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Efficient Erbium-Doped Fibre Amplifier

with an integral isolator

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ABSTRACT

A composite erbium-doped fibre amplifier configuration is presented which incorporates an isolator within the length to suppress the backward amplified spontaneous emission. The configuration shows increased gain efficiency accompanied by quantum-limited noise performance.

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Erbium-Doped Fibre Amplifiers (EDFAs) [1] are expected to be extensively used in telecommunications owing to their compatibility with the fibre network, low insertion loss, high gain and low noise figure (NF). It has been predicted theoretically [2] and demonstrated experimentally that the highest gain efficiencies are achieved when the Er^{3+} is pumped at 980nm [3,4]. However, it has also been realised that there is a trade-off between noise and gain efficiency. Under conditions of maximum gain efficiency EDFAs exhibit NFs well above the 3dB quantum limit and any attempt to reduce the amplifier NF results in a significant gain-efficiency reduction [5].

The main limitation to the performance of the EDFA is imposed by the amplified spontaneous emission (ASE). In a co-propagating scheme and with high amplifier gain, the backward-travelling ASE acquires high intensity, especially at the input end of the EDFA, thus depleting the pump power and reducing the population inversion of the active medium. This results in a gain efficiency decrease and NF increase. In this communication, a composite EDFA configuration is studied which, when compared with the conventional configuration, eliminates the gain efficiency/noise trade-off and allows increased gain efficiency accompanied by quantum-limited noise performance.

The proposed configuration is shown in Fig. 1. An isolator is incorporated into the active (erbium-doped) part of the amplifier in order to extinguish the backward ASE. The signal and forward ASE are allowed to propagate through the isolator experiencing minimal losses (α_S). Two WDM couplers are spliced on either side of the isolator enabling the pump power to by-pass the isolator which is usually lossy at the pump wavelength. The pump loss (α_P) is, therefore, determined by the coupler and splice losses.

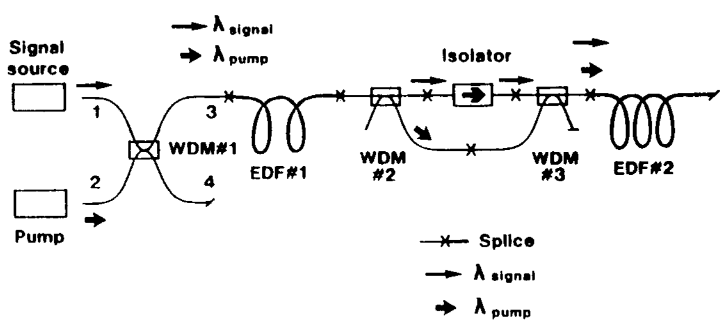

Figure 1: Proposed composite EDFA/isolator configuration.

For the calculation of the amplifier gain and NF pumped at 980nm, a 3-level model was utilised which uses the equivalent overlap integral and ASE-bandwidth approximations [6]. The rest of the parameters refer to Ge/SiO_2 fibres and were determined experimentally [7]. In Figures 2(a) and (b), the gain and noise figure of the proposed composite EDFA/isolator are plotted against the position of the isolator inside the amplifier for various isolator extinction ratios using α_S=2dB and α_P=0.5dB. Compared to the conventional EDFA which for the same conditions has a gain of 36dB and NF=4dB, the presence of the isolator produces a significantly improved performance (gain of 42.3dB, NF=3.2dB) which depends on (weakly) its position and extinction ratio. The backward ASE is effectively suppressed for an isolator ER of 30dB and no advantage is gained for higher ERs. The optimum isolator position is found to be at a distance of ~30% of the total EDFA length measured

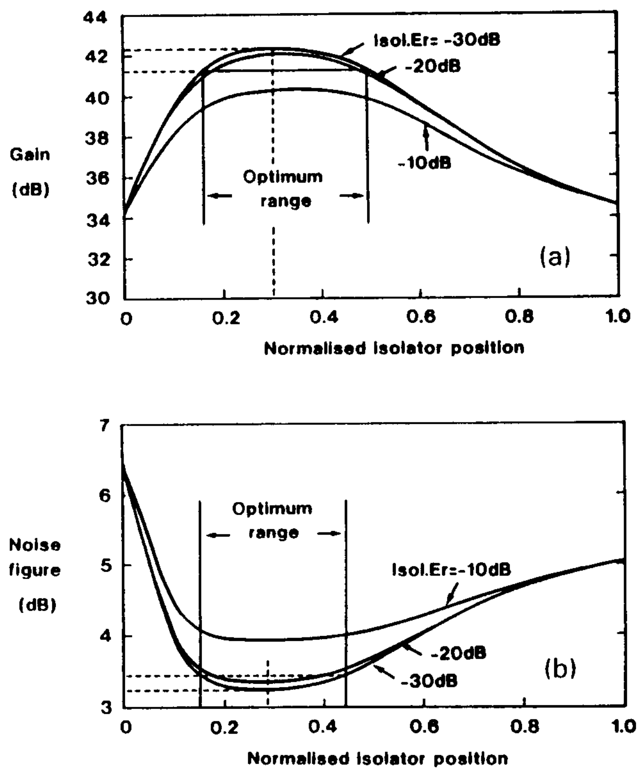

Figure 2: (*a*) Gain and (*b*) amplifier NF versus normalised isolator position for isolator extinction ratios of -10, -20 and -30dB. Input pump power: 10mW, input signal power: -45dBm, fibre NA = 0.3, EDFA length = 6.7m, α_p = 0.5dB, α_s = 2dB.

from the input end. However, it is clear that there is a range of positions around the optimum ($\sim \pm 0.15$ of total EDFA length), (the *optimum range*), within which the amplifier NF and gain vary slightly (less than about +0.15dB and -1dB, respectively). The isolator can be placed anywhere within this optimum range with only a small sacrifice in the absolute optimum performance.

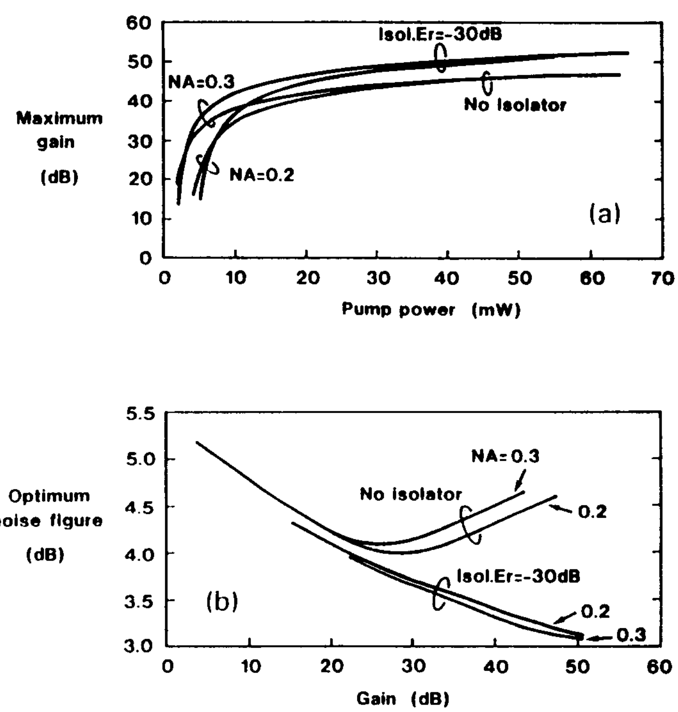

Figure 3: (*a*) Maximum gain versus pump power and (*b*) NF versus optimum gain with optimum fibre length and the isolator at optimum position. Input signal power: -45dBm, fibre NA: 0.2 and 0.3, isolator ER: -30dB, α_p = 0.5dB, α_s = 2dB.

By suppressing the backward ASE close to the input end, a larger fraction of the pump power is transformed into signal power, giving a higher gain efficiency and lower NF. In Figure 3(a), the maximum gain achievable with the isolator at the optimum position and the composite EDFA/isolator at optimum length is plotted against the input pump power for an isolator ER of -30dB and fibre NA's of 0.2 and 0.3. This is compared with the maximum gain achieved with a conventional EDFA (without isolator) at the optimum length. It can be seen that at high pump power a gain increase of about 5dB is achieved by incorporating an isolator. However, owing to its insertion loss, below a certain gain ("cross-over" gain) the introduction of the isolator is detrimental to the gain. In Figure 3(b), the NF of the composite and conventional EDFA is plotted versus gain for the pumping conditions of Fig. 3(a). It is clearly evident that under fully optimised conditions the NF of the composite EDFA decreases monotonically with the gain level and approaches the 3dB quantum limit, whereas the conventional amplifier exhibits an increasing NF at high gain levels. Here a NF improvement as high as 1.5dB can be achieved. We conclude therefore that the suppression of the backward ASE by means of the integral isolator results in a gain increase accompanied by near quantum-limited NF. Such a combination of characteristics is impossible in the conventional EDFA configuration [5]. It is also shown that at low gain, despite the gain decrease there is still a small improvement in the NF.

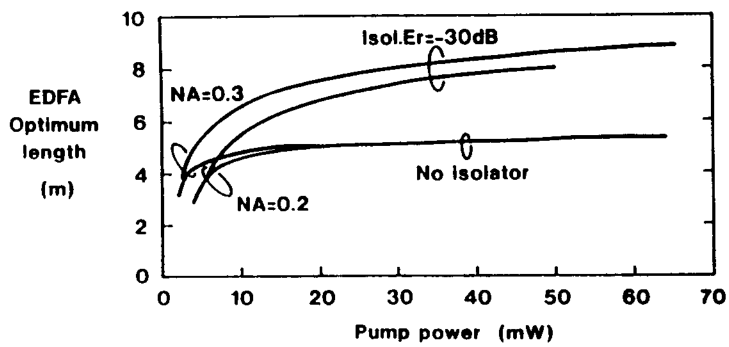

Figure 4: Optimum EDFA length versus input pump power. Parameters as in Fig.3.

Owing to the elimination of the saturation caused by the backward ASE, the pump power absorption occurs over longer EDF lengths when an isolator is incorporated and the optimum length of the composite EDFA is increased. In Figure 4, the optimum EDFA length is plotted versus the input pump power for the conventional (no isolator) and the composite EDFA (isolator ER=-30dB) and for fibre NA's of 0.2 and 0.3. We see that the optimum length of the composite EDFA is some 80% longer than its conventional counterpart.

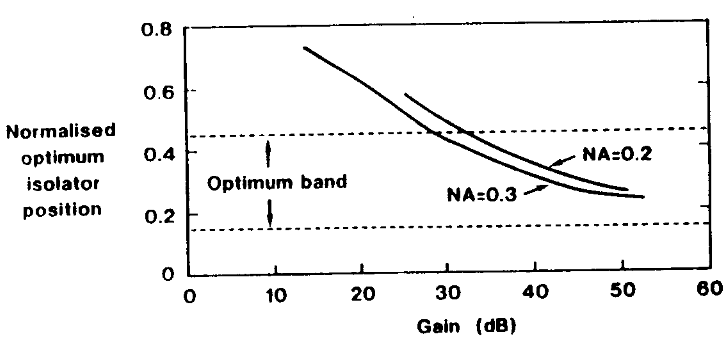

Figure 5: Optimum isolator position normalised to optimum fibre length versus amplifier gain.

The build-up of the backward ASE depends on the amplifier gain which in turn is expected to affect the optimum isolator position. In Figure 5, the optimum isolator position is plotted versus the amplifier gain for fibre NA's of 0.2 and 0.3. The optimum isolator position is normalised to the optimum EDF length for each amplifier gain. For gains greater than ~30dB the optimum isolator position lies within the 0.30 ± 0.15 optimum range and indicates that by placing the isolator at about 0.30 of its optimum length (corresponding to ~40dB gain) guarantees optimum amplifier performance over a wide range of gains.

It should be noted that in the case of an EDFA pre-amplifier, the benefits of increased gain efficiency and lower noise provided by locating the isolator within the amplifier are not at the expense of any further components, since it is commom practice to employ an isolator at the amplifier input. In this location the isolator insertion loss has a deleterious effect on the receiver since it adds to the NF [$NF_{TRUE} = NF_{AMP}$ + Insertion Loss(dB)]. Relocating the isolator to within the EDFA therefore has the further benefit of removing its insertion loss from the critical amplifier input to a position where it actually improves the NF. Thus the total potential NF improvement can be as high as 2.5dB in a practical EDFA pre-amplifier receiver. Thus, the simple action of relocating the isolator should considerably improve the relatively-high NF (6-10dB) observed in experiments to date [8] of which input losses are a major component.

In conclusion, a composite EDFA/isolator configuration is described which incorporates an isolator to suppress the build-up of the backward ASE. The optimum position of the isolator has been calculated and the improvement in the gain and noise performance of the composite EDFA estimated. It is shown that compared with the conventional configuration the proposed EDFA can exhibit enhanced gain efficiency accompanied by near-quantum-limited noise performance.

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