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Multichannel Crosstalk and Pump Noise in an Er^{3+}-Doped Fibre Amplifier Pumped at 980nm

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Er^{3+}-doped single-mode fibre amplifiers operating around 1.54μm are emerging as promising contenders for use in future high bit-rate long-haul communication systems [1,2,3,4]. They have the advantage over semiconductor amplifiers of being wholly compatible with telecommunications fibre, thus eliminating both splice loss and end-face reflections which would be detrimental to amplifier performance, and are polarisation-independent. Fibre-to-fibre gains in excess of 34dB have been demonstrated [1] with excellent saturation and noise performance [2]. However, as with all optical amplifiers, noise on the pump (injection current or optical wave), will feed through to the amplified signal. In addition, owing to homogeneous broadening, competition for the available gain between two amplified channels closely-spaced in wavelength leads to inter-channel modulation in an ASK system. We show here that the very long fluorescent time-constant in Er^{3+} (τ = 14ms, cf 1ns for semiconductor amplifiers) suppresses these effects by >40dB at frequencies > 100kHz, thus providing a further advantage for this type of amplifier.

The results were obtained using an optimised fibre amplifier optically pumped at 980nm, as shown in the experimental configuration of Figure 1. The outputs from two DFB InGaAsP diode lasers operating around 1.535μm were combined using a 3dB fibre coupler. These signals were then combined with the pump beam from a Styryl 13 CW dye-laser using a second (dichroic) fibre coupler, which was in turn spliced to the amplifier fibre. The Er^{3+}-doped fibre had an NA of 0.16 and a λ_{cutoff} of 975nm. A length of 8.7m was found to be optimum for a launched pump power of 15mW. The output end of the fibre was terminated so as to eliminate back reflections into the amplifier from the fibre end-face and a germanium PIN photodiode was used to monitor the amplified signal output.

The gain characteristics (Figure 2) of the amplifier pumped at 15mW were obtained using one of the DFB lasers operating at the wavelength of peak gain (1535nm). The DFB laser was modulated with a 50% duty cycle at ~20kHz to allow the use of lockin techniques. For low input signals (<200nW), an unsaturated gain of 34dB was obtained, with 3dB gain saturation occurring for an output of ~1.5mW. For large input signals, a maximum saturated output power of 8.5mW was achieved.

In order to measure the effect of pump noise on the system performance, the dye-laser beam was modulated by applying band-limited (25kHz) white noise to an acousto-optic modulator placed in the beam path. The resulting pump noise measured 16% rms (0.1%/√Hz). Figure 3 shows frequency spectra of the amplifier output in the presence of pump noise for three levels of input signal, 66nW, 6.6μW and 230μW, normalised to a pump noise of 1% rms per unit resolution bandwidth. Resulting output powers (including amplified spontaneous emission) were 0.6mW, 2mW and 3mW respectively. It can be seen that at low frequencies, the pump noise led to a modulation of 1.8% - 2.4% (per unit resolution bandwidth) in the output signal. At higher frequencies, a roll-off of 6dB per octave is observed, with 3dB breakpoints at 100Hz, 270Hz and 450Hz respectively as the signal level is increased. The breakpoint frequency increase with signal strength is due to the greater rate of stimulated emission at higher signal levels, which effectively shortens the excited-state lifetime. Extrapolating to frequencies > 100kHz, a noise suppression of > 40dB is obtained, indicating that pump noise should not limit the performance of communication systems employing Er^{3+}-doped fibre amplifiers.

The dominant peak of the Er^{3+} fluorescence spectrum in silica/germania glass has a linewidth of ~8nm centred at λ=1.535μm, giving a useful gain bandwidth of ~3nm (3.7×10^{11}Hz). WDM communication systems are able therefore to operate with several closely-spaced channels in this band. In order to measure the signal crosstalk characteristics of the fibre amplifier, the DFB lasers were temperature-tuned to a separation of 0.75nm and positioned either side of the gain peak. By maintaining a constant signal level of 22.5μW on diode A and varying the power of diode B from 100nW to 100μW, the cross-saturation characteristics of the amplifier could be measured. In this way, the homogeneous and inhomogeneous linewidths were estimated to be 4nm and 7nm respectively. Since the homogeneous linewidth exceeds the operating bandwidth, gain competition occurs and crosstalk between channels will be observed.

Interchannel crosstalk was measured by modulating diode B with a 5MHz, 100% modulated sinusoidal signal whilst simultaneously 100% modulating signal A at frequencies ranging from 10Hz to 20kHz. The nonlinear saturation characteristic of the amplifier mixes the signals and gives sidebands on the 5MHz signal. Three regimes of operation were considered: (a) signals A and B large, (A=27μW, B=19μW), (b) signal A large, signal B small (A=27μW, B=470nW) and (c) signals A and B small (A=20nW, B=18nW). The ratio of upper sideband to fundamental power for these three conditions is plotted in Figure 4. As with the pump breakthrough, the crosstalk is seen to roll off at high frequencies and, provided the signal contains no information at frequencies <100kHz, crosstalk will be suppressed by >40dB.

In conclusion, we have demonstrated that pump noise and multichannel crosstalk effects in Er^{3+}-doped fibre amplifiers are minimised by the long (τ~14ms) fluorescence lifetime of Er^{3+}. High pass filtering above approximately 100kHz at the detector should eliminate any excess noise which may be encountered.

Acknowledgements

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References

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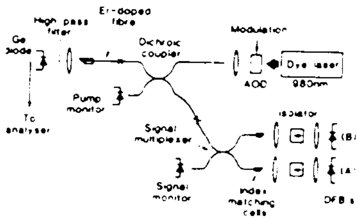

Figure 1 Experimental configuration

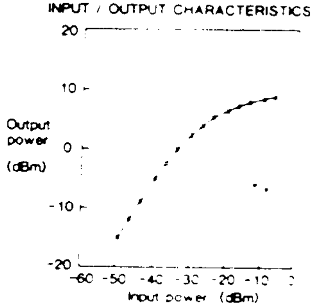

Figure 2 Gain characteristic of Er³⁺-doped fibre amplifier pumped with 15mW power

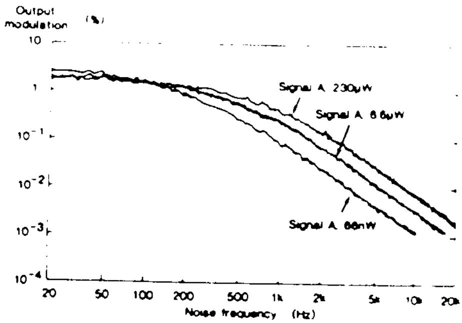

Figure 3 Pump noise transfer characteristics of amplifier at three different signal levels

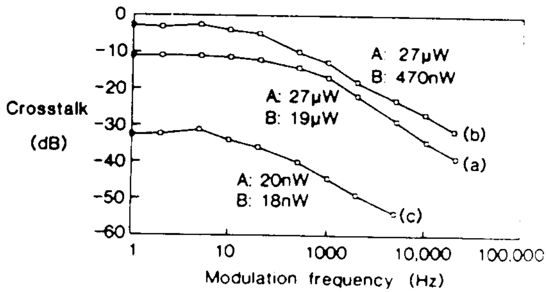

Figure 4 Amplifier crosstalk characteristics for three regimes of operation : (a) large signal, (b) mixed signal and (c) small signal