# [ME06] Gain-clamped L-band EDFA using narrow and broadband fiber Bragg gratings for gain-flattened

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## Introduction

In the wavelength division multiplexing (WDM) networks, the signal power in the link is varies with the changes in number of signals and link losses. A sudden signal added/dropped can caused the surviving signal have power transient (Desurvire, 1989; Sun *et al.*, 1997) and when these signal is amplified by the erbium-doped fiber amplifier (EDFA), unequally signal power between channel became larger and causes an error detection at the receiver (Zhou *et al.*, 2000). The increasing demand intended the networks provider to increasing link capacity. At maximum gain bandwidth of C and L band, a single fiber can carry 80 channels data (Scheerer *et al.*, 1999) using gain-flattened EDFA has been reported.

To archive the gain-clamping capability, the clamp laser is injected into the EDFA to maintain the average population inversion by using the homogeneous broadening properties of the gain medium (Zirngibl, 1999). The clamp laser for clamping purposed is generated internally or externally depends on required output power.

Introducing a gain-clamp EDFA to the network system has disadvantage to dense WDM configuration. The gain-clamp EDFA usually reducing channel number due to small clamp bandwidth available. Therefore, the new design of gain-clamp EDFA should have both capabilities for bigger channel number configuration.

The gain-flattened EDFA required a special pumping configuration to produce flat gain profile. The normal pumping configuration is producing higher gain at wavelength close to erbium emission wavelength (L-band ~ 1560 nm) and lower gain at longer wavelength.

Considering this problem, Jung *et.al* has reported a high-efficient gain-flat EDFA by incorporating FBG to their configuration (Jung *et al.*, 2002) to flatten the EDF gain.

### Experimental setup

Figure 1 show an experimental setup of gain-clamped L-band EDFA with narrow and broad-band FBG. The narrow-band FBG has reflection wavelength at 1560 nm with 3 dB bandwidth of 0.3 nm and broad-band FBG has reflection wavelength at 1545 nm with 3 dB bandwidth of 42 nm. The input end of the amplifier consists of two circulator spliced in series with narrow band FBG. The VOA is connected at port 3 of circulator 2 and port 1 of circulator 1 in purpose to control the amount of the backward ASE. The broad band FBG is spliced at the end of the EDF before the isolator to reflect C-band spectrum back to the EDF. The design uses a 50 m length of 400ppm $Er^{3+}$ concentration EDF. The 980 nm pump with 92 mW output power is injected into the EDF by using WDC after circulator 2. The VOA attenuation is varies from 0 to 24 dB where 0 dB attenuation setting represent the maximum clamp laser power is injected back to the EDF.

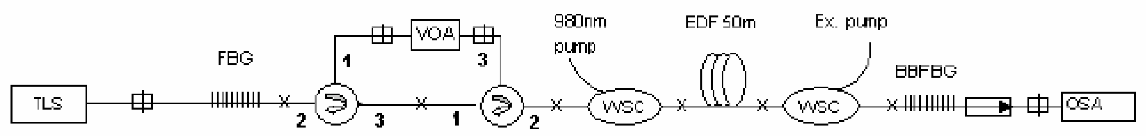


FIGURE 1 Experimental Configuration

## Results

Figure 2 shown gains as a function of input signal power for variously VOA attenuation setting. VOA is set from 0 to 24 dB to study the effect of different clamp laser power with gain flattened configuration. When the clamp laser is 'cut-off', the amplifier has maximum gain of 12.4 dB. The maximum gain available is small due to the insufficient EDF length and pump power. Another reason is the pump wavelength where pumping with 980 nm is producing low gain than 1480 nm pumping (Massicott et al., 1992). At maximum clamp laser power, the amplifier has clamped an input signal power up to 0 dBm with gain at 6.74 dB. The design has maintained the gain-clamped capability to 16 dB VOA attenuation setting and gain variation of less than ±0.20 dB. At lowest clamp laser power, the amplifier gain is about 9.79 dB.

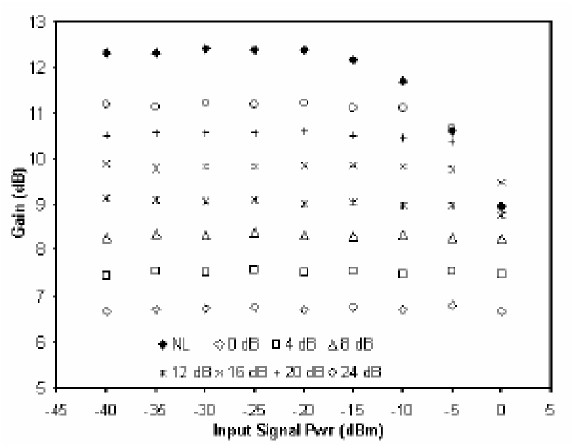


FIGURE 2 Gain against input signal powers for 0 to 24 dB VOA attenuation setting (NL: clamp laser off)

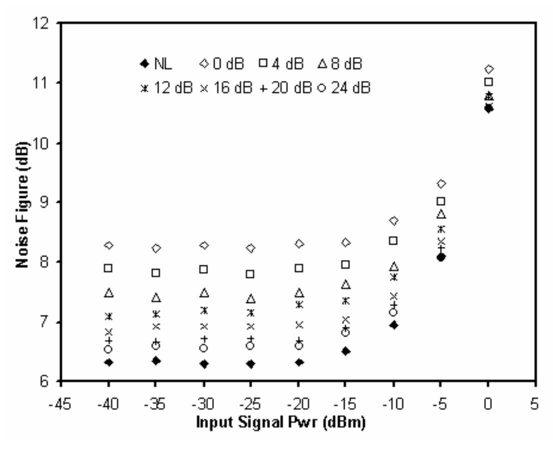


FIGURE 3 Noise figure as a function of input signal powers with VOA attenuation setting varies from 0 to 24 dB. (NL: clamp laser off)

A gain-clamp EDFA is producing higher noise figure (NF) from standard EDFA because clamp laser creates higher gain saturation in the EDF. With this design, the higher recorded NF is11.24 dB at 0 dB VOA setting where the higher clamp laser is injected into the EDF. The NF penalty drops with reduced clamp laser power and also input signal power.

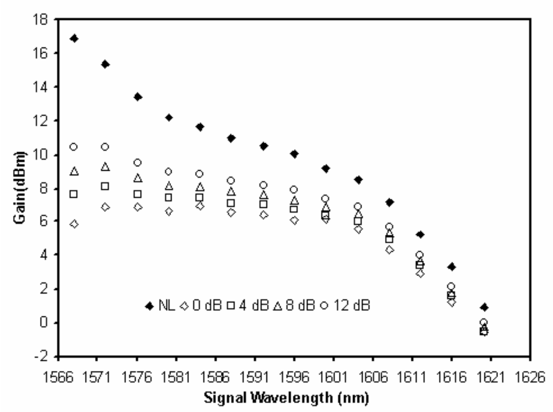


FIGURE 4 Signal gain over against signal wavelength at 0 to 12dB VOA attenuation setting. (NL: No loop)

The gain-flatness of the configuration is shown in Fig. 4. At maximum clamp laser power, the gain profile is flatted to ± 1 dB from 1568 nm up to 1600 nm. The gain available at setting is 6.49 dB. The flatness of gain profile however decreased with increasing VOA attenuation showing a limit of gain-flatness capability from this design.

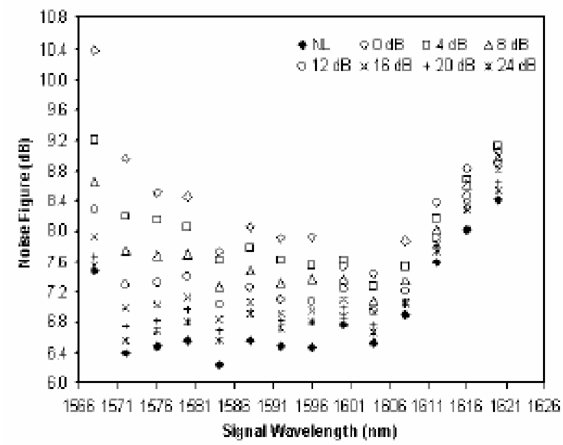


FIGURE 5 Noise figure against signal wavelength at 0 to 24dB VOA attenuation setting. (NL: No loop)

The NF from 0 dB to 12 dB VOA attenuation maintains below 9.2 dB. At shorter wavelength where the injected signal wavelength is closed to clamp laser wavelength, the higher NF is caused by the clamp signal itself and at the longer wavelength, the effect of ESA (Excited Stimulated Emission) is dominated the NF values.

## Conclusion

The proposed designs have both gain-clamp and gain-flattened capabilities for WDM application. For gain-clamp application, the design have maximum gain at 6.74 dB for input signal up to 0 dBm with less than 0.14 dB variation while the gain-flattened application, the design has a flat gain of 32 nm from 1568 to 1600 nm with ± 1 dB gain variation. The design is capable to reduce the development cost for the network provider where the amplifier is built-in with gain-clamped and gain-flattened capabilities.

However, the proposed design has lower gain and not suitable for long distance and booster application. Due to this design will be used in WDM system, other testing needed to be study such as power variation and crosstalk between different channels.

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