Gain and Noise Figure Enhancements of both C and L Bands Double Pass Erbium Doped Fiber Amplifier

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Abstract

In this study, designed and optimized C and L band Erbium Doped Fiber Amplifiers (EDFA) around 70 nm bandwidth, 36.53 dB average gain with an average noise figure of 5.8 dB properties are used. For this purpose, 16 channels Wavelength Division Multiplexed (WDM) system with channel spacing of 5.3 nm is taken into account. -30 dBm powers at the input signals (1530 nm- 1610 nm) are applied to three port filter and then input signals are separated into C and L bands. Each band signals are separately amplified in double pass configuration. Finally, all signals are combined into a coupler and the overall configuration has wide bandwidth, high gain and low noise.

1. Introduction

Nowadays, fiber optic components are frequently used in communication systems. These systems have many properties such as high capacity, wide bandwidth, and fast transmission. However, due to the attenuation of the fiber cable in the transmission line with a length of 100 km, optical repeater must be used in such kind of systems. EDFAs are the most commonly used popular optical repeaters because of its attractive properties such as simple, compact structure, high gain, and low noise figure. They are generally used in C band (1530-1565 nm) but with the increasing demand, it can also be used in L band (1570-1610 nm) region. Therefore, longer transmission lines are necessary in the ultra-long fiber optic communication. Hence, high optical gain, low noise figure, and wide bandwidth are desired for such kind of systems.

In literature, there are many studies implemented about EDFA applications and optical gain which is one of the most important characteristic quantities [1-23]. These are single pass EDFA [24-26], double pass EDFA [27-31], many pass EDFA configurations [32-34], artificial intelligence applications [35-38], and temperature characterization [39-43]. In addition, some studies are related to both gain improvement and noise figure in double pass EDFA [44-52]. Yucel et. al. proposed a new and simple C band double pass technique in studies [53-54], Liang et. al. obtained a high clamped gain and low noise figure implemented using a fiber Bragg grating in L band EDFA [55]. Chang et. al. proposed a dual pumped double-pass L-Band EDFA with high gain and low noise figure [56]. Yi et. al. improved the gain and noise figure in double-pass L-band EDFA by incorporating a fiber Bragg grating [57]. Zhang et. al. developed the noise figure with a double-pass EDFA by using a Hi-Bi fiber loop mirror as ASE rejecter [58]. Harun et. al. proposed an efficient and low noise double-pass L-Band EDFA in their studies [59-61].

In this study, the gain and noise figure of both C and L bands double pass EDFA configuration is improved and simulated by OptiAmplifier 4.0 software. As a result of it, high gain, low noise figure and wide bandwidth are obtained. In addition, this configuration can be applied to practical applications.

2. Simulation Setup

A conventional and new double pass C+L band EDFA configuration schemes are respectively shown in Figure 1 (a) and (b).

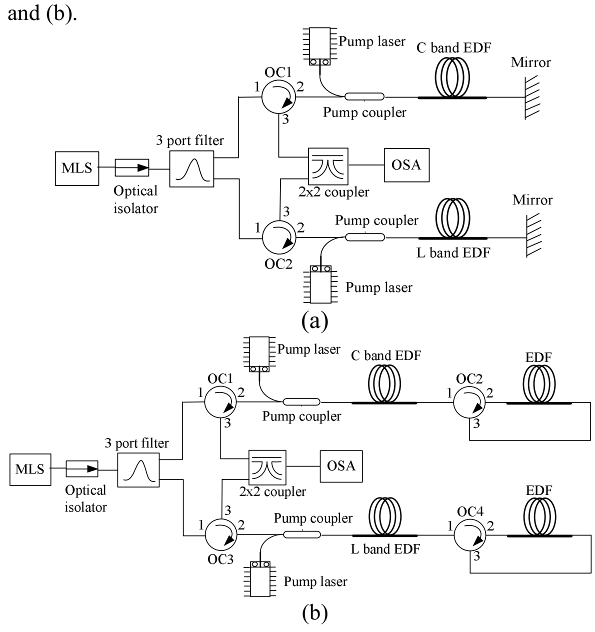

Fig. 1. C+L band EDFA configurations, (a) conventional, (b) new configuration.

In Figure 1 (a), conventional C+L band double-pass scheme has two optical circulators (OC) which have 3 ports in each arm (C and L band). Optical circulator is located at end of 3 port filter in this configuration. The input signals are applied into a multiple laser source (MLS) and passing through port 1 to port 2 of optical isolator which blocks back reflections, then the input signal applied to 3-port filter and finally C and L band signals are separated. C band signals passing through port 1 to port 2 of OC1 are combined with the pump signal through a pump coupler, and then, these signals are entered as inputs of the C band EDF which has the properties given in Table 1. The amplified signals are reflected by the faraday mirror that is located at the output end of the C band EDF. 100% reflected signals enter into C band EDF again. Following the same procedure, all signals return to port 2 of OC1 and then passing port 2 to port 3 by reaching to optical spectrum analyzer (OSA). The same process is performed in the same way in the other arm. L-band EDF characteristics are also given in Table 1. Pump laser used has 1480 nm wavelength and 100 mW power in all the configurations.

Proposed C+L band double pass EDFA configurations are shown in Figure 1 (b). This configuration is different from the conventional configuration via its short length EDF of the output return loop of optical circulators (OC2 and OC4). In addition to that, all materials and the parameters are the same as in Figure 1 (a). EDF characteristics are given in Table 1.

Table 1. All EDF properties.

Parameters	C band EDF	L band EDF	EDF
Fiber length	9.5 m	60 m	3 m
Erbium concentration	227 ppm	300 ppm	466 ppm
Erbium radius	1.68 µm	1µm	1µm
Core radius	1.77 µm	1µm	1µm
Numerical aperture	0.19	0.31	0.31
Life time	10 ms	10 ms	10 ms

3. Results and Discussions

Figure 2 shows that the optical gain spectrum of the two configurations for the -30 dBm of 1530-1610 nm input signals, in which the solid and dashed lines represent the gain spectrum in the conventional and proposed double pass EDFA configurations, respectively.

The gain along C+L band nm is averagely enhanced by 14 dB in comparison with that in conventional double pass configuration. This enhancement varies between 4 to 25 dB. In addition, the gain spectrum of the proposed scheme is flattened; however, the gain spectrum of the conventional model is not flat. In the simulation, the results for all configurations are measured at the same operating conditions such as EDF lengths, pump powers, pump wavelengths, input signal powers and wavelengths.

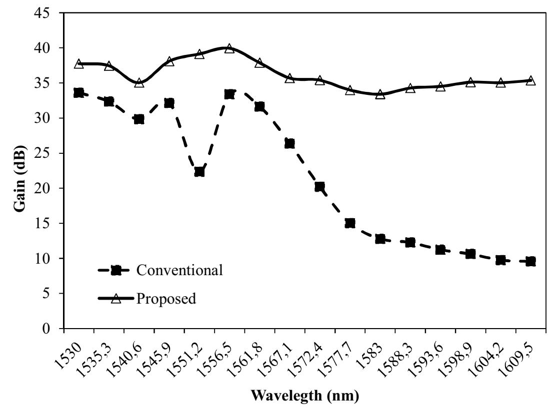

Fig. 2. The comparison of the gain spectrum of both configurations.

Figure 3 shows the noise figure spectrum of the two configurations for the same input signals, in which the solid and dashed lines represent the noise figure spectrum in the conventional and proposed double pass EDFA configurations. The conventional double pass EDFA configuration amplifies the signal; however, the background amplified spontaneous emission (ASE) is too strong because of the increased noise figure. As it can be seen in Figure 3, the traditional system, noise figure has been considerably higher in particular L-band. In contrast, the proposed system has an average of 5.8 dB noise figure for both C+L bands. The proposed system is better than the traditional system along all wavelengths.

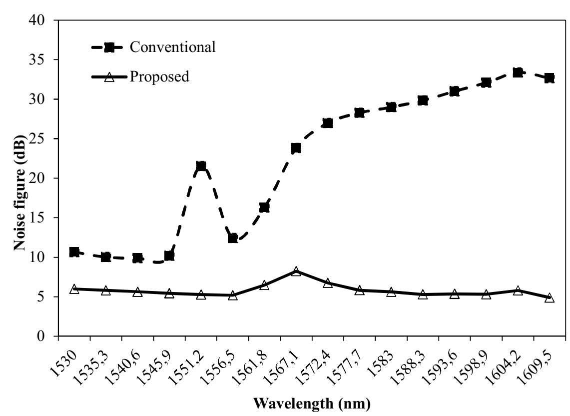

Fig. 3. The comparison of the noise figure spectrum of both configurations.

The noise figure of the C+L band signals are reduced because of the output loop in OC2 (for C band arm) and OC4 (for L band arm). The amplified ASE signals in the C band and L band EDF are attenuated in EDFs for each arm. Thus, it is useful to achieve a low noise figure in proposed configuration as well as high gain. The noise figure is calculated by the below formula [54];

$$NF = \frac{1}{G} + \frac{P_{ASE}}{Gh\nu\,\Delta\nu} \tag{1}$$

where G is the gain of EDFA , P_{ASE} is ASE power, h is Plank constant, ν is signal frequency and, $\Delta\nu$ is the frequency bandwidth. However, ASE power must be defined for both forward (P_{ASE}^{+}) and reverse direction (P_{ASE}^{-}) for the traditional double pass EDFA and total ASE power is [54, 62]:

$$P_{ASE} = P_{ASE}^{+} + P_{ASE}^{-} \quad (2)$$

In the proposed system, depending upon the lengths of the fibers obtained from the first pass of the signal, the gain of the amplifier is [43, 54, 61-64]:

$$G_{(f)} = \frac{P_{s(f)}(L_1) + P_{s(f)}(L_2)}{P_s(0)} = \exp(-\alpha_s (L_1 + L_2)).$$
$$\exp\left(\frac{h\nu_s}{P_s^{IS}} \left[\frac{P_p(0) - P_p(L_1) - P_p(L_2)}{h\nu_p} + \frac{(P_s(0) + P_{ASE}^{\pm}(0)) - (P_{s(f)}(L_1) - P_{s(f)}(L_2) + P_{ASE}^{\pm}(L_1) + P_{ASE}^{\pm}(L_2))}{h\nu_s} \right] \right) \quad (3)$$

where, $G_{(f)}$ is forward gain, $P_{s(f)}$, P_p are signal and pump power at the forward direction, respectively. α_s is absorption of the signal, L_1, L_2 are the lengths of C or L band EDF and second EDFs, respectively, ν_s and ν_p are the signal and pump frequencies. P_s^{IS} is the intrinsic saturation power of the signal. In the proposed system, the EDFs loop mirror is used as the reverse direction ASE power rejecter.

4. Conclusion

In this study, the proposed double pass C+L bands EDFA combining with an EDF in the output loop of the second circulator for each arm has been analyzed. With this configuration, the double pass EDFA gain is increased and noise figure is reduced. 4.15-25.29 dB gain improvement is obtained for C+L band signals with an input power of -30 dBm, and the decrease in noise figure is between 4.66-27.76 dB for the same band. For the viewpoint of economical usage of pump power and short EDF lengths of the first and second section, the proposed system may play an important role in the development of practical C+L band double pass EDFAs.

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