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ERBIUM-DOPED-FIBRE OPTICAL LIMITING AMPLIFIER

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ABSTRACT: A novel configuration of an erbium-doped-fibre optical output-limiting amplifier (OLA) is presented which is realised by simply introducing a differential lump-loss between the signal and the pump power at a particular point along the fibre. The OLA exhibits an input-power dynamic range in excess of 30dB and the capacity to control optically the level of the constant-output signal.

1. Introduction. Optical-fibre limiting amplifiers (OLAs) can provide a constant output-signal power (±0.5dBm) for a range of input-signal powers, called the *dynamic range*, and are expected to be extensively used in long-haul telecommunication systems and distribution networks to overcome problems caused by power variations due to unwanted transmission/distribution losses. Such variations of the output power can impose stringent requirements on the dynamic range of the various optical and electronic components of the network. Limiting-power amplification has been demonstrated using two [1] or three [2] cascaded EDFAs which require high pump power and a multiple pumping scheme as well as a number of optical components, such as isolators and very narrow-bandwidth optical filters. Another approach utilises a single EDFA placed in a self-adjusted fibre loop [3] utilising well-designed WDM couplers and optical isolators to avoid oscillation of the loop.

In this communication, we describe a novel configuration of an OLA which comprises a single EDFA incorporating a differential lump-loss between the pump and the signal. The introduction of the differential lump loss enhances the effect of the generic gain saturation on the response of the ordinary EDFA and results in a much "harder" limiting. The proposed configuration exhibits a dynamic range in excess of 30dBm and has the additional capacity of controlling optically the level of the constant output-signal power. The response of the proposed device is fully analysed and initial experimental evidence of the limiting action is provided.

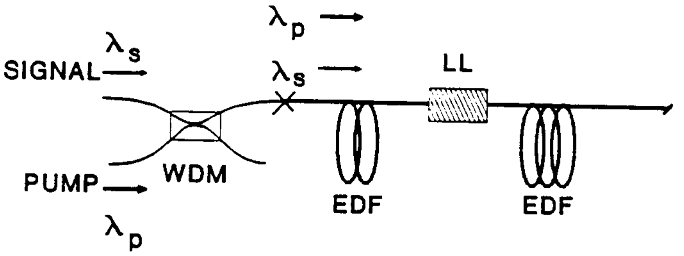

Figure 1: The proposed OLA configuration.

2. OLA description and principle of operation. The proposed OLA configuration is shown in Figure 1. The pump and the signal are launched into a length of erbium-doped fibre (EDF) by means of one/two wavelength-division-multiplexing (WDM) couplers employing a uni-/bi-directional pumping scheme. The limiting action of the amplifier is accomplished by the introduction of a lump-loss (LL) mechanism inside the EDF length which attenuates the signal, the forward- and the backward-propagating amplified spontaneous emission (ASE). The pump is allowed to propagate along the EDF with no or minimal losses. The differential loss between the signal and the pump power can for example be introduced by simply bending tightly the Er-doped fibre at a particular point along its length.

2(a) Principle of operation: The underlying principle of operation of the proposed OLA is explained with reference to Figure 2 where the pump and signal evolution along the normalised fibre length are shown for the two extreme input signal powers of -25dBm and 0dBm. The pumping is unidirectional with a pump power of 20mW. The loss for the signal, forward and backward ASE is 2dB while for the pump it is 0.5dB The limiting action is achieved by the balance between the pump and amplified-signal power in stages I and II, before and after the lump-loss position, respectively. In stage I, both signals are amplified, with the low-input-power (-25dBm) signal attaining lower levels than the high-input-power (0dBm) one, as expected. However, the pump power is depleted at a slow rate by the low-input-power signal and there is sufficient remnant pump power available in stage II to amplify the attenuated low-input signal to the same level as the high-input signal. On the other hand, although the high-input-power signal attains a higher level throughout stage I, it heavily depletes the pump power which drops below threshold towards the end of stage II and, as a consequence, the signal is slightly attenuated to level-off with the low-input-power one. The signals of intermediate input power evolve in an analogous manner and converge to the same output level. The same principle of operation applies in the case of bi-directional pumping.

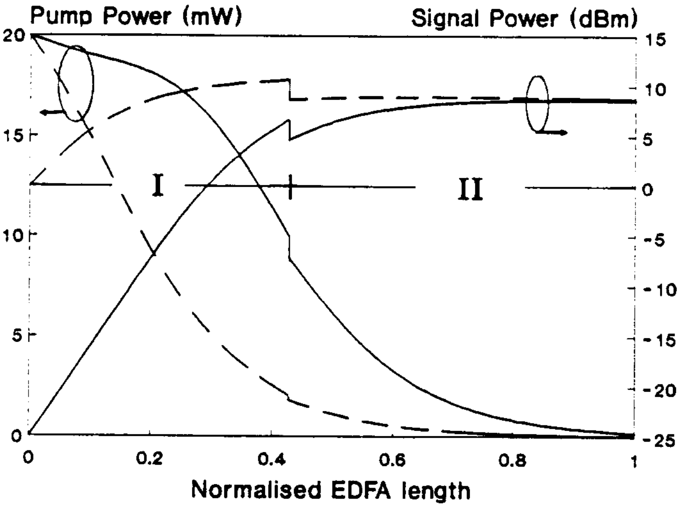

Figure 2: Pump and signal power evolution along the OLA for two extreme input signal powers of -25dBm (solid line) and 0dBm (broken line). The input pump power is 20mW.

2(b) Optimum Loss Position - Dynamic Range: As already mentioned, the limiting action of the proposed OLA relies on the balance between the relative remnant pump and signal power at the position of the lump-loss. Therefore, it is expected that the strength and the relative position of the lump-loss along the fibre length affects the transmission characteristics and dynamic range of the OLA. Two different lump-loss mechanisms are considered.

In Figure 3(a), the calculated input/output signal characteristics and noise figure of the proposed OLA are presented (solid line) and compared with the ordinary EDFA where no lump-loss is present (broken line). The lump-loss is placed at the optimum position (~ 3.75m from the input end) and induces losses of 3dB and 0dB at the signal and pump, respectively. The fibre is 6m long and pumped uni-directionally with 20mW of pump power. "Hard"-limiting is attained over an input-power dynamic range in excess of 25dBm. The limiting action is apparently achieved at the expense of a slight increase in noise figure at the high-input-power end of the dynamic range.

In Figure 3(b), the calculated input/output response and noise figure of an OLA (solid line) are plotted in which the lump-loss is introduced through the insertion of an optical isolator placed at the optimum position (~ 3.5m from the input end) [4]. The input pump power is 20mW and the EDF length is 8.2m. The isolator extinction ratio is 30dB and the signal and pump loss are 2dB and 0.5dB, respectively. In this case, in addition to the differential loss between the pump and signal there is introduced a 30dB differential lump-loss between the forward and backward ASE which results in higher amplifier gain within the low-input-signal regime [4] and extends the dynamic range of the OLA. The broken line corresponds to the no-loss case. With the isolator at optimum position, the OLA exhibits a dynamic range in excess of 30dBm. The NF of the OLA in this case remains close to 3dB for most of the dynamic range.

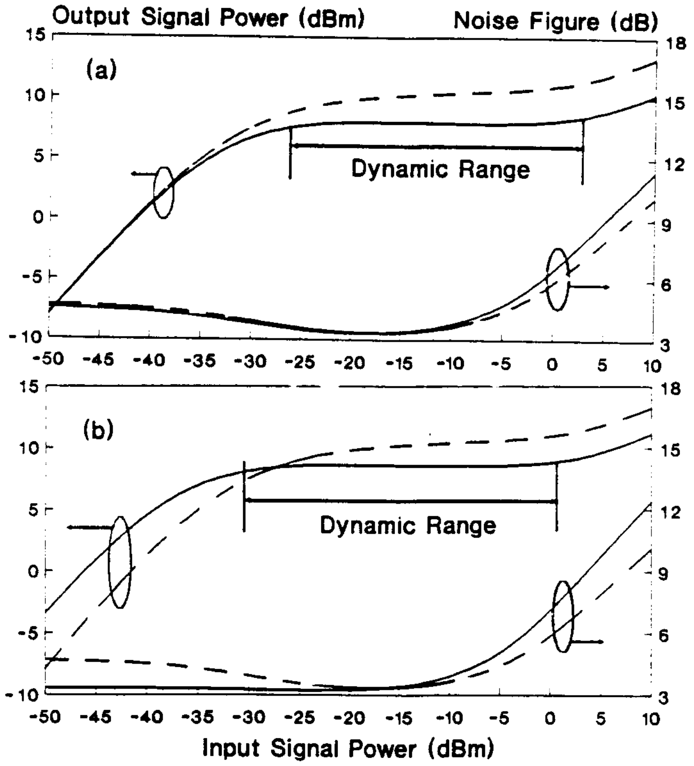

Figure 3: Output signal power and noise figure of the proposed OLA (solid line) against the input signal power. Differential lump loss is introduced by (*a*) a tightly-bent fibre, and (*b*) an optical isolator. The broken line corresponds to an optimised conventional EDFA. The input pump power in both cases is 20mW.

2(c) **Output-signal control:** An important feature of the proposed OLA is the possibility of controlling the output signal power optically by varying the input pump power. In Figure 4, the input-output signal response of the OLA is shown, obtained with uni-directional pumping and various input pump powers. The parameters are the same as in Figure 3(a). By increasing the input pump power from 20mW to 60mW, the signal output of the OLA increases from ~8dBm to ~14dBm and is accompanied by an ~20% increase in the dynamic range of the OLA.

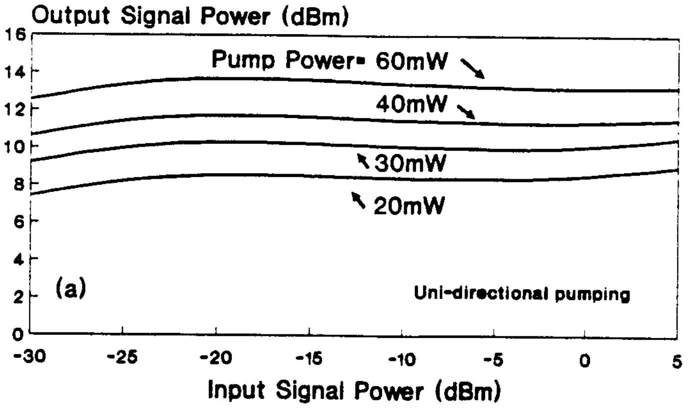

Figure 4: Input/output response of the OLA for input pump powers of 20, 30, 40 and 60mW.

3. Experimental results. An OLA was constructed by incorporating an optical isolator inside an Er-doped fibre to induce the pump/signal differential loss. The fibre NA was 0.24, the cut-off wavelength 900nm and the peak signal absorption at 1536nm was 0.95dB/m. The OLA length was 85m and the isolator was placed at 25m from the input end. The isolator extinction ratio was greater than 30dB and the signal insertion lump-loss was 2.1dB. The pump by-passed the isolator by means of two WDM couplers suffering total loss of 0.6dB [4]. Preliminary results demonstrating the limiting action and the output control of the proposed OLA are shown in Figure 5 and compared with results for an optimised conventional EDFA employing a 60m length of the same doped fibre.

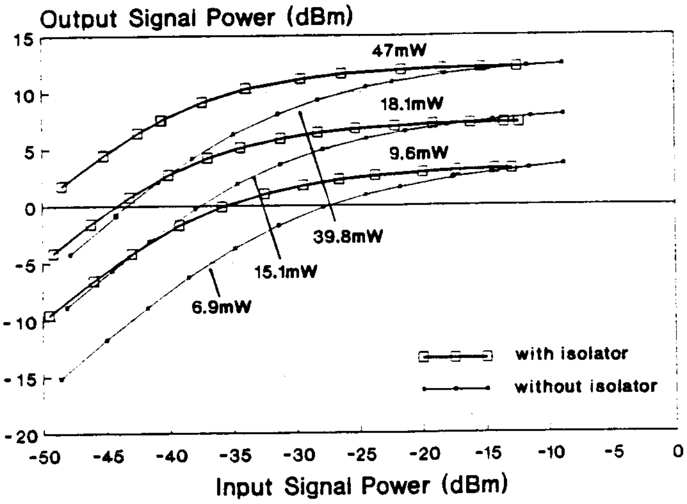

Figure 5: Experimental results with and without isolator for the indicated input pump powers.

4. Conclusions. A novel OLA configuration is described which incorporates a differential lump-loss between the signal and the pump to enhance the effect of the generic gain saturation on the input/output characteristics of the ordinary EDFA. The optimum relative position of the loss along the fibre is calculated and an input-power dynamic range in excess of 30dB is predicted. The level of the constant signal output can be controlled optically by means of the input pump power. Preliminary experimental results demonstrate the limiting action and the output control of the proposed configuration.

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