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# Performance Improvement for Hybrid L-band Remote Erbium Doped Fiber Amplifier/Raman using Phase Modulator

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**ABSTRACT**

We have demonstrated the performance improvement of L-band hybrid remote Erbium-doped fiber amplifier by introducing a phase modulator to suppress the stimulated Brilloiun scattering (SBS) effect in the transmission. The transmission gain has improved by 12.65dB while the noise figure has reduced by 47.1dB when 0dBm signal power is generated at 1590.05nm wavelength. Furthermore, the optical signal-to-noise ratio has improved from 7.81dB to 29.72dB when the signal power is varied from -30dBm to 0dBm. By implementing a phase modulator to the input signal somehow able to produce better performance regarding gain, noise figure and optical signal-to-noise ratio, especially at the higher signal power as the gain, has been transferred to the Stokes signal and the amplified signal.



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## 1. INTRODUCTION

Owing to the ever increasing demand and greater bandwidth in telecommunication system leads to the longer distance of transmission distance in optical communication system. However, the effect of attenuation and dispersion in the transmission fiber cannot be eliminated as the signal light propagating through it. This results in some designs on discrete and remote optical amplifier particularly in C-band [1], [2], S-band [3] and L-band [4]-[6] region to overcome this effect. The dispersion effects can be eliminated by introducing dispersion compensating grating, zero dispersion fiber as well as dispersion shifted fiber. These techniques improve the signal performance when it reaches the transmission ends. Hybrid Raman/EDFA is one of the techniques that are used to improve the gain efficiency for the L-band with the integration of Raman amplification in the remote erbium doped fiber amplifier (R-EDFA) [7], [8].

EDFAs have introduced a longer transmission length due to its capabilities of improving the signal gain for even another thousands of kilometers. However, this also will introduce a variety of fibre nonlinearities such as stimulated Brillouin Scattering (SBS) [9], Raman scattering [10] and others. The phase noise will firstly increase drastically and then gradually become flat when the input power is above the SBS threshold. Many methods have been introduced to suppress the SBS such as by using phase modulation [11], fiber Bragg grating [12], using a linearly chirped diode laser [13], and etc. However, phase modulation is among the simplest technique and very effective.

This paper reported on the use of phase modulator to suppress the SBS effect in the L-band hybrid R-EDFA. A phase modulator with five different tones selection channels has been introduced at the input signal to overcome the SBS effect in the transmission. By using this simple technique, the work have proven that the amplified signal gain has improved significantly as well as the distributed Raman gain and the noise figure.

## 2. EXPERIMENTAL SETUP

Figure 1 shows the experimental setup for remote EDFA using single wavelength dispersion compensating grating (DCG). It consists of Tunable Laser Source (TLS), Raman Pump Unit (RPU), optical spectrum analyzer (OSA) and Optical Power Meter (OPM) as the optical devices involved in this experiment.

While for passive optical components consist of wavelength division multiplexing (WDM), C/L band couplers, L-band isolator, L-band circulators and DCG. An Erbium doped fiber with a numerical aperture of 0.22, a mode field diameter of 6.2µm, EDF with peak absorption coefficient of 39dB/m at 1530nm and a cut off wavelength of 923 has been used as the gain medium throughout the experiment. A 41km Truewave single mode fiber (SMF) has been used to generate the Raman amplification when the pump light generates from the RPU propagates through it. In this experiment, the pump light is propagated inversely with the signal light generated from the TLS. A 1590.05nm signal light will be propagated into the DCG and it will compensate the total dispersion during the light propagation. Futhermore, a phase modulator has been placed just after the TLS to overcome the stimulated Brilloiun scattering effect in the transmission line. The pump light and the signal light will be multiplexed together using C/L coupler for double pass amplification when propagating through that EDF. The amplified signal will then be circulated using a circulator into the Raman gain medium before producing the output that is measured using an OSA. The OSA will be used to measure the output performance such as transmission gain, Raman distributed gain, noise figure, optical signal-to-noise ratio and R–EDFA gain.

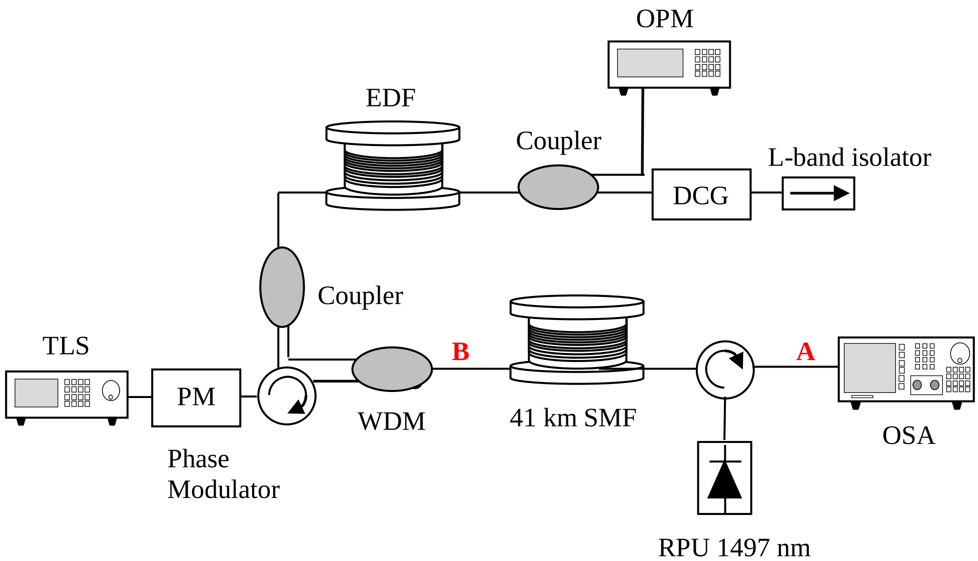


Figure 1. The experimental setup of the remote EDFA using single wavelength dispersion compensating grating.

## 4. RESULTS AND DISCUSSIONS

Figure 2 shows the transmission gain of the amplified signal when the input signal power is varied from -30dBm to 0dBm when the phase modulator is not implemented in the setup. The measurement is taken at Point A after the signal has gone through the double pass amplification in the EDFA and Raman amplification after propagating through 41km SMF. At low input signal which is equal to -30dBm, the transmission gain obtained is around 41.4dB and it keeps reducing as the signal power increases. At the highest signal power, which is around 0dBm, the transmission gain obtained is around 8.5dB. As can be seen in Figure 2, the gain reduced tremendously as the input signal increases. This is due to the presence of SBS effect which is more apparent at high input signal where the gain has been transferred to the Stokes signal and the amplified signal. This finally brings to inaccuracy to the data obtained due to this SBS effects.

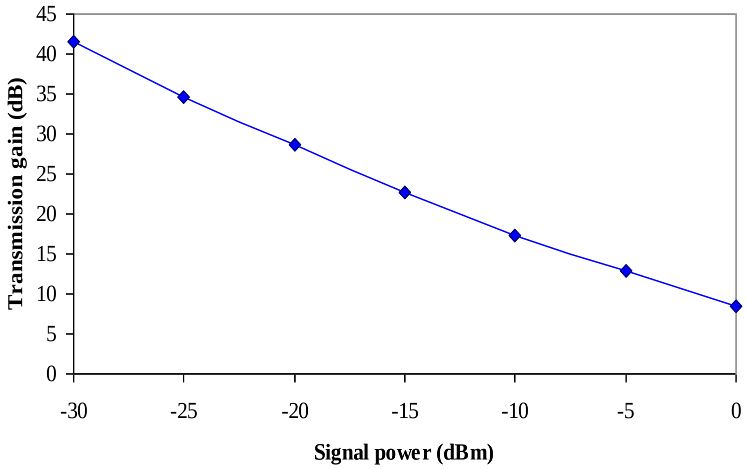


Figure 2. Transmission gain at different signal power with SBS occurrence

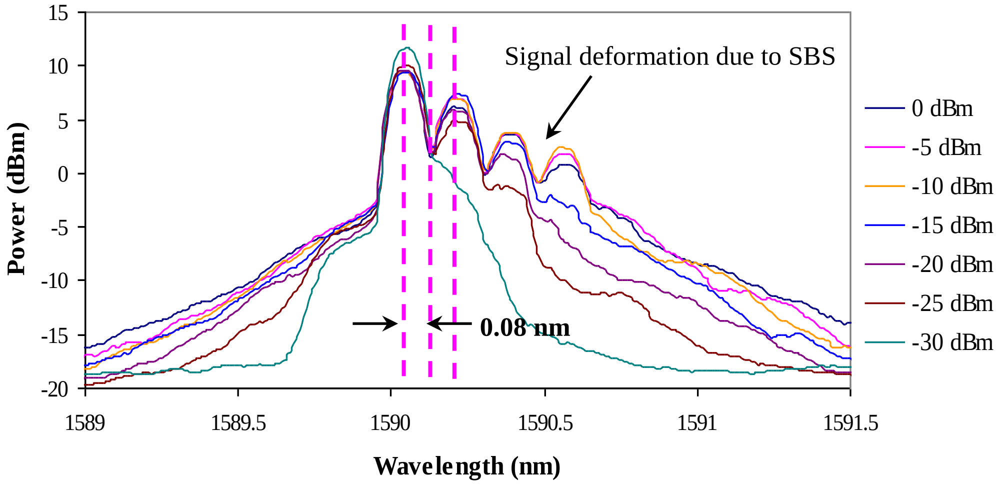


Figure 3. Output spectrum with SBS effect at different signal power

Figure 3 shows the output spectrum that is observed at point A where the SBS effect can be meaningfully observed with 0.1nm resolution bandwidth at optical spectrum analyzer. The accumulation of the transmission gain that is contributed by the R-EDFA gain and the Raman amplification contributes to the presence of this SBS effect. The summation of these two components exceeds the threshold for the SBS to take place. The narrow linewidth of the propagating signal also contributed to the occurrence of this SBS. All of these reasons induced the power transferred from the original signal to the first-order Stoke signal which is around 10GHz or 0.08nm spacing. It can be concluded that the SBS effect is more prominent at lower input signal due to the signal amplification.

Figure 4 and Figure 5 show the noise figure (NF) and optical signal-to-noise ratio (OSNR) with the existence of SBS at different signal power. It is clearly can be seen in the graphs have a reverse relationship between each other. The NF starts to increase when the signal power is increased while the OSNR starts to reduce when the signal power is increased. The highest NF of 53.5dB is obtained at the highest signal power due to the nonlinearity effect in the fiber. As the NF is increased, this finally brings to the worst OSNR as more noise is added to the amplified signal. When the signal power is equal to 0dBm, the OSNR of 6.38dB is attained. So, in order to abolish the SBS effects in the transmission, phase modulation technique has been introduced to broaden up the linewidth of the input signal by introducing a few frequencies to drive the phase modulator.

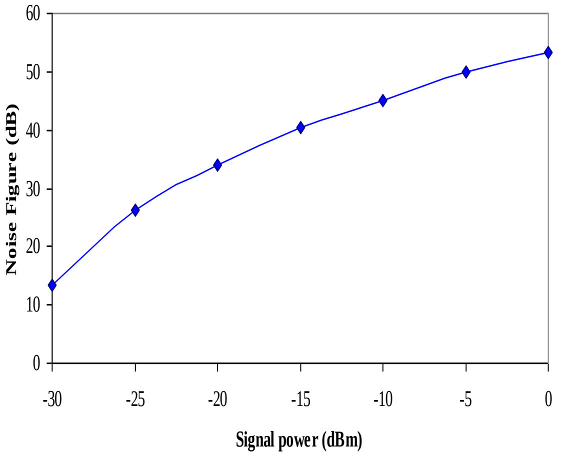


Figure 4. The overall NF when the signal power is varied from -30 dBm to 0 dBm with SBS occurrence

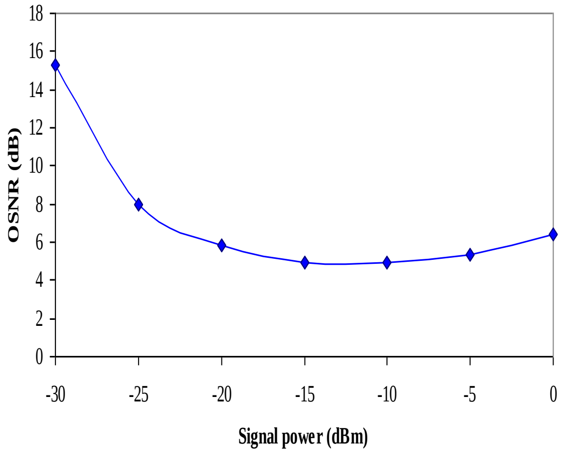


Figure 5. OSNR with the existence of SBS at different signal power

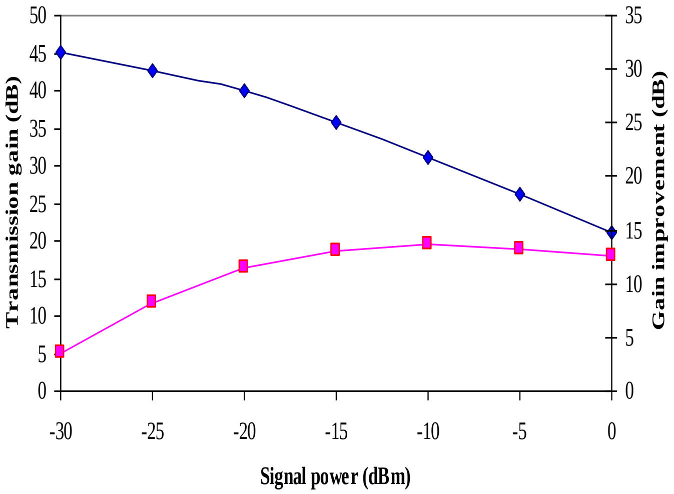


Figure 6. Transmission gain and gain improvement after suppressing the SBS in the transmission line

Referring to Figure 6, it is clear that the gain has improved drastically when a phase modulator is installed in the setup. The transmission gain at 0dBm signal is around 21.15dB and the gain has been improved by 12.65dB when the SBS has been suppressed. From the characterization, it is obtained that the SBS threshold power is around 8dBm. When the SBS occurred in the transmission line, a portion of the transmitted light is propagated back in the direction of the transmitter. This result in saturation to optical power at the receiver as well as problems related to back-reflection in the optical signal. So the installation of this phase modulator improved the gain transmission tremendously especially when the input signal is high (0dBm).

At low input signal which is around -30dBm, the measured transmission gain is around 45.11dB where the gain has been improved by 3.53dB. Nevertheless, the gain starts to reduce drastically when the signal power goes beyond the input saturation power which is referred to as -23dBm due to the saturation effect.

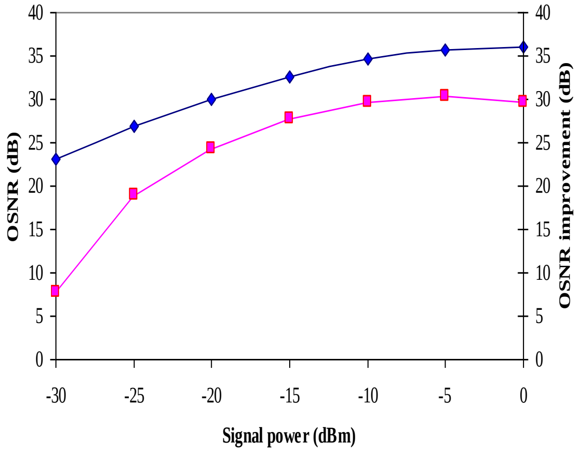


Figure 7. The OSNR with its improvement at different signal power

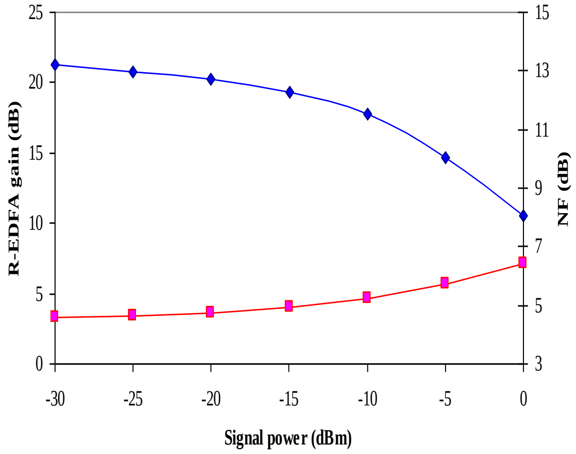


Figure 8. The R-EDFA and noise figure (NF) in a function of signal power

The OSNR together with its improvement in the function of signal power has been shown in Figure 7. It can be concluded that the OSNR improves enormously when the linewidth of the propagated signal is broadened up using phase modulator in the setup. The OSNR increases progressively from 23.07dB to 39.10dB when the signal power is varied from -30dBm to 0dBm. The OSNR is improved dramatically when PM is applied to the setup where the improvement is from 7.81dB to 29.72dB when the signal power is varied from -30dBm to 0dBm. It can be concluded that the overall performance improves when the propagated signal is free from the SBS effects.

The R-EDFA gain decreased gradually from 21.3dB to 18.3dB when the input signal is varied from -30dBm to -13dBm when referring to Figure 8. This R-EDFA gain is attained at Port C in the experimental setup. However, when the input signal reaches the saturation point, which is around -13dBm, the gain starts to reduce extremely to 10.5dBm at 0dBm signal. The saturation effect is caused by the higher number of signal photons that contribute to the declining of gain at the higher signal levels. The NF pattern is totally inversed with the gain pattern where the NF keep increasing with the increment of signal power as depicted in Figure 2.When the input signal is at -30dBm, the NF attained is around 4.6dB while when at the highest input signal (0dBm), the NF obtained is around 6.4dB. This is due to the supplementary source spontaneous emission that developed together with the propagated signal.

## CONCLUSION

We have demonstrated the performance improvement of L-band hybrid R-EDFA when a phase modulator is introduced to suppress the SBS effect in the transmission. The transmission gain has improved by 12.65dB at 0dBm signal power when the effect of SBS is fully suppressed. At the same time, the noise figure improves tremendously from 53.5dB to 6.4dB at 0dBm signal when the linewidth of the amplified signal is broadened up using a phase modulator. Besides having improvement in terms of gain and NF, the OSNR also successfully improved from 7.81dB to 29.72dB when the signal power is varied from -30dBm to 0dBm. By introducing a phase modulator into this L-band hybrid R-EDFA helps to improve the signal power as it reduced the gain competition between the amplified signal and the Stokes signal generated from the SBS effect.


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