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Measurements of non-linear noise re-distribution in an SOA

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Abstract: Measurements of the noise statistics after a semiconductor optical amplifier (SOA) demonstrate non-linear noise re-distribution with a strong power and bandwidth dependence.

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Introduction

Many devices for all-optical signal processing are based on the non-linear saturation characteristics of semiconductor optical amplifiers (SOAs) [1,2]. We present measurements of the noise statistics after amplification by an SOA, which clearly demonstrate noise suppression due to gain dynamics and a change in the form of the noise distribution. The results are particularly important for all-optical regenerators employing SOAs [2,3].

The experimental setup

The setup, shown in Fig. 1(a), consists of a cw laser (LD), a noise source in the form of a fiber amplifier (EDFA 1), optical band-pass filters, the examined amplifier (SOA/EDFA2), a detector and a bit-error rate test-set (BERT). The probability density functions (PDFs) are derived from measuring the BER as function of decision threshold voltage [4]. We have investigated a commercial bulk InP/InGaAsP SOA and compared it to a fiber-based pre-amplifier.

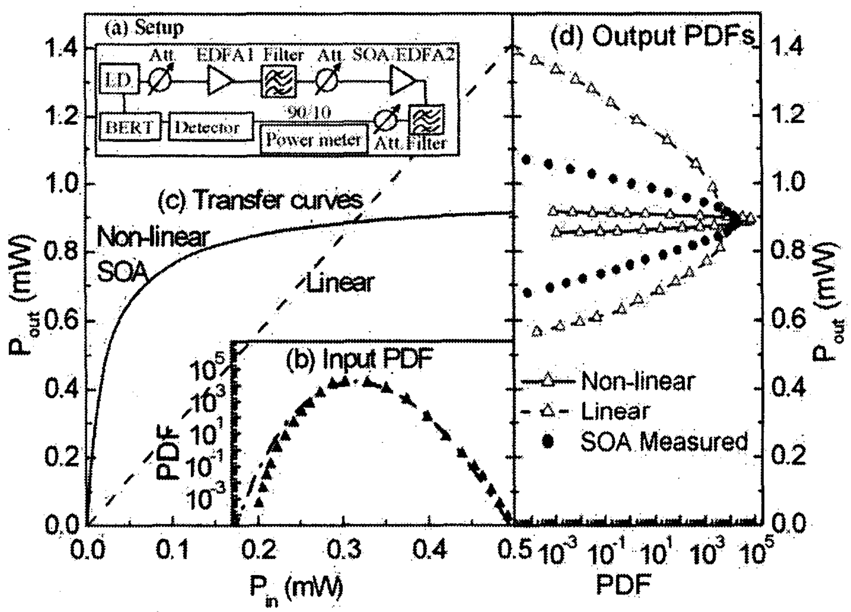

Fig. 1. (a) Schematic of the measurement setup, (b) the PDF measured after the noise source (solid triangles) compared to a non-central χ^2 distribution (dash-dotted line), (c) the measured static transfer functions for the SOA studied (solid line) and a linear transfer function with the same gain as the SOA at P_{in}=-5dBm (dashed line) and (d) the measured PDF for the SOA (solid circles) compared to the input PDF transformed with the static transfer function (open triangles and solid line) and linear transfer (open triangles and dashed line).

Results

The concept of non-linear noise redistribution is illustrated in Figure 1. The measured input and output PDFs are shown in 1(b) and (d), respectively. We include in 1(d) the input PDF transformed according to a linear transfer function as well as the measured non-linear transfer function. It is clearly seen that the measured PDF falls in-between these two limiting cases. This can be explained as a consequence of the gain dynamics of the SOA, which also govern noise-redistribution due to self-modulation of the gain. The measurement bandwidth (≈10 GHz) is thus of the same order as the modulation bandwidth of the SOA, and the noise transformation can be described neither by the static (saturation) transfer curve, which implies too strong noise suppression due to the non-linearity, nor by a linear transfer function, which neglects the gain dynamics all-together.

Figure 2 compares PDFs measured for an SOA and an EDFA (EDFA2) for different input powers. The absence of a narrowing of the noise distribution after the EDFA is explained by the slow dynamics of the EDFA compared to the measurement bandwidth. This renders the EDFA a linear device, in terms of noise transformation, despite operation beyond the DC saturation power. Figure 2 also includes fits to non-central χ^2 distributions and the deviations show that the tails of the noise distribution are strongly modified, with important consequences for BER–estimates.

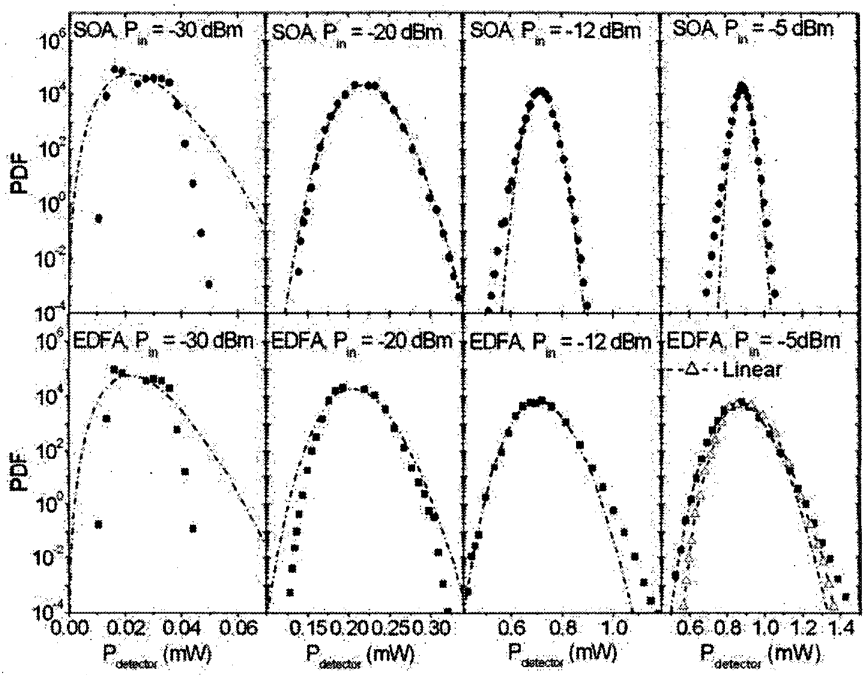

Fig 2. Measured PDF for the SOA (top) and the EDFA (bottom) compared to a non-central χ^2-distribution with the same mean and standard deviation. The last EDFA (P_{in}=-5dBm) is also compared to the linearly transferred input PDF from Fig. 1 (open triangles).

Fig. 3 shows the standard deviation and skewness of the measured PDFs, plotted against the mean values. The non-linear transfer function of the SOA reduces the width of the PDF compared to the linear EDFA. The skewness describes the asymmetry of the PDF [5], with a positive/negative number indicating a long high/low power tail. It is clearly seen that the redistribution in the SOA gives a shift from positive to negative skewness when the power is increased, in accordance with the static transfer function.

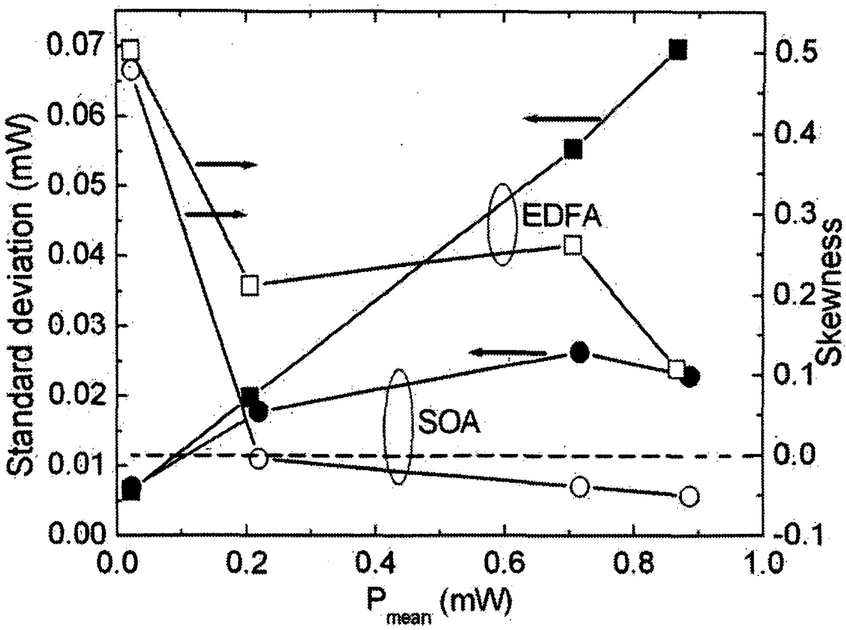

Fig. 3. The standard deviation and skewness of the PDFs after the second amplifier, as a function of mean output power.

Conclusions

By measuring the noise distribution after optical amplification we have shown that the gain dynamics of an SOA induce noise suppression and a change of the tails of the noise distribution, with important consequences for all-optical regenerators.

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