NOISE IN ERBIUM-DOPED FIBRE AMPLIFIERS

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ABSTRACT

Noise mechanisms in an Erbium fibre amplifier are experimentally characterised. System advantages of 13dB and 7dB are predicted when used as a power- or pre- amplifier respectively.

INTRODUCTION

Recently the in-line Er^{3+} -doped optical fibre amplifier has attracted much attention[1,2] since it offers the potential of high gain, high saturation output power and high bandwidth operation. Compared to semiconductor injection amplifier, a fibre amplifier has the advantage that it can be spliced to standard telecommunications fibre with very low loss. This attribute also ensures low optical feedback and eliminates the partial resonances which plague semiconductor optical amplifiers. Thus quantum-noise limited operation of a fibre amplifier is more easily achievable.

We present here experimental measurements which quantify the various noise contributions in the Erbium-doped fibre amplifier and predict its performance for different signal powers and optical bandwidths.

We show that as a power amplifier following the transmitter 13dB extra transmission capability can be obtained with no detrement in overall system noise. As a preamplifier preceding a photodiode, maximum sensitivity is improved by ~7dB compared with a direct detection Ge APD in a 1GHz bandwidth.

NOISE MECHANISMS.

The output from an optical fibre amplifier is a combination of amplified signal and broad-spectrum amplified spontaneous emission (ASE).

If the input signal is coherent its noise contribution is the usual shot noise associated with the amplified signal level. There is also a shot noise associated with the level of the ASE. Additional noise terms are introduced by the mixing on the detector of the amplified signal and the spectral components of the ASE to give signal-spontaneous beat noise and spontaneous-spontaneous beat noise[3].

The power spectral density of the signal-spontaneous beat noise is independent of the optical bandwidth, whereas spontaneous-spontaneous beat noise is a direct function of optical bandwidth. Thus reducing the optical bandwidth reduces the spontaneous-spontaneous beat noise contribution and at low signal input powers where this noise dominates, optical filtering can be an advantage.

EXPERIMENTAL.

The experimental configuration for the measurement of gain and noise is shown in figure 1. A length of Erbium-doped fibre[4]

(NA = 0.2, λ_{cutoff} = 1050nm, dopant concentration ~150ppm) was used with the ends terminated so as to provide negligible feedback into the amplifier. Pump light from a DCM dye laser (100mW, 665nm) was coupled into the fibre via a dichroic beamsplitter.

A signal beam from a DFB laser operating at 1.536μm was counter-propagated through the fibre and the output was tapped with the dichroic mirror. The amplified signal could be optically filtered through a monochromator (FWHM 1nm) or measured directly with a Ge detector. Unfiltered the ASE was found to have a spectral width of ~3nm.

The DFB laser was direct modulated with 100% modulation depth at a frequency of 2MHz. The peak signal level was set to either 100, 10 or 2μW at the input of the fibre. Amplified signal output power, ASE power with and without the signal present and signal to noise (S/N) ratio were measured as a function of amplifier length.

RESULTS.

The dependence of amplified signal and ASE power on fibre length are shown in figure 2 for a constant pump level and for the 3 signal input powers shown.

It can be seen that the amplifier gain saturates for lengths greater than ~5m after which the total average output power is ~10dBm. For low input powers of -27 and -20dBm, synonymous with the amplifier operating as a preamplifier, high signal gains of 29 and 28dB are achieved, giving output powers of 2 and 8 dBm respectively. Operating as a power-amplifier with a high input power of -10dBm, a high gain of 23dB can still be achieved, giving an output power of 13dBm. As the majority of this power can be coupled into a telecommunications fibre the amplifier typically gives a power advantage of 13dB over a semiconductor source[5] and a corresponding improvement in system margin.

Gain saturation is seen to affect the ASE. For short amplifier lengths (<3m) the ASE is independent of input signal. However at longer lengths, where gain saturation is more pronounced the ASE significantly decreases with increasing input powers owing to gain competition. This effect actually improves the output S/N ratio.

The amplifier output S/N ratio {$20\mathrm{Log}_{10}$(peak-peak signal/rms noise)} normalized fo a 1GHz bandwidth is plotted against fibre length in figure 3. The behaviour for the 3 input signal levels is shown with and without optical filtering on the output. In all cases the output noise was significantly greater than predicted from simple shot noise, indicating the existence of signal-spontaneous and spontaneous-spontaneous beat noise components.

With the high signal input of -10dBm the output S/N ratio is independent of spectral bandwidth for all amplifier lengths, which is expected when the predominant noise is signal-spontaneous beat noise. For a lower input signal of -20dBm the output S/N ratio is independent of optical filtering for short amplifier lengths but improves with reduced spectral bandwidth for longer lengths where a transition from signal-spontaneous to spontanous-spontaneous beat noise limited operation occurs. With the lowest input signal of -27dBm the output S/N ratio is improved significantly by optical filtering from which we infer that when unfiltered the amplifier is spontaneous-spontaneous beat noise limited.

The output S/N ratio is seen to decrease with increasing amplifier length for all signal inputs. This is because the signal and pump light are counter-propagated and can be explained as follows. For short amplifier lengths significant inversion of the erbium ions is achieved, whereas, for longer lengths the inversion is incomplete, leaving a region of high fibre loss. Since erbium is a three-level system this causes the ASE to build disproportionately with the gain[6], thus decreasing the output S/N ratio.

It is envisaged that an amplifier with co-propagating signal and pump light will achieve a slightly better and more constant S/N ratio with length. From our results we predict that detected S/N ratios in a 1GHz bandwidth of ~52 and ~26dB should be achieved for an amplifier with signal inputs of -10 and -40dBm respectively. The latter requires some spectral filtering. Since a S/N ratio of 22dB is typically required to achieve a 10^{-9} BER, an erbium fibre preamplifier and receiver would have a sensitivity of about -40dBm (pk-pk). This is some 7dB better than the sensitivity of a direct detection Ge APD which is ~-33dB (pk-pk)[5].

CONCLUSION.

The noise characteristics of an Erbium-doped fibre amplifier with counter-propagating signal and pump light have been investigated.

When operated as a power-amplifier a maximum amplified signal output of 13dBm and gain of 23dB were obtained. The amplifier output S/N ratio was found to be limited by signal-spontaneous beat noise to 52dB in a 1GHz bandwidth. Thus when incorporated into a digital link, typically 13dB extra transmission capability with no detrement to a 10^{-9}BER will be obtained.

When used as a preamplifier, maximum gains of 30dB and minimum input signal levels of -40dBm are predicted for the amplifier to achieve a 10^{-9}BER in a 1GHz bandwidth. This compares favourably with a typical maximum sensitivity for a Ge APD detector of -33dBm.

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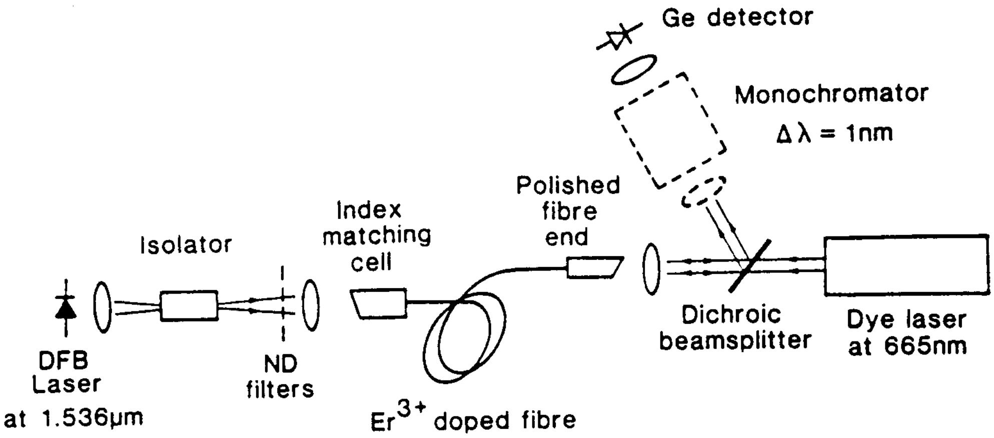

Figure 1 Schematic of the Erbium-doped fibre amplifier experiment.

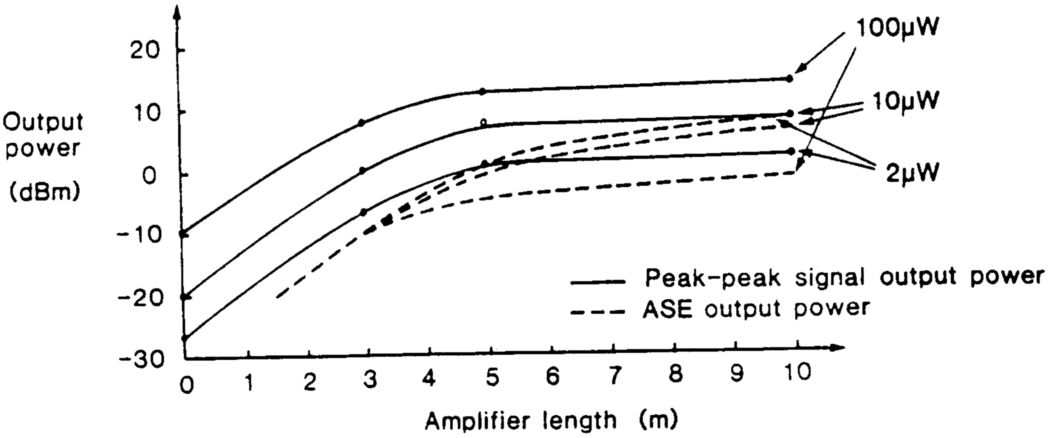

Figure 2 The dependence of peak-peak signal power and amplified spontaneous emission (ASE) output from the amplifier on fibre length.

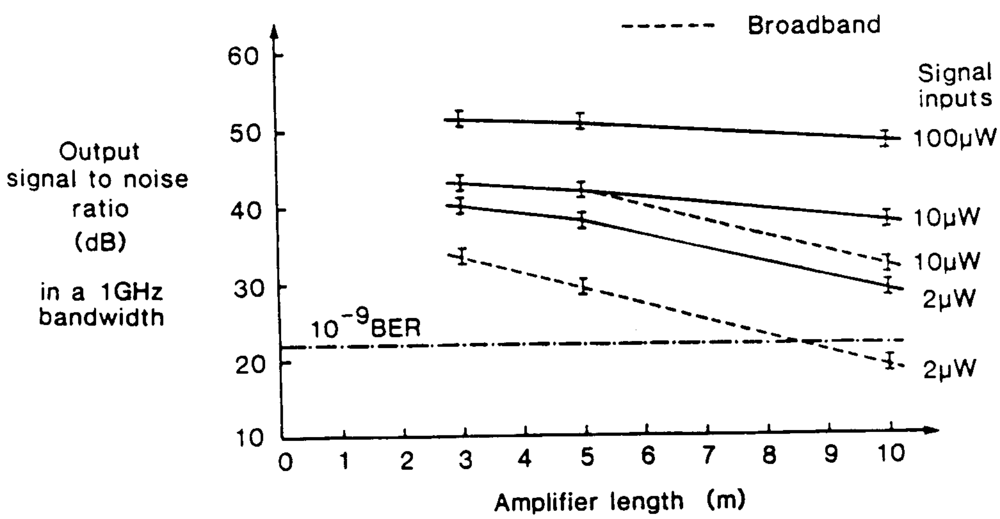

Figure 3 The dependence of amplifier output signal to noise ratio {20Log(peak-peak signal/rms noise)} on fibre length for the three signal inputs, with an without optical filtering on the amplifier output.