NOVEL NOISE MEASUREMENT SETUP WITH HIGH DYNAMIC RANGE FOR OPTICAL RECEIVERS

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A novel method is proposed, and verified experimentally, for wideband noise measurements with high dynamic range on optical receiver front ends. A synthetic white noise source, based on delayed selfhomodyne mixing, is calibrated with a weak shot noise source. The receiver noise is reconstructed from the calibrated synthetic noise source by ratio measurements.

The design, characterisation and testing of receivers for optical transmission systems require measurements of the receiver noise, e.g. in terms of the absolute single-sided spectral noise density of the equivalent noise current of the preamplifier input. For amplifiers with an electrical input, ratio measurements with calibrated external electrical noise sources are commonly used, because of their simplicity. Ripple in receiver gain and spectrum analyser sensitivity will not affect the measurement accuracy. For receivers with an optical input ratio measurements with very weak (shot) noise sources have been reported (e.g. Reference 1). The spectral noise density of these sources is related to their associated DC current via [$i_n = \surd(2 . q . I_{DC})$], and therefore accurately known.

Various constant light sources can be used as shot noise sources. An incandescent lamp generates pure shot noise but may suffer from severe coupling losses in the case of pigtailed optical receivers. The use of unmodulated LEDs and lasers as shot noise sources will overcome this problem but may suffer from inaccuracy caused by (unknown) additional noise generated in the active semiconductor layer [2].

In general, shot noise sources must be kept weak for noise measurements to avoid DC overloading of the optical receiver (10 pA/$\surd$(Hz) shot noise is associated with 312 μA DC current). This will limit the dynamic range of the measurement.

We realised a ratio noise measurement setup with a synthetic white noise source, based on delay selfhomodyne mixing [3]. Up to 300 pW/q(Hz) optical noise power density was available associated with less than 100 μA DC. We developed a two step calibration method based on ratio measurements, to calibrate the synthetic noise source with pure shot noise in an additional reference receiver, and applied this source to determine the noise level of optical receivers under test.

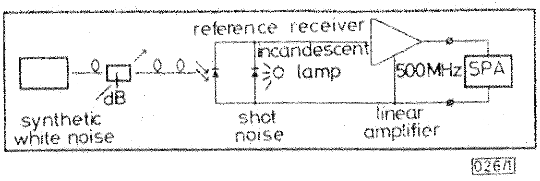

Fig. 1 *Setup for calibration of synthetic noise source*

Experimental setup: For the generation of synthetic noise, we constructed a delay selfhomodyne sweeper [3] (DFB laser, 1530 nm, 60 dB isolator, 10 m delay line, manual polarisation adjustment and 10 MHz modulation frequency). From DC to a frequency $B = \Delta\nu$ the spectrum of the photodiode current is assumed to be flat, where $\Delta\nu$ is the maximum frequency deviation from the optical carrier frequency [3].

Fig. 1 shows the calibration setup for the synethetic noise source. The low noise 500 MHz reference receiver was based on a second order current current feedback [4] amplifier (ATF132.84 input FET, 40 mA/V), and two shunted identical photodiodes (2 × 1·2 pF, connectorised, without pigtail). For the shot noise, a simple 1 W miniature lensed incandescent lamp (pocket torch) illuminated one of the photodiodes. When switched on, it caused $I_{DC} = 53\,\mu$A (DC) diode current and $i_n = \surd(2 . q . I_{DC}) = 4{\cdot}1$ pA/$\surd$(Hz) associated shot noise. The output noise was detected by an HP70905A spectrum analyser (SPA), 300 kHz resolution bandwidth and 1 kHz video filter. The SPA was computer controlled to perform postprocessing of data.

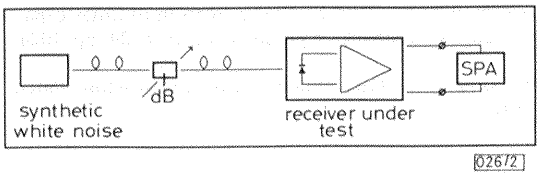

Fig. 2 *Setup for ratio noise measurements on optical receivers*

Fig. 2 shows the setup used for noise measurements on arbitrary optical receivers with a calibrated synthetic noise source. Other white noise sources, e.g. based on heterodyne mixing of laser and LED, or the noise of optical amplifiers, would also have been good candidates for the measurement setup, but were not investigated.

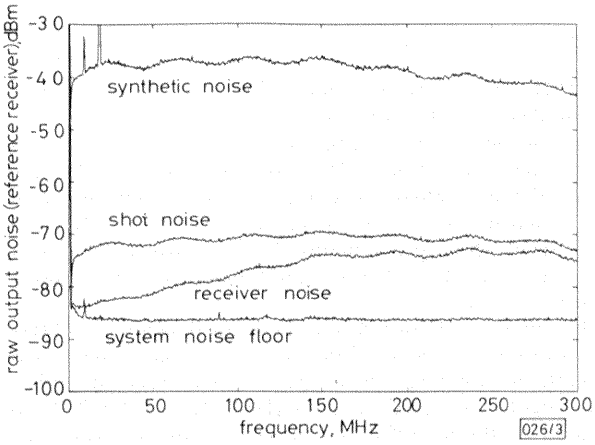

Fig. 3 *Raw spectral measurements performed on output of reference receivers*

Calibration of synthetic noise source: Four raw spectral measurements were performed on the output of the reference receiver when the noise sources and the reference receiver were switched on and off (see Fig. 3).

The measured output noise is a mix of various additional uncorrelated noise sources, e.g. the combination of shot noise, amplifier noise and instrument noise. Further, it is affected by the gain of the reference receiver.

Therefore the first correction step was to determine the contribution of the individual sources to the combined output noise (see Fig. 4). The gain function was then reconstructed from this plot by smoothing the output spectrum of the (pure) synthetic noise source. Fig. 5 shows the equalised spectra and, as expected, demonstrates that the correction steps result in a shot noise spectrum that is truly flat. Finally, the equivalent input noise current was reconstructed by scaling these plots to a value that causes the average shot noise current in a band of

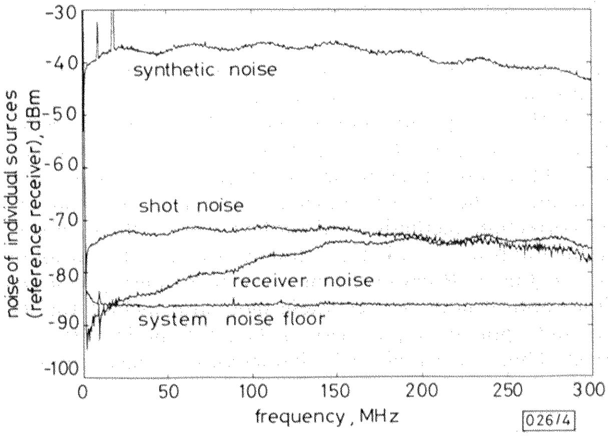

Fig. 4 *Contribution of individual sources to combined output noise*

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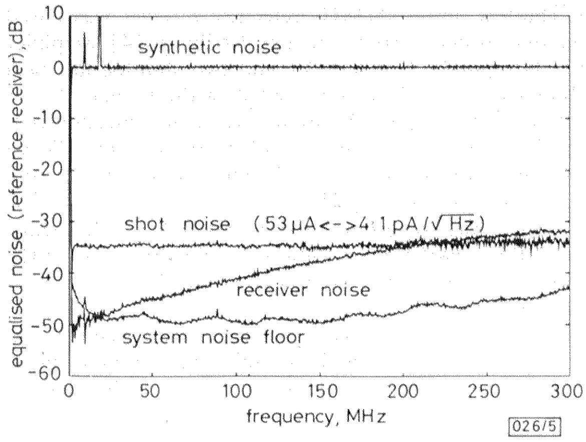

Fig. 5 *Equalised noise spectra*

50–150 MHz to satisfy the value of $4{\cdot}1\,\mathrm{pA}/\sqrt{(\mathrm{Hz})}$ caused by $53\,\mu\mathrm{A}$ diode current (see Fig. 6).

From all these steps we concluded that the synthetic noise source generates $225\,\mathrm{pA}/\sqrt{(\mathrm{Hz})}$ noise current density. The ratio of the associated current ($60\,\mu\mathrm{A}$ DC) and the noise current density is a characteristic figure: $\beta = I_{DC}/i_n = \sqrt{(71{\cdot}5\,\mathrm{GHz})}$. This ratio remains the same when the optical signal is attenuated and fed to a photodetector with unknown responsivity.

Although the calibration was performed below 150 MHz, the calibration is valid over the entire frequency band where the synthetic noise source is 'white'. We observed with a 22 GHz lightwave signal analyser (HP70810A + HP70908A), calibrated by the manufacturer, a white noise spectrum over more than 20 GHz bandwidth.

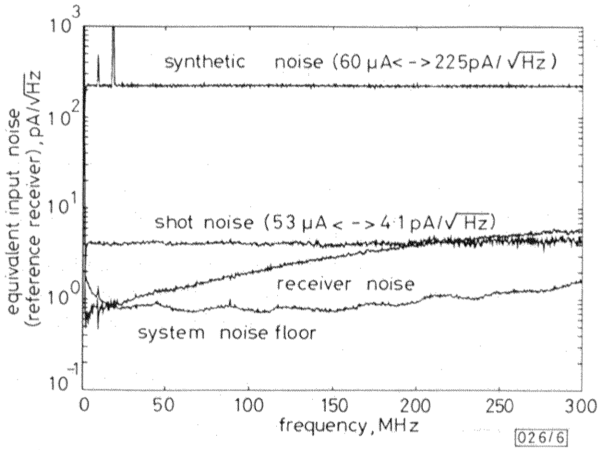

Fig. 6 *Equivalent input noise current*

Measurement of receiver under test: A portion of $85\,\mu\mathrm{W}$ optical power of the calibrated synthetic noise source was fed to a 3 GHz HP83410B optical receiver, which is associated with $85/\beta = 315\,\mathrm{pW}/\sqrt{(\mathrm{Hz})}$ equivalent optical noise power density. Three raw spectral measurements were performed on the output of the receiver under test (see Fig. 7). Using the same correction methods as described before, these spectra were unwrapped, equalised and finally scaled to the absolute values in Fig. 8. Because the measurements were performed with an optical noise source, these plots also include the RF decay and ripple in responsivity of the photodiode in the test receiver. Thus, an overall O/E characterisation has been performed.

Conclusions: We propose a novel [5] method for wideband optical noise measurement with a white synthetic noise source in combination with a two-step calibration method. To perform absolute and accurate measurements, shot noise and an additional LF reference receiver were used for calibration.

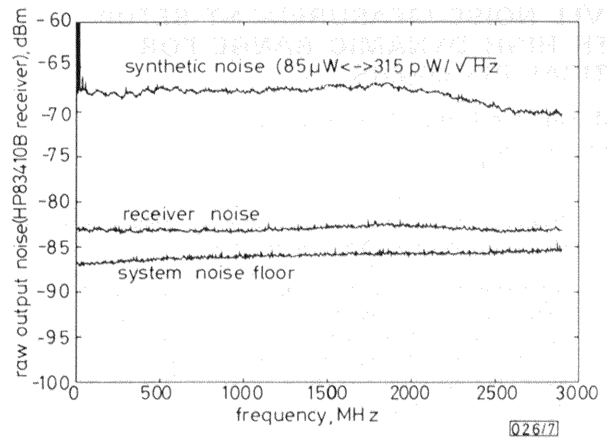

Fig. 7 *Raw spectral measurements performed on output of receiver under test*

The method combines the simplicity of ratio measurements, with the absolute accuracy of shot noise sources, with the high dynamic range and flexibility of synthetic white noise sources. Therefore it is applicable in a wide spectral range for a wide range of optical receivers (such as pigtailed, noisy, frequency dependent multigigahertz receivers with poor DC offset), without modifications on the receiver under test. Furthermore, the method provides measurements that are valid, in $\mathrm{pW}/\sqrt{(\mathrm{Hz})}$, at the optical input of the test receiver.

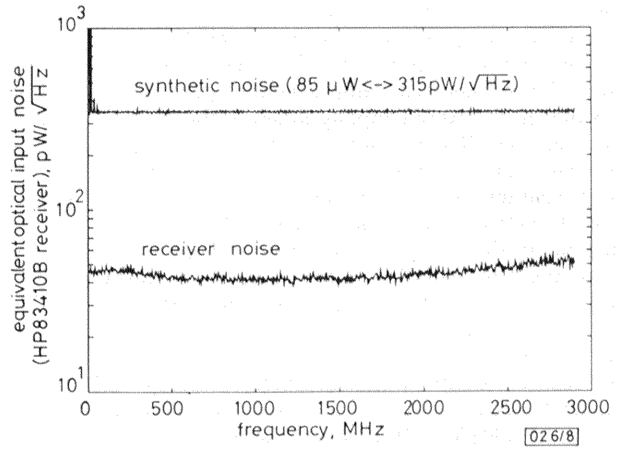

Fig. 8 *Equivalent optical input noise*

We applied this method to measure the noise level of an HP measurement receiver, thus demonstrating the usefulness of our method. We demonstrated that the delay selfhomodyne sweeper is a good synthetic noise source for noise measurements.

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