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INFLUENCE OF FORWARD AND BACKWARD TRAVELLING REFLECTIONS ON THE GAIN AND ASE SPECTRUM OF EDFA's

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ABSTRACT

Optical reflections at the *input* of an optical amplifier increase the noise more than those at the output. Measurements with 21 dB gain and 21 dB return loss indicate that an optical isolator at the *input* improves the noise figure by 3 dB more than one at the output.

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INTRODUCTION: Performance degradation due to Fresnel reflections (from connectors, splices, and passive components) and Rayleigh backscattering, is an important consideration in optical fiber telecommunication systems incorporating erbium-doped fiber amplifiers (EDFA's). It is generally accepted that in order to eliminate the possibility of laser action and interferometric interference due to Fresnel reflectors on either side of the EDFA, an optical isolator (OI) should be located at either the input or the output of every EDFA [1]-[5]. Furthermore, in receiver preamplifier applications, an OI at the input to the EDFA can yield substantial improvement in receiver sensitivity by preventing backward propagating ASE (B-ASE) from entering the transmission fiber and thus contributing to the forward propagating ASE (F-ASE) through re-amplification of the backscattered component [4]. In this paper, we experimentally examine the influence of reflections on EDFA gain and the F-ASE spectrum, and thus determine the relative advantages that may be gained by locating an OI at either the input or the output of an EDFA. Our results indicate that when optical reflections are in the order of the amplifier gain, then locating an OI at the *input* yields at least 3 dB more improvement in the noise figure than locating one at the output.

EXPERIMENT: A schematic diagram of the experimental setup is indicated in Figure 1. Angled biconic connectors were used throughout in order to minimize undesired reflections, and OI's were used at the input to all measurement apparatus. Return loss (RL) in excess of 50dB on the output side and 35dB on the input side of the EDFA (attributed to the WDM) was attained. The pump was a 1480nm packaged LD module that delivered approximately 50mW of optical power out of its SMF pigtail at a drive current of 500mA. Accounting for losses in the WDM, 3dB coupler and SMF/EDF connection, a maximum pump power of 15 mW was launched into the 35m EDF, which had an erbium ion dopant concentration of 160ppm and was gain flattened by means of alumina co-doping of the core [6]. Measured small signal gain at 1538nm was 21.7dB.

A variable reflector [7] was used on the indicated 3dB coupler branches to simulate reflections at the input and output. Since the WDM characteristic across the wavelength range of interest varied by only 1dB, a reflector at the signal input of the WDM is predicted to have a similar, though slightly lesser impact. Two reflection levels were used in our tests: 30dB RL chosen as being comparable to the RL anticipated from distributed reflections due to Rayleigh backscatter in a long length of SMF [3],[4], and 21dB chosen as being comparable to the EDFA gain at 1538nm. The latter is considered an interesting case for which observations may be extrapolated to EDFA's operating at higher gain (30-35dB), in which case unavoidable distributed reflections due to Rayleigh backscattering may yield an equivalent RL in the order of the EDFA gain.

No Optical Isolator: For the EDFA operating unsaturated and without OI's at the input or output, the impact of 30dB RL at both input and output (and also 21dB RL) was examined. In order to perform absolute gain measurements, a 1538nm signal was introduced and maintained at a sufficiently small level to ensure that it contributed no significant gain saturation effects on the F-ASE and B-ASE spectra. The F-ASE spectra were compared to the situation under which the EDFA operated with negligible reflections at either the input or output. A 30dB RL at both ends resulted in a small change in EDFA performance, with gain compression of 0.5dB measured at 1538nm, and a maximum enhancement of 1.3dB in the F-ASE spectrum in the region of 1556nm. Introducing 21dB RL at both ends resulted in a catastrophic impact upon the F-ASE spectrum and gain. The F-ASE spectra with negligible reflection and with 21dB RL are indicated in Figure 2, and it is observed that Fabry-Perot resonances are sufficient to cause laser action at the longer wavelengths near 1560nm. This causes a small signal gain compression of 6.6dB at 1538nm and indicates that at least one OI is required somewhere in the EDFA.

Optical Isolator at Output: In Figure 3, the reflection at the output has been eliminated (RL >50dB), and the F-ASE spectra are compared for RL of 35dB and 21dB at the input. The EDFA is now stable, but there exists a considerable enhancement in the F-ASE power for a RL of 21dB (particularly at the longer wavelengths). Furthermore, a 2.1dB gain compression is measured at 1538nm, and when coupled with the F-ASE noise power enhancement it is estimated that the EDFA noise figure has been degraded by more than 4 dB at 1538nm. This degradation can be attributed directly to the presence of reflected B-ASE.

Optical Isolator at Input: In Figure 4, the reflection at the input has been eliminated (RL approximately 35dB) and the difference between the F-ASE spectra for RL of >50dB and 21dB at the output is indicated. It is observed that the F-ASE power spectral density is reduced at all wavelengths when the 21dB RL reflection is present. This is due to gain compression effects within the amplifier which are also evidenced by a measured 1.3dB reduction in small signal gain at 1538nm. It is estimated that the EDFA noise figure is now degraded by less than 1dB over all wavelengths of interest.

In an WDM system, the input power to an EDFA may be significant, and it is therefore of interest to also consider the impact of OI location when the EDFA is saturated. We have determined that the overall impact for each combination of RL is similar in nature, but always less than that observed for the corresponding unsaturated case.

CONCLUSIONS: The influence of reflections on the gain and F-ASE spectrum of an EDFA has been examined experimentally in both unsaturated and saturated conditions. We observed that reflected B-ASE results in a substantially larger impact on EDFA noise figure than reflected F-ASE. Consequently, an optical isolator placed at the input is more effective in reducing the noise figure than one placed at the output. Locating a second optical isolator at the output helps minimize gain compression effects, but it has little further influence on the noise figure.

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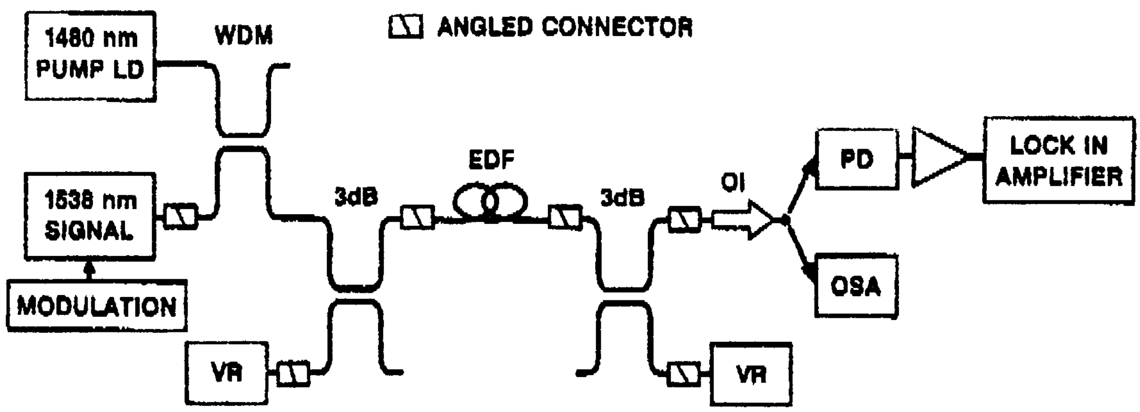

Figure 1. Experimental Setup. (VR: Variable Reflector; OSA: Optical Spectrum Analyzer; PD: Photodetector; OI: Optical Isolator; EDF: Erbium-Doped Fiber; WDM: Wavelength Division Multiplexer; 7° angled biconic connectors used throughout).

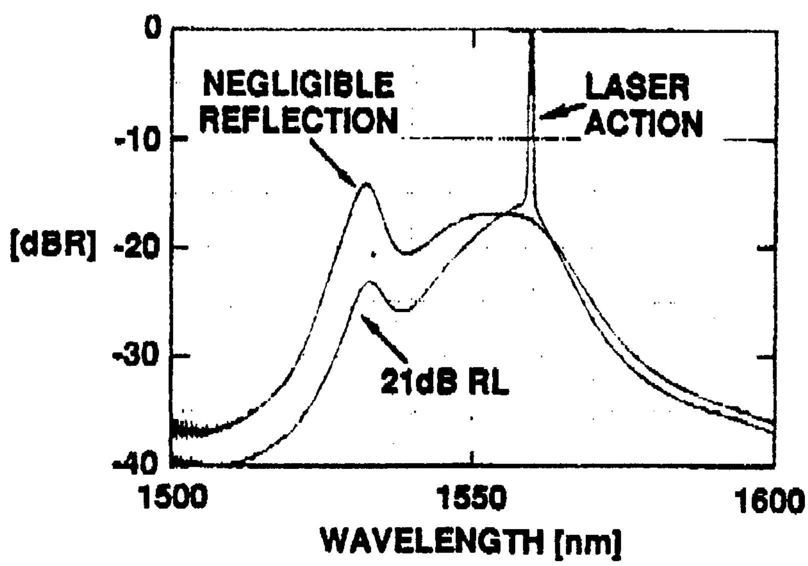

Figure 2. F-ASE Spectra (reflections at both input & output)

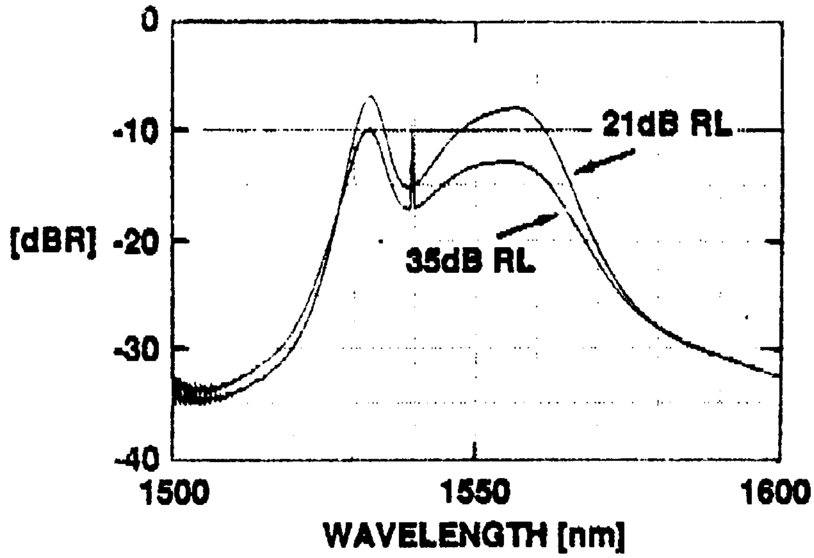

Figure 3. F-ASE Spectra (reflections at input only).

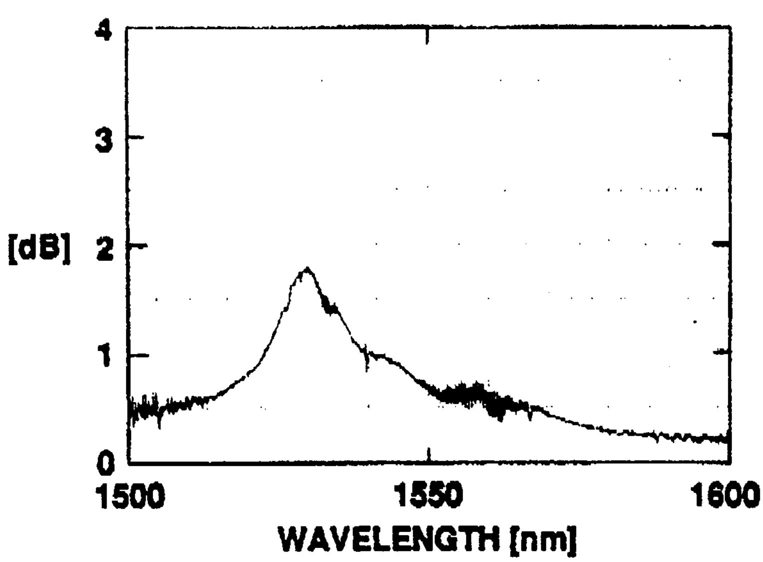

Figure 4. Difference in F-ASE spectra for RL > 50dB and 21dB at the output (reflections at output only).