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Post Deadline Papers

Session Tu-10

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Excess Photon Noise from High-Power Doped Fibre Superluminescent Sources
P.R. Morkel, R.I. Laming and D. N. Payne
University of Southampton, U.K.

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Integrated-Optic Michelson-Interferometer in Glass with Thermooptic Phase Modulation for High Resolution Displacement Detection
D. Jestel, A. Baus and E. Voges
University of Dortmund, F.R.G.

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Coherent Detection of Stimulated Brillouin Backscatter on a Photo conductive Three wave Mixer
J.K.A. Everard and R. Thomas
Kings College London, U.K.

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Fiber-Optic Magnetic Gradiometer Utilizing the Magnetic Translational Force
H. Okamura
NTT Transmission Systems Laboratories, Japan

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Increasing Multiplexed Fiber Sensor Array Performance by Use of a Singlemode/Multimode Recombiner
A. Dandridge, A.D. Kersey, A.B. Tveten and A.M. Yurek
U.S. Naval Research Laboratory, U.S.A.

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Fiberoptic Ring Laser Gyroscope
S.P. Smith, F. Zarinetchi and S. Ezekiel
Massachusetts Institute of Technology, U.S.A.

EXCESS PHOTON NOISE FROM HIGH-POWER DOPED-FIBRE SUPERLUMINESCENT SOURCES

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ABSTRACT

Measurement of the noise characteristics of a superluminescent erbium-doped silica fibre source shows a noise component in addition to shot noise which prevents the SNR of the source output increasing beyond a fixed value. The additional noise component can be attributed to excess photon noise and will be present in all broadband sources emitting above a certain power.

INTRODUCTION

For a number of optical sensor applications including the Fibre Optic Gyro (FOG), a broadband optical source is required for optimum operation of the sensor. In the case of the FOG, the short coherence length associated with a broadband source effectively overcomes detrimental effects associated with coherent backscatter and the optical Kerr effect[1].

Potential sources for the FOG include superluminescent diodes (SLD's) and the newly-developed super-radiant rare-earth-doped fibres. SLD's operating at 1300nm are capable of providing around 1mW of optical power into a single-mode fibre and are characterised by linewidths >40nm. Rare-earth-doped fibres have been shown to provide >30mW of single mode power in the case of a laser-diode pumped Nd-doped silica device[2], and are characterised by linewidths in the range 2-20nm.

High-power light sources are preferred in order to provide enough signal at the detector so as to maximise the SNR of the sensor. In general, any detection scheme will show a threshold level of detected signal power below which the noise floor of the receiver dominates over the photon noise in the detected signal. Below this threshold level an increase in signal level increases the SNR (signal/noise power ratio) according to $\langle I_s \rangle^2$, where $\langle I_s \rangle$ is the mean detected current signal, and hence is highly desirable. Above this level the SNR will increase in proportion to $\langle I_s \rangle$ if we assume that the signal fluctuations are limited by quantum or shot noise. This is the shot noise limited case. In this case an increase in signal level is still desirable as it leads to an increase in SNR.

In this paper we show that a broadband superluminescent source has an additional noise component which will dominate over shot noise at high signal powers. Consequently, at these high signal powers the SNR does not increase with increasing signal power and no advantage results from injecting further power. We show that the signal level at which the excess noise dominates over shot noise and the maximum SNR obtainable under such conditions is determined by the optical linewidth of the source. In a typical case for a 1300nm SLD ($\Delta\lambda$=50nm) the received photocurrent level at which the SNR becomes limited by excess photon noise is around 3μA and the maximum SNR will be around 130dB.

EXPERIMENTAL

Figure 1 shows the experimental set-up used for determination of the noise characteristics of an erbium-doped silica superluminescent source. A 7.3m length of erbium-doped germanosilicate fibre (NA 0.17, second-mode cutoff 950nm, Er^{3+} concentration 60 ppm) was pumped at 980nm with approximately 40mW of power from an Argon-ion-pumped Styryl-13 dye laser. The pump input end of the fibre was cleaved normally, leaving a 4% Fresnel reflection and the signal output end was carefully terminated in an index matching cell in order to prevent feedback and laser oscillation. Using this set-up, in excess of 3mW of superradiant optical power at 1535nm in an approximate 2nm linewidth could be obtained from the source. The spectrum of the source was continuously monitored with an Anritsu spectrum analyser and the power incident onto an InGaAs detector (Epitaxx ETX300) was varied with an adjustable attenuator. The mean DC signal (photocurrent) level was monitored with an oscilloscope and the signal fluctuations were simultaneously monitored using a Marconi RF spectrum analyser. A 500kHz-bandwidth, low-noise amplifier was incorporated after the photodetector at mean signal levels below $\approx 80\mu A$. The signal fluctuations were measured around 100kHz to minimise 1/f noise and pump-noise feed-through into the superluminescent source output. This detection system enabled the signal and noise powers to be accurately monitored over a 600:1 range in signal level.

THEORY

For light from a single-mode, unpolarised thermal source, the mean square photo-current fluctuations produced in a photodetector in a bandwidth B can be written[3]:

$$\langle I_s{}^2 \rangle = 2e\langle I_s \rangle B + \langle I_s \rangle^2 B/\Delta\nu \qquad (1)$$

Here the first term is the well-known shot noise and the second term represents excess photon noise due to beating of the various Fourier components within the broadband spectrum. The coherence area of the source has been taken as equivalent to the detection area. Both the shot noise and the excess photon noise noise can be considered as "white" noise sources at frequencies of electronic interest. The term $\Delta\nu$ is determined by the optical linewidth of the source and is defined by:

$$\Delta\nu = \frac{\left(\int P(\nu)d\nu\right)^2}{\int P^2(\nu)d\nu} \qquad (2)$$

where $P(\nu)$ is the power spectral density of the optical field

Hence, the SNR of the received signal can be written:

$$\mathrm{SNR} = \frac{\langle I_s\rangle^2}{\langle \Delta I_s{}^2\rangle} = \frac{\langle I_s\rangle}{2eB + \langle I_s\rangle B/\Delta\nu} \qquad (3)$$

For

$\langle I_s\rangle \ll 2e\Delta\nu$, $\mathrm{SNR} = \langle I_s\rangle/2eB$ shot-noise limited

$\langle I_s\rangle \gg 2e\Delta\nu$, $\mathrm{SNR} = \Delta\nu/B$ excess-noise limited

Note that when excess-noise limited, the SNR is constant for all values of received power.

RESULTS

Figure 2 shows the measured noise current from the superluminescent fibre source as a function of mean detected signal current, along with similar measurements for a narrow-line He-Ne laser for comparison. The solid lines represent theoretical calculation of shot-noise current and detected excess photon-noise current as determined by Equation (1). We have used the measured linewidth of 2nm to calculate $\Delta\nu$. As can be seen in Figure 2, the noise of the superluminescent-fibre output is dominated by excess photon noise in the range of the experimental measurements, the noise current increasing by 10 dB/decade of signal. However, the He-Ne laser signal is seen to be shot-noise limited within the same range of signal levels, the noise current increasing by only 5 dB/decade of signal. The threshold detector-current level (I_{th}) at which excess photon noise dominates over shot noise for the superluminescent fibre source is calculated to be only 80nA.

Figure 3 shows the power SNR in unit bandwidth as a function of mean received signal-current for both the superluminescent source output and the He-Ne output. The solid lines represent SNR calculated from Equation (3) and the points represent experimentally-measured values. An increase in SNR associated with shot-noise-limited behaviour of 10dB/decade of signal is observed for the He-Ne source, whereas the superfluorescent source shows a SNR limited to a value given by $\Delta\nu$, in this case 114dB, in good agreement with theory.

SUMMARY

Investigation of the noise characteristics of a superluminescent fibre source shows an excess-photon-noise component associated with light from a thermal source. Similar noise characteristics will be expected of other broadband sources, such as SLD's.

The threshold photocurrent level at which excess photon-noise dominates over shot noise is given by the frequency width of the source light and is typically in the range 50nA-3μA for spectral widths in the region 1-50nm centred on 1300nm. For a typical sensor application where 20dB round-trip optical loss may be incurred by the source light, and assuming unitary detector responsivity, this range of threshold values corresponds to source powers in the range 5-300μW. Since the threshold level depends on received power, there is no benefit whatever in injecting more optical power unless the insertion loss of the sensor increases or to overcome receiver noise. The maximum obtainable SNR is given by the optical bandwidth of the source and for this range of linewidths, will be in the range 112-130dB.

It should be noted that the excess-noise described here is additional to the shot noise and it can therefore, in principle, be compensated using a two-detector reference scheme.

REFERENCES

1. R.A.Bergh, B.Culshaw, C.C.Cutler, H.C.Lefevre & H.J.Shaw, "Source Statistics and the Kerr effect in fibre optic gyroscopes", Opt.Lett.,7, pp 563-565.

2. I.N.Duling, L.Goldberg, W.K.Burns, "High power diode-pumped superluminescent fibre source", paper TUP4, Proc. CLEO 89, Baltimore U.S., April 1989.

3. H. Hodara : "Statistics of thermal and laser radiation", Proc. IEEE., Vol. 53, p. 696, 1965.

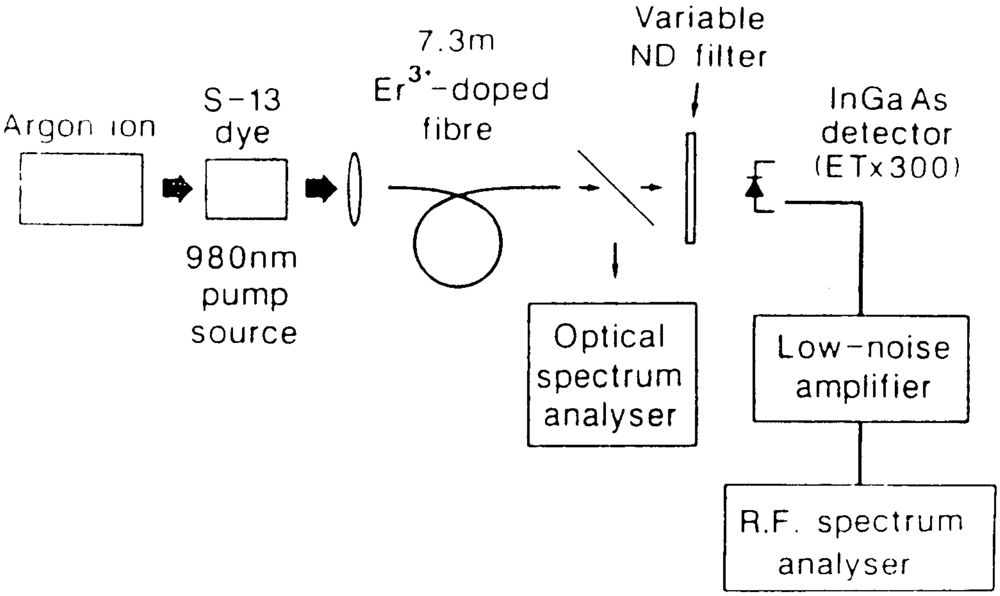

Fig. 1. Experimental configuration for noise measurements. Low noise amplifier incorporated for signal levels <80μA.

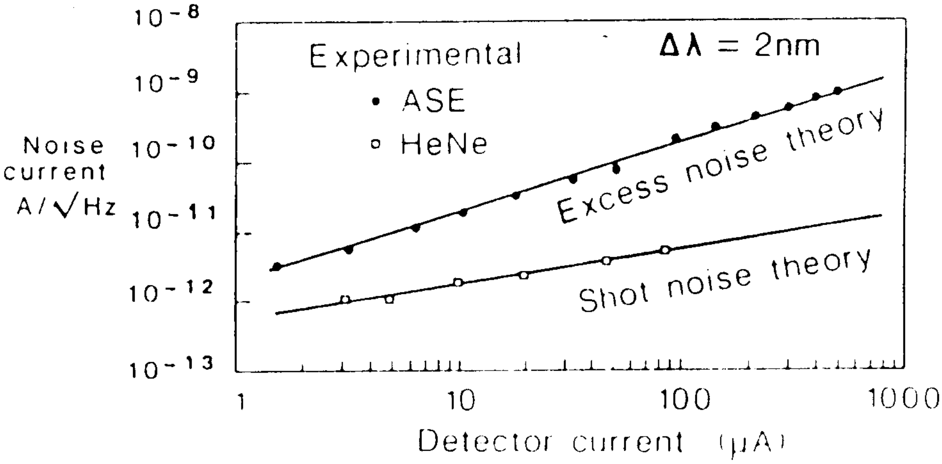

Fig. 2. Superradiant source & He-Ne noise current vs signal level. Points represent experimental values and solid lines represent theory.

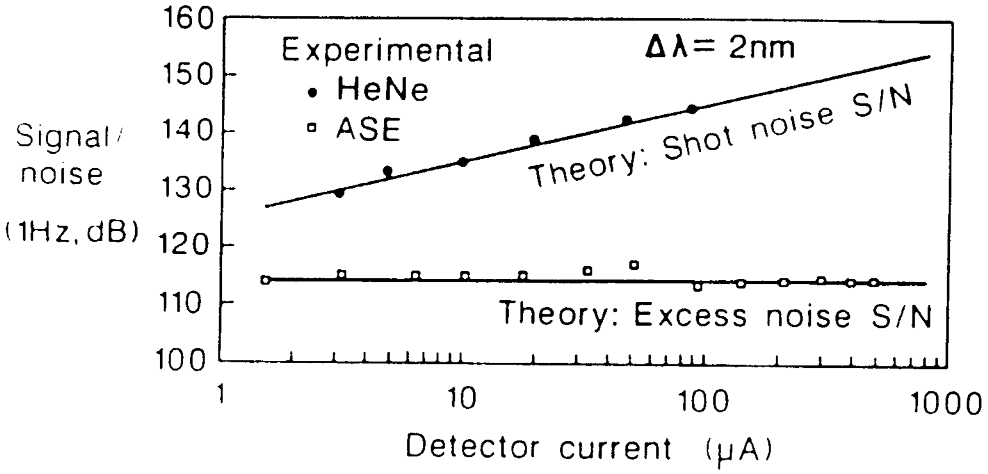

Fig. 3. Superradiant source and He-Ne SNR vs detected signal level.