All-Optical Gain Clamped Double-Pass L-Band EDFA Based on Partial Reflection of ASE

Sulaiman Wadi Harun,^{a)} Norhakimah Md Samsuri,
and Harith Ahmad

Photonics Laboratory, Department of Physics, University of Malaya

50603 Kuala Lumpur, Malaysia

a) wadi72@yahoo.com

Abstract: A new gain clamping scheme in double-pass L-band erbium-doped fiber amplifier (EDFA) based on partial reflection of amplified spontaneous emission (ASE) into the EDFA is demonstrated using a narrowband fiber Bragg grating as an ASE reflector. The proposed amplifier achieves a good gain clamping characteristic up to -12 dBm of input signal power with gain variation of less than 0.5 dB from a clamped gain of 22.0 dB. The noise figure within the gain-clamping region is maintained below 5.0 dB. The low noise figure is achieved since the proposed amplifier is not based on lasing mechanism. The proposed amplifier is also expected to be free from the relaxation oscillation problem.

Keywords: gain clamping, double-pass amplifier, L-band EDFA

Classification: Photonics devices, circuits, and systems

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1 Introduction

In order to cope with the rapidly growing demand for transmission capacity, the long-wavelength band (L-band, 1570 to 1600 nm) region of the erbium-doped fiber amplifier (EDFA) is about to be widely used in wavelength division multiplexing (WDM) systems, together with the conventional-band (C-band, 1530 to 1560 nm) region [1]. Terabit/s WDM transmission systems have been recently demonstrated by utilizing both C-band and L-band [2]. However L-band EDFAs have lower power conversion efficiency compared with a C-band EDFA due to their operating wavelengths that are far away from the Er^{3+} peak absorption at 1531 nm. Therefore, a double-pass L-band EDFA has been introduced in our earlier work to improve gain in this region [3]. Besides gain improvement, the amplifiers for the WDM systems must also be able to manage optical gain variation of surviving channels due to dynamic add/drop or abrupt failure of the other signal channels.

Recently, a double-pass gain clamped L-band EDFA based on a ring laser configuration has been introduced to solve the gain variation problem [4]. However, the gain clamped amplifier has two shortcomings resulting from the lasing mechanism. One is that it has a relatively high noise figure since the population inversion is clamped at low value. The other is that surviving channels have to experience transient power excursions due to relaxation oscillation. In this paper, an all optical gain-clamped L-band EDFA scheme based on reflecting of backward amplified spontaneous emission (ASE) into the EDFA is proposed and experimentally demonstrated using a fiber Bragg grating (FBG) at input end of the second stage. Due to non-optical cavity structure, the proposed gain-clamped EDFA should be free from the two shortcomings.

2 Configuration of the L-band EDFA

The schematic diagram of the gain-clamped double-pass L-band EDFA is shown in Fig. 1. The configuration is a two-stage amplifier, which is forward pumped by 980 nm laser diodes. Both erbium-doped fibers (EDF1 and EDF2) are an alumina-silicate EDF having an absorption coefficient of 6.1 dB/m at 1531 nm. EDF1 and EDF2 have a length of 12 m and 50 m and are pumped at 68 mW and 102 mW, respectively. Two wavelength selective couplers (WSCs) are used to combine the 980 nm pump from each laser diode with the test signal. A broadband FBG (FBG2) with a reflectivity of more than 92% and a bandwidth of 44 nm centered at 1587 nm is employed at the output end of EDF2. It retro-passes the test signal back into the system for gain enhancing. A narrowband FBG (FBG1) with a reflectivity of 99.9% and a 3 dB bandwidth of 0.2 dB centered at 1560.7 nm is incorporated at the input end of the second stage. It reflects a portion of backward ASE from EDF2 back into the amplifying stage for gain clamping. An optical circulator (OC) is placed between the two stages to route the amplified signal into optical spectrum analyzer (OSA). It also prevents the backward ASE of second stage from entering the first stage. A tunable laser source (TLS) is used for the

evaluation of the amplifier performances in conjunction with an OSA. The amplifier performance is also measured for an unclamped amplifier, which is obtained by removing FBG1, for comparison purposes. Fig. 2 shows the reflection spectra of both broadband and narrowband FBGs.

Fig. 1. Experimental set up.

Fig. 2. Reflection spectra of both broadband and narrowband FBGs.

3 Results and discussion

In order to evaluate the gain clamping and noise performances, the gain and noise figure are measured as a function of input signal power. The input signal wavelength is set at 1580 nm. As shown in Fig. 3, the signal gain is practically constant for small input signal powers. This value is treated as the maximum signal gain, and the critical power is defined as the maximum input signal power which causes the gain to decrease by 0.5 dB from its maximum value. As the input signal power increases, the solid square symbols that represent the unclamped amplifier drops very quickly ($P_{\text{crit}} = -24$ dBm),

on the other hand, the solid circle symbols that denote the gain-clamped amplifier changes very little ($P_{\text{crit}} = -12$ dBm). About 22.0 dB of a clamped gain is achieved by the proposed amplifier with gain variation of less than 0.5 dB till input signal power increases up to -12 dBm. The high clamped-gain level is obtained due to the fact that the test signal is amplified twice in different directions in the second stage of the system, and the total gain is significantly increased due to the increase in effective EDF length. The output power is measured in the range of -17.9 to $+9.5$ dBm as input signal power increases from -40 to -12 dBm.

The gain clamping is due to the incorporation of FBG that reflects a portion of backward ASE from the second stage. The reflected ASE goes back into the second stage EDFA and amplified while passing through the EDFA. Intensity of the reflected ASE is strongly dependent on the intensity of the externally applied signal. It is maximum in case of no external signal. When external signal is launched into the EDFA, it consumes a part of the amplifier gain, then the intensity of backward ASE decreases. As a result, the intensity of the reflected ASE decreases. Because of this all-optical complementary property of the two signal intensities up to some input intensity level of the externally applied signal, the total intensity remains constant automatically. Therefore, the amplifier gain can be fixed regardless of the externally applied signal intensity as shown in Fig. 3. Amplifier power loss due to the FBG is negligible because the proposed gain-clamped amplifier has the same gain as the unclamped amplifier has for saturated input power range around 0 dBm.

Compared to the unclamped amplifier, the proposed amplifier has similar or a little better noise figure at input signals less than -12 dBm as shown in Fig. 3. The noise figure level is also relatively lower compared to that of previously reported gain-clamped double-pass amplifier [4]. This is attributed to

Fig. 3. Gain and noise figure (NF) as a function of input signal power.

there is no population inversion degradation due to lasing mechanism. Both gain-clamped and unclamped amplifiers have maintained the noise figure of below 5.0 and 5.1 dB, respectively at input powers of less than -12 dBm as shown in the figure. This is attributed to the placement of optical circulator OC between the two stages, which prevents the amplified signal and backward ASE from propagating into the EDF1. Therefore the population inversion of the input part of the amplifier is hardly affected by the intense lights and the noise figure could be kept low. The proposed amplifier is also expected to have no relaxation oscillation-related power variation because it is not based on lasing mechanism.

4 Conclusion

A gain-clamped double-pass L-band EDFA with high clamped gain and low noise figure has been presented based on reflecting ASE using a narrowband fiber Bragg grating. The high gain is obtained due to the incorporation of the broadband FBG operating at L-band region to retro-pass the test signal back into the system. The gain clamping is achieved by reflecting a portion of backward ASE back into the system. The gain is clamped at 22.0 dB from -40 to -12 dBm with a gain variation of less than 0.5 dB and a noise figure of less than 5.0 dB. Since the proposed amplifier is not based on lasing mechanism, it could achieve the low noise figure and is expected to be free from relaxation oscillation problem.