibre materials [1]–[4] and gain equalizers [5], [6]. Macro and micro bending techniques have also been explored to get flat gain spectrum [8], [9], but all these components and techniques are expensive and sensitive to temperature and strain.

In this paper, we propose a gain-flattened amplifier, which uses a cascaded configuration of EDFA with Raman amplifier. This configuration allowed us to demonstrate a 40 dB flat-gain at input signal power of 3 mW and a gain incursion of about1.1 dB in the 1530–1565 nm wavelength region.

PROPOSED SETUP

The Hybrid Optical Amplifier (HOA) configuration consisting of Raman Amplifier and Erbium Doped FibreAmplifier is shown in Fig.1. The experimental setup consists of 175 DWDM channels with spacing of 0.1 nm covering the Conventional C-band (1530–1565 nm). The information is generated by 175 optical transmitter modules as shown in the block diagram, which consists of a Pseudo random binary sequence pattern generator (PRBS), continuous wave laser (CW laser), electrical signal generator and an external modulator. The PRBS pattern generator provides us with a maximal length pseudo-random binary sequence, with data rate set to 10 Gbps and then converted to optical medium by using electrical signal generator, continuous wave lasers and an external modulator. The electrical signal generator provides a square wave electrical signal based on the input signal and the maximum and minimum values specified by the user, the CW laser is used in the lambda grid mode providing an input power of 3 mW while the external modulator provides Mach-Zhender modulation to the signal. The signal is then given to an optical multiplexer whose parameters are described in Table I. A Bi-directional fibre (BDF) was used as a Raman amplifier's gain-medium cascaded with Erbium Doped Fiber Amplifier. The parameters are mentioned in Table II. At the receiver side we use a compound optical receiver which consists of a photo-detector, preamplifier, and a post amplifier. The photo- detector model converts an optical input signal to an electrical current. This photocurrent is then passed to the preamplifier model which converts it to a voltage. Finally, the post-amplifier model contains a set of baseband filters that shape the output waveforms.

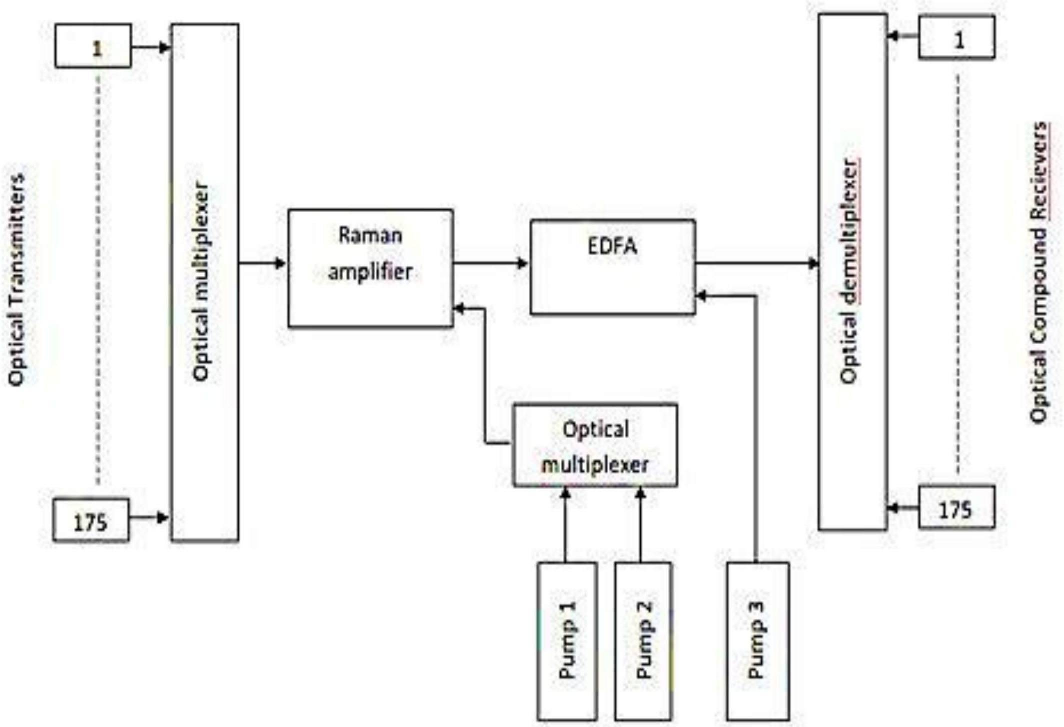

***Fig. 1**: Proposed block diagram of Hybrid Optical Amplifier.*

***Table1:** properties of optical multiplexer*

Number of ports	Filter type	Filter bandwidth(meters)	Filter spacing (meters)
175	Trapezoidal	0.1×10^{-9}	0.1×10^{-9}

***Table 2:** Properties of Raman Amplifier and EDFA*

	Length	Pumping power	Pumping wavelength	Pumping scheme
Raman Amplifier	50 meters	500 mW	Pump1: 1480 nm Pump2: 1454 nm	Counter pumping
EDFA	20 meters	800 mW	Pump3:980 nm	Counter pumping

RESULT AND DISCUSSION

Fig. 2 shows the Gain spectra for different pump powers ranging from 100 mW to 1000 mW for the two different EDFA pump wavelengths, 980 nm and 1480 nm. It is observed that with the increase in pump power the gain gradually increases, also the gain provided due to the 980 nm wavelength is significantly higher than the gain provided by 1480 nm wavelength because the 980 nm wavelength provides a higher inversion than 1480 nm, i.e. there is incomplete inversion for 1480 nm due to the non-zero emission cross section, which drains population out of the upper state. Also, 980 nm provides greater separation between the laser wavelength and pump wavelength and due to this reason it introduces less noise.

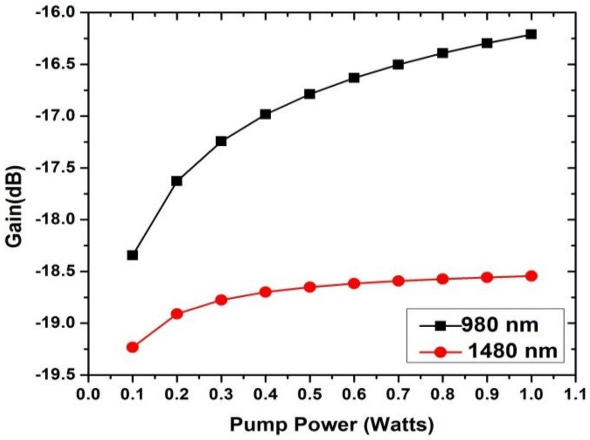

Fig. 2: *Gain spectra of HOA for different pump powers at 980 nm and 1480 nm pumping wavelengths of EDFA*

Fig.3 shows the gain spectra with changing EDFA length from 5 m to 50 m. It is observed that the gain peaks at between 12 to 15 meters and then gradually decreases. This is due to the fact that after a certain length of the EDF the pump power doesn't have sufficient energy to stimulate population inversion hence the part of the fibre, where the pump power loses its effect, the signal is absorbed by the fibre and results in decreasing gain.

Fig.4 shows the gain spectra for different wavelengths for different EDF lengths. If fiber is too short, there are not sufficient erbium irons to absorb all the pump photons, and if fiber length is too long, the end section of the fiber is under pumped, so pump to signal conversion efficiency is reduced after certain increment of the fiber length. It is observed that gain spectra shows an increase from 10 m to 20 m but starts to decrease

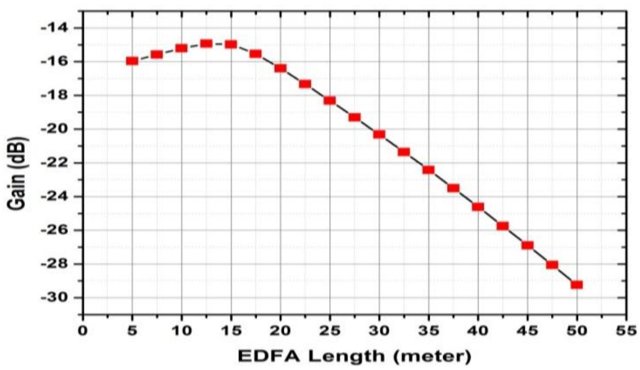

Fig. 3*: Gain spectra of HOA for different lengths of EDFA.*

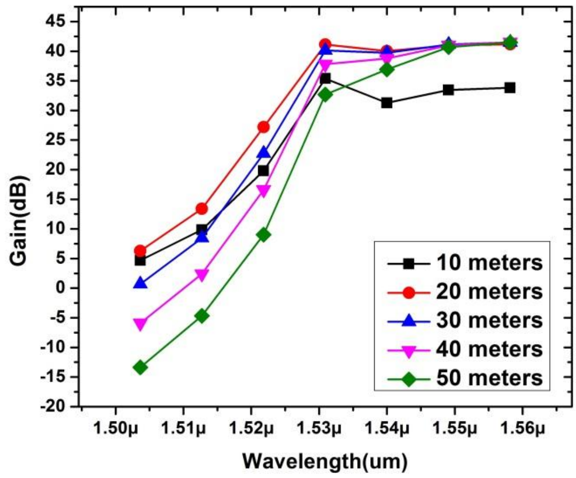

Fig. 4: *Gain spectra of HOA for effect of different EDFA lengths at different wavelengths*

as the length further increases and becomes the least at 50 m. The reason is the same as that mentioned for Fig.3 and the point to be noted is that based on the pump power an optimum length of the EDF needs to be decided.

Fig.5 describes the gain spectra for different wavelengths for different EDFA pump powers. It is observed that with the increasing pump powers the gain increases. This happens because there are a limited number of erbium dopant ions hence until and unless there are dopants remaining in the ground state higher the pump power greater will be the number of ions that will get excited to higher state. Though this will not be the case when there are no dopants remaining in the ground state and increasing pump power will have no effect. Fig.6 shows the Gain spectra of HOA for different wave- lengths and it is observed that a flat gain across the C-band (1530 nm-1565 nm) with gain > 40 dB with variation of < 1.2 dB is observed.

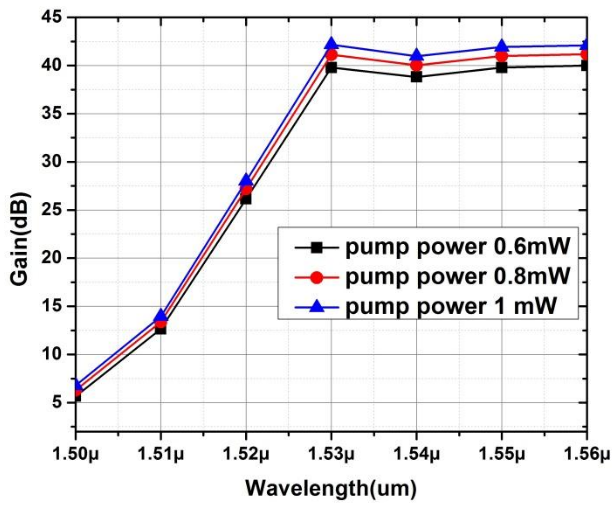

Fig. 5: *Gain spectra of HOA for effect of different EDFA pump powers at different wavelengths*

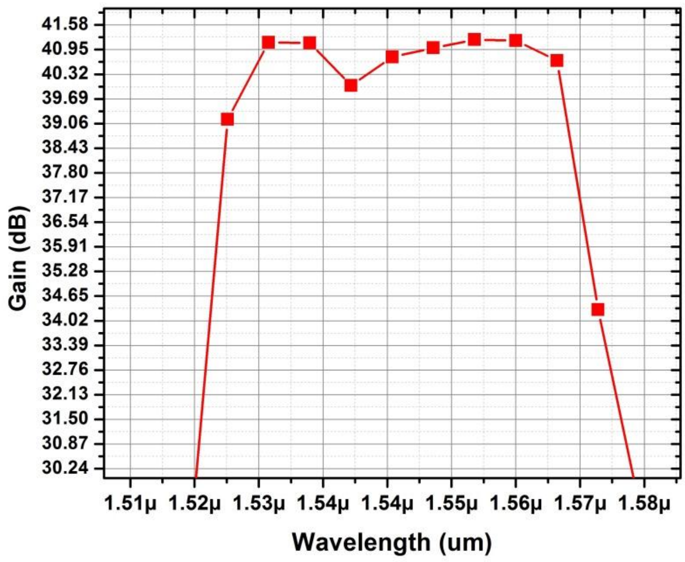

***Fig. 6:** Gain spectra of HOA for different wavelength.*

Fig.7 shows the output optical power for different wave- lengths from 1530 nm to 1565 nm.Fig.8 shows the Noise Figure spectra of HOA for different wavelengths and it is observed that the noise figure across the C-band (1530 nm-1565 nm) keeps decreasing with increase in wavelength. Comparisons of proposed work with previously published papers of getting flat gain on conventional band (C-band) using different techniques shown in Table III. The flat gains provided by other techniques give flat gain below 30 dB in almost all the cases while flat gain provided by the proposed link gives average of 40 dB gain for entire C-band.

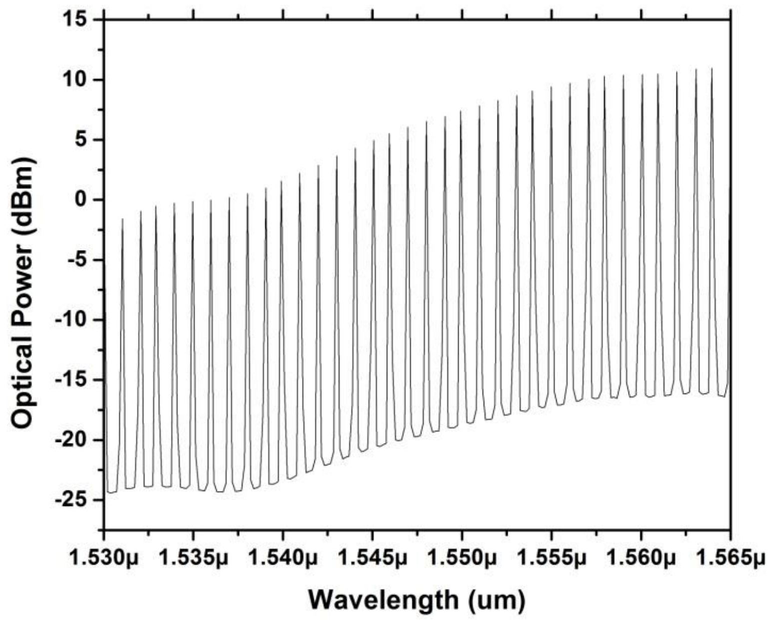

***Fig. 7**: output optical spectrum of the DWDM system*

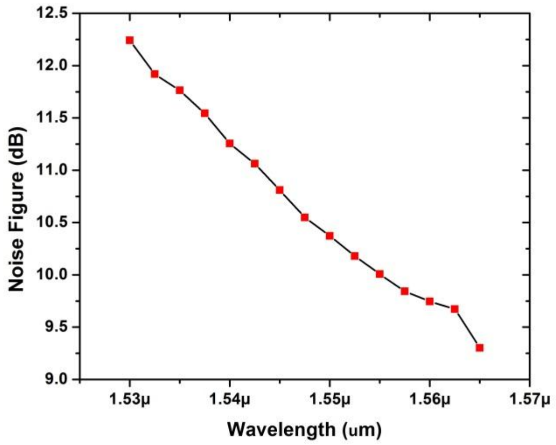

Fig. 8: *Effect of increment of wavelength on noise figure of the system.*

CONCLUSION

In this paper, a hybrid optical amplifier is proposed using a raman amplifier and EDFA with input power of 3mW which provides a gain > 40 dB with variation <1.2 dB over the entire C-band, i.e. from 1530 nm to 1565 nm. The proposed link provides the highest gain value ever reported over C-band, which gives cost effective solution in design of optical link.

Table 3: *Brief comparison of proposed work with early reported work.*

Reference	Technique	Range of wavelength with flat gain	Average Gain
[1]	Zr based erbium doped Fibre and Semiconductor Optical Amplifier	1530 nm to 1560 nm	28 dB
[2]	Combining two differently doped fibres	1530 nm to 1560 nm	18 dB
[3]	Fluoride-based erbium-doped Fibre amplifier	1532 nm to 1560 nm	26 dB
[4]	Bismuth-based erbium-doped Fibre amplifier	1530 nm to 1620 nm	10 dB-13 dB
[5]	Using all-fibre acousto-optic tuneable filters	1530 nm to 1565 nm	22.5 dB
[6]	Using long-period grating filter	1530 nm to 1570 nm	22 dB
[7]	Double-pass configuration With an IsoGain erbium-doped fibre (EDF)	1528 nm to 1568 nm	25 dB
[8]	Temperature insensitive broad and flat gain C-band EDFA based on macro-bending	1530 nm to 1565 nm	25 dB
[9]	Using microbending long-period fibre gratings	1525 nm to 1558 nm	30.2 dB
[10]	Erbium doped fibre amplifier With flexible selective band	1530 nm to 1565 nm	19 dB
Proposed work	Hybrid Optical amplifier	1530 nm to 1565 nm	40 dB

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