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GAIN AND NOISE FIGURE PERFORMANCES OF L-BAND EDFA WITH AN INJECTION OF C-BAND ASE

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Abstract. The effect of injecting conventional band amplified spontaneous emission (C-band ASE) on the performance of long wavelength band erbium-doped fiber amplifier (L-band EDFA) is demonstrated. A circulator and a broadband fiber Bragg grating (FBG) were used to route a C-band ASE into the amplifier system. Injection of a small amount of ASE (attenuation of 20 dB and above) improves the small signal gain with a negligible noise figure penalty compared to that of an amplifier without the ASE injection. A maximum gain improvement of 3.5 dB is obtained at an attenuation of 20 dB for signal wavelength of 1580 nm. At very large amount of ASE injection (VOA=0 dB), the gain of the amplifier is clamped at 15.2 dB from –40 to –10 dBm with a gain variation of less than 0.3 dB. The saturation power is also increased from –8 dBm (for without ASE injection) to 2 dBm (VOA=0 dB) with a slight noise figure penalty. These results show that the ASE injection technique can be used either for gain improvement or gain clamping in L-band EDFA.

Keywords: Gain clamping, optical amplifier, L-band EDFA, gain enhancement, amplified spontaneous emission

Abstrak. Kesan suntikan pancaran spontan terkuat (ASE) jalur-C terhadap prestasi jalur-L penguat gentian terdop-erbium (EDFA) ditunjukkan. Sebuah pekeliling dan parutan gentian Bragg lebar jalur luas digunakan untuk menyalurkan ASE jalur-C ke dalam sistem penguat. Dengan penyuntikan sejumlah kecil ASE (20 dB pelemahan dan lebih), gandaan isyarat kecil ditingkatkan tanpa peningkatan nilai hingar berbanding penguat tanpa suntikan ASE. Peningkatan gandaan maksimum adalah sebanyak 3.5 dB dan dicapai semasa pelemahan 20 dB untuk isyarat 1580 nm. Walau bagaimanapun, jika penguat disuntik dengan jumlah ASE yang besar (VOA=0 dB), gandaan penguat didapati mendatar pada 15.2 dB dari –40 hingga –10 dBm dengan variasi gandaan kurang daripada 0.3 dB. Kuasa tepu juga bertambah dari –8 dBm (semasa tiada ASE) kepada 2 dBm (VOA=0 dB) dengan sedikit peningkatan nilai hingar. Keputusan ini menunjukkan bahawa teknik menyuntik ASE boleh digunakan sama ada untuk meningkatkan gandaan atau untuk menetapkan nilai gandaan dalam EDFA jalur-L.

Kata kunci: Penetapan gandaan, penguat optik, EDFA jalur-L, penambahan gandaan, pancaran spontan terkuat

1.0 INTRODUCTION

The need to extend the bandwidth of dense wavelength division multiplexing (DWDM) system has resulted in research aimed at transmitting outside the conventional

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wavelength band (also known as the C-band, ranging from 1530 to 1565 nm). Transmission in the region of 1570 to 1610 nm (referred to as the L-band), which effectively doubles the potential bandwidth, has been reported [1]. A wide band amplifier can be constructed by combining the C- and L-band erbium-doped fiber amplifier (EDFA) in parallel. However, the L-band lies at the tail of the erbium amplification window, where the inversion rate is low. Therefore, the L-band requires longer erbium-doped fibers (EDFs) to obtain the same gain as that obtained by a C-band EDFA. Recently, efforts have been taken to develop an L-band EDF with a high erbium-doping concentration to reduce the fiber length. However, a high concentration of erbium ions may result in pair-induced quenching effects [2], which potentially reduce the pump power conversion efficiency and degrades the noise figure for an EDFA. Another effort to reduce fiber length involves the use of unpumped EDF [3] and double pass technique [4].

As the complexity of the networks increases in DWDM networking, a major potential problem associated with the amplifier is the need for the control of the gain of EDFAs due to circumstances such as faults, adding and dropping of wavelength, and rerouting. In these cases, the total input signal power to the amplifier varies abruptly causing the dynamics of the population inversion to change accordingly. Therefore, the amplifier gain increases or reduces with the potential to cause receiver saturation or bit error rate increment. Thus, a gain-clamping mechanism is desired. To date, there have been various research efforts to clamp the gain in C- and L-band EDFAs [5-6]. In this paper, we demonstrate the effect of injecting a C-band ASE on L-band EDFA. This ASE injection technique shows a possible application either for gain improvement or gain clamping in L-band EDFA.

2.0 EXPERIMENTAL SET UP

The experimental setup is shown in Figure 1. The erbium-doped fiber (EDF) used in the experiment is commercially available and has a numerical aperture (NA) of 0.22, cut-off wavelength of 920 nm, and peak absorption of 6.1 dB/m at 1531 nm. The length of EDF is fixed at 50 m. A 980 nm laser diode is used as a pump source with a

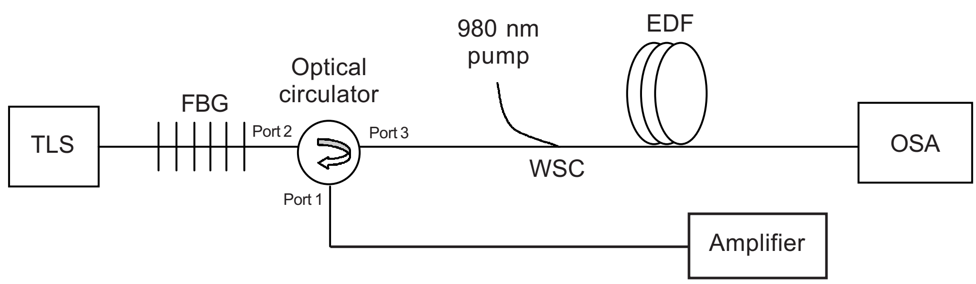

Figure 1 Experimental set up

maximum pump power of 92 mW at the EDF input end. The wavelength selective coupler (WSC) combines the input test signal and the 980 nm pump into the EDF. The C-band ASE from a C-band EDFA is fed into the EDF section using an optical circulator and a fiber Bragg grating. At the amplifier input end, a broadband FBG with a center wavelength, bandwidth and reflectivity of 1545 nm, 40 nm, and 99% respectively, is employed as a broadband reflector. The measured reflection spectrum of the FBG is shown in Figure 2. The forward ASE light from the C-band EDFA is routed by the optical circulator, reflected by the grating and then co-propagated with the signal. A variable optical attenuator (VOA) is used to control the power level of the launched C-band ASE. A tunable laser source (TLS) is used for the evaluation of the amplifier performance in conjunction with an optical spectrum analyzer (OSA), which uses the interpolation technique to evaluate noise figure.

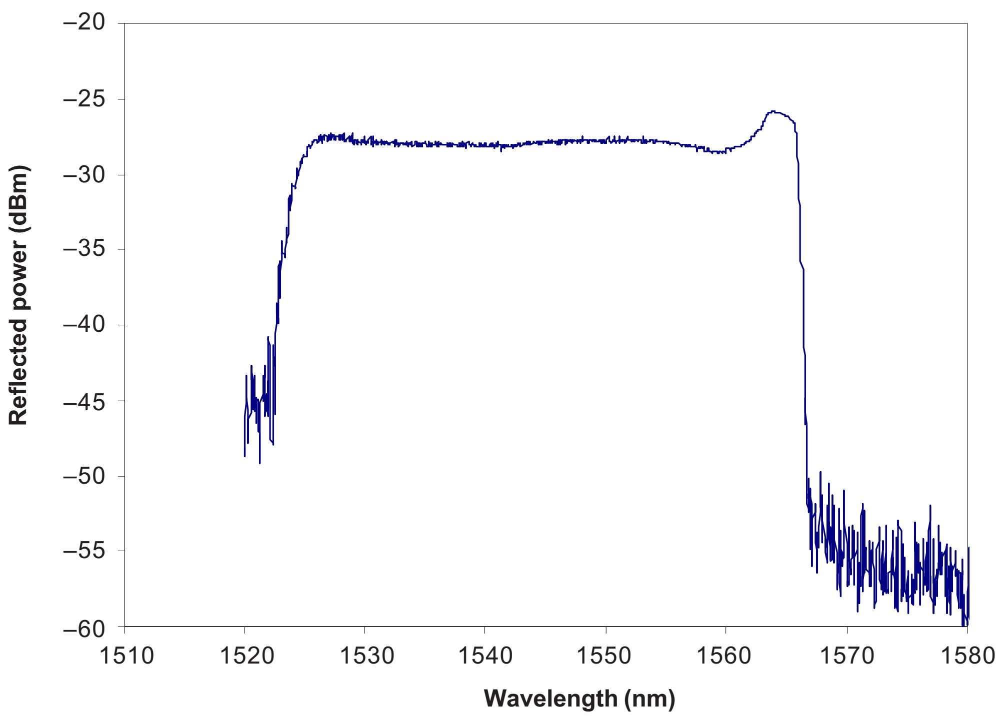

Figure 2 Reflection characteristics of the FBG

3.0 RESULT AND DISCUSSION

Figure 3 depicts the ASE spectra of the amplifier with and without an injection of C-band ASE, where the thick line represents the amplifier without ASE. The pump power is fixed at 92 mW. As apparent in the figure, the amplifier with a large amount of ASE injection (VOA = 0 dB) shows a lower L-band ASE than that of the amplifier

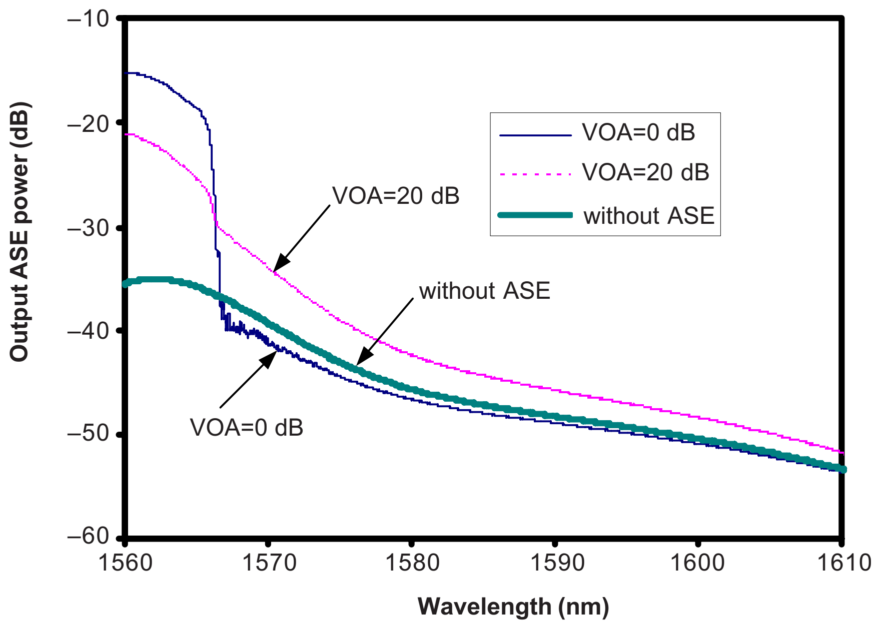

Figure 3 ASE spectra of the amplifier with and without C-band ASE

without ASE injection, at the L-band region (above 1567 nm). This reduction of L-band ASE is obtained due to the injection of a large amount of C-band (1525 to 1567 nm) ASE that causes limitation of population inversion at the longer wavelength region. The large increase in ASE below 1567 nm is due to the FBG. The excess power of the injected C-band ASE is included in the measured output ASE. However, the injection of low power of ASE (VOA = 20 dB) dramatically increases the ASE level at the L-band region. The ion population inversion is increased by this amount of ASE through energy transfer from short wavelength to longer wavelength.

Figures 4 and 5 show the optical gain and noise figure characteristics at 1580 nm respectively, as functions of input signal power against the VOA losses. The pump power is fixed at 92 mW. The characteristic of the amplifier without the injection of backward ASE is also shown for comparison. Figure 6 shows the small signal gain and noise figure against the VOA loss respectively, when input signal power and wavelength are fixed at –30 dBm and 1580 nm, respectively. At attenuations of 20 dB and above, the gain level increases with the amount of the injected ASE power as shown in Figures 4 and 6. The small signal gain improvement of 3.5 dB is obtained for the attenuation of 20 dB compared to the amplifier without the ASE injection. Figure 7 shows an injected ASE spectrum at attenuations of 0 and 20 dB. The ASE power is –40 dBm at 1531 nm for the attenuation of 20 dB. This amount of ASE has increased the population ion inversion at the input end of the EDF, and hence, improves the L-band signal gains. This technique shows that the injection of C-band ASE (total power should be less than –14.1 dBm) can be utilized to enhance the L-band performance.

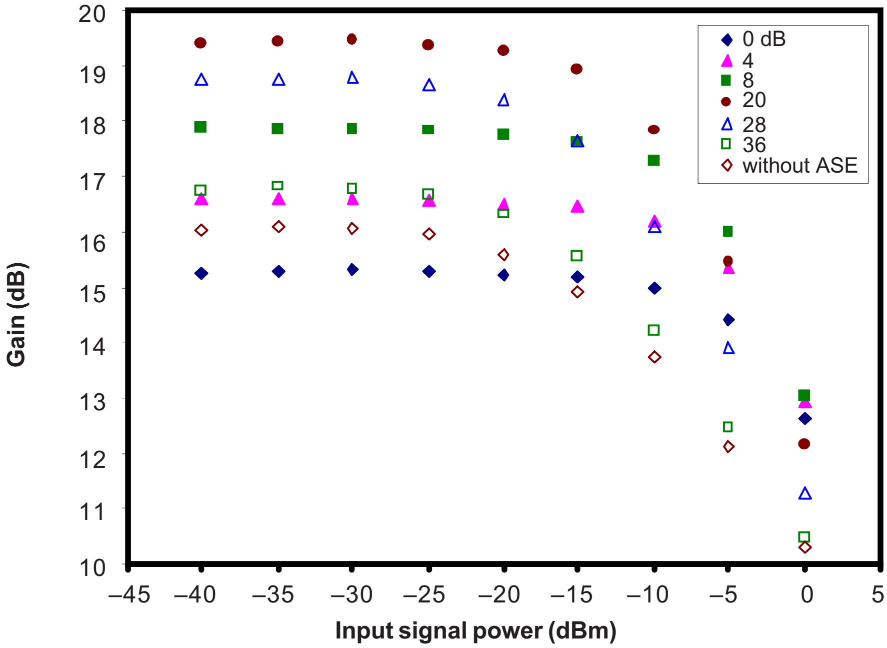

Figure 4 Gain as functions of input signal power at various VOA losses

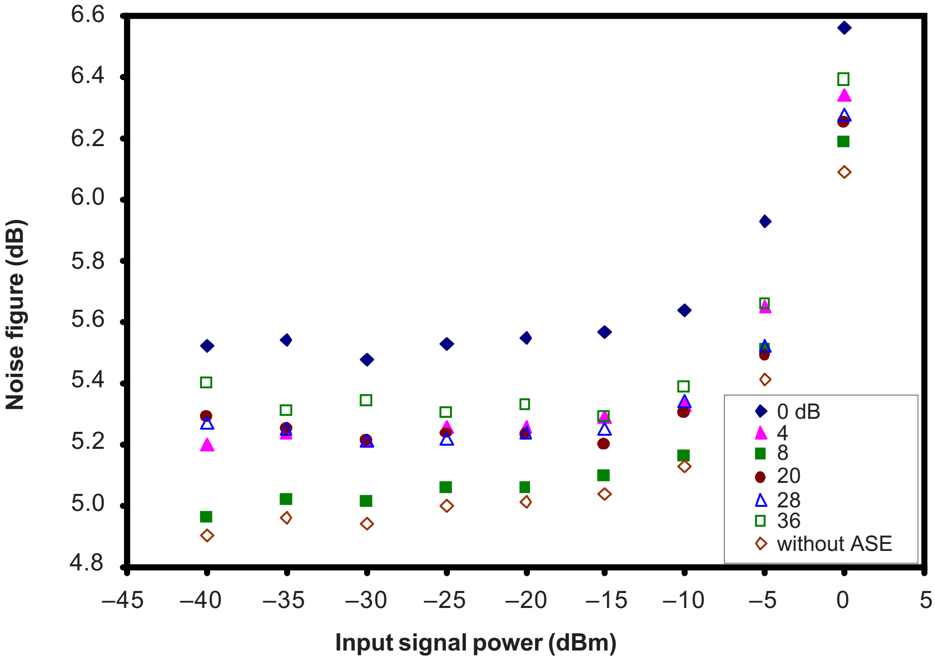

Figure 5 Noise figure as functions of input signal power at various VOA losses

Besides gain improvement, this technique also produces almost negligible noise figure penalties as shown in Figure 5.

However, the gain level is decreased for higher amounts of ASE (< 20 dB of attenuation) as shown in Figures 4 and 6. At attenuation of 0 dB (total ASE power of 6 dBm), the gain is clamped at 15.2 dB from –40 to –10 dBm with gain variation of less than 0.3 dB. The saturation power also increases from –8 dBm (for without ASE injection) to 2 dBm (VOA = 0 dB). The ASE power is measured to be –20 dBm at 1531 nm for attenuation of 0dB as shown in Figure 7. The L-band amplification mechanism is made possible by the intra-Stark level multi-phonon transitions and re-absorptions that transfer energy from the short wavelength (C-band) to the longer wavelength (L-band). Therefore, injecting a large amount of C-band ASE into EDF 1 depletes the number of ions in ground state. This limits the population inversion, which in turn reduces gain, thereby clamping the gain. A lower VOA loss enables a higher injected ASE power, which severely degrades the amount of available inversion. The noise figure for the gain clamped amplifier (VOA = 0 dB) is slightly higher at an average value of 5.5 dB, compared to the unclamped amplifier (without injection of ASE) as shown in Figures 5 and 6. A large amount of injected ASE induces an incomplete population inversion in the EDF as given by the inversion parameter $n_{sp} = \{\sigma_e(\lambda)N_2\} / \{\sigma_e(\lambda)N_2\text{-}\sigma_a(\lambda)N_1\}$, where σ_e is the emission cross section, σ_a is the absorption cross section, N_2 is the population density of the upper state, and N_1 is the population density of the lower state, which leads to the noise figure degradation.

Figure 8 shows the gain and noise figure as functions of input signal wavelength for amplifiers with and without ASE. The input signal power is fixed at –30 dBm. The

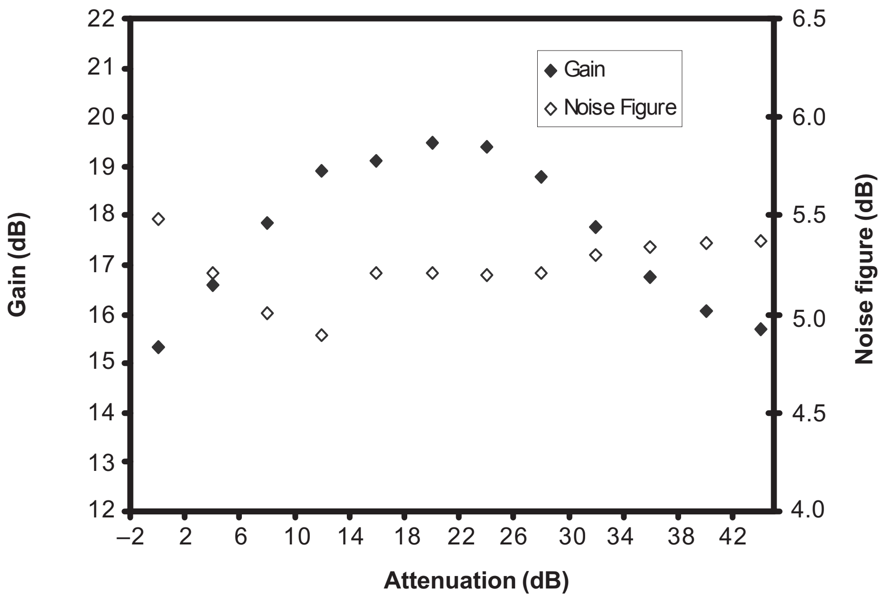

Figure 6 Gain and noise figure against the VOA loss

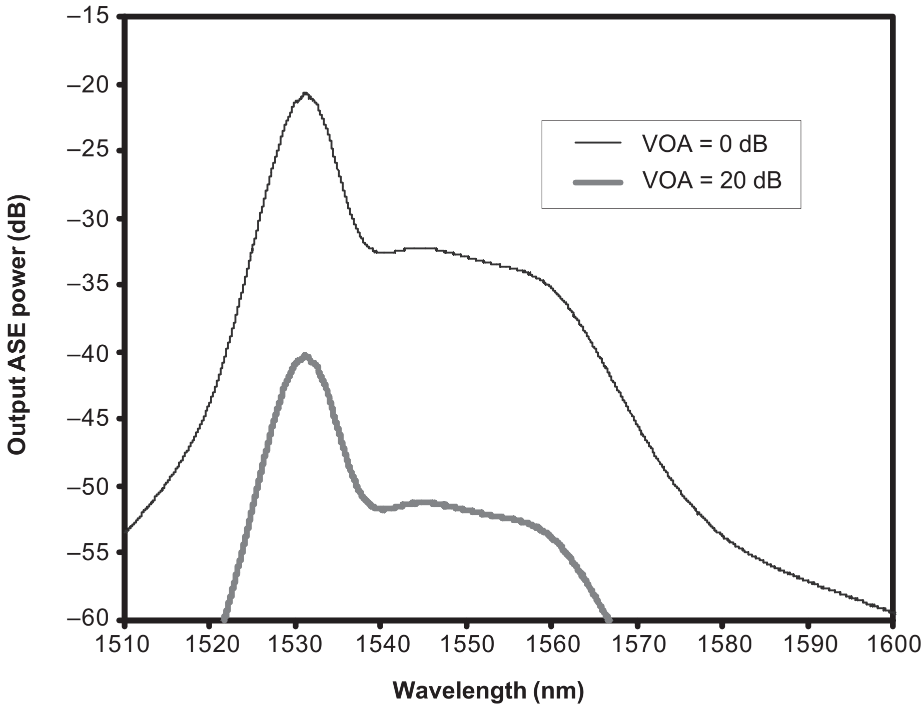

Figure 7 Injected C-band ASE spectrum at attenuations of 0 and 20 dB

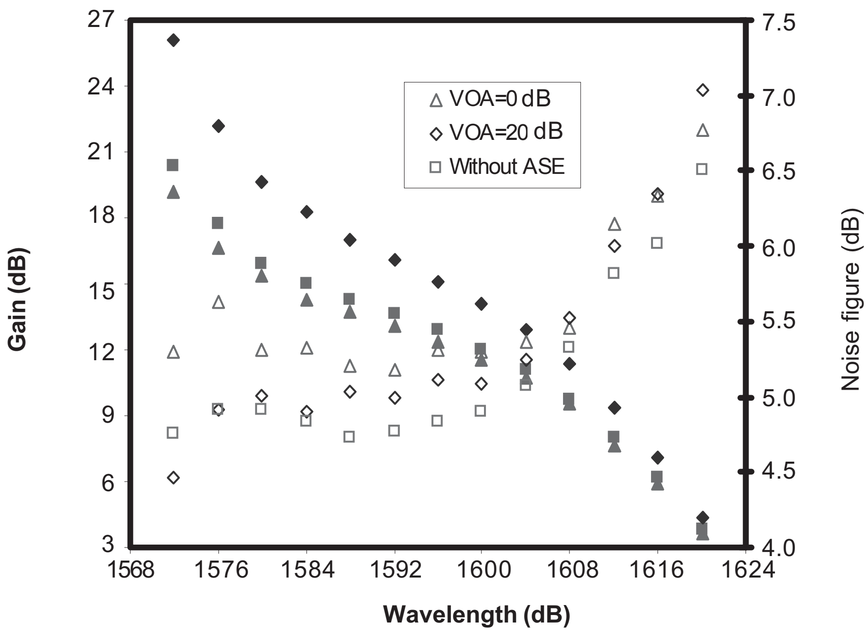

Figure 8 Gain and noise figure as functions of input signal wavelength

gain reduction is observed for the amplifier with VOA = 0 dB particularly at shorter wavelength. The noise figure penalty is also higher at shorter wavelengths. This is attributed to the gain clamping effect, which is greater at the shorter wavelength. However, at VOA = 20 dB, the amplifier shows a gain improvement at whole input signal wavelength with negligible noise figure penalties. However, the gain improvement is higher at shorter wavelength due to the injected C-ASE powers that are higher at shorter wavelength. The maximum gain improvement of 6.9 dB is obtained at input signal wavelength of 1568 nm. The corresponding noise figure has also improved about 0.9 dB.

4.0 CONCLUSION

The effect of injecting C-band ASE on a L-band EDFA is demonstrated in this paper. Compared to the amplifier without the injected ASE, the amplifier with the ASE has shown a small signal gain improvement of 3.5 dB at attenuation of 20 dB with a negligible noise figure penalty at signal wavelength of 1580 nm. With the ASE injection at attenuation of 0 dB, the gain of the amplifier is clamped at 15.2 dB from –40 to –10 dBm with a gain variation less than 0.3 dB. The saturation power is increased from –8 dBm (for without ASE injection) to 2 dBm (VOA = 0 dB) with slightly noise figure penalty. These results show that the ASE injection technique has a possible application either for gain improvement or gain clamping in L-band EDFA.

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