NOVEL ELECTRICAL NOISE SOURCE BASED ON LIGHTWAVE COMPONENTS

R. F. M. van den Brink
PTT-Research, Dr. Neher Laboratories
P.O. Box 421
2260 AK Leidschendam, The Netherlands

KEY TERMS

Variable noise sources, shot-noise calibration, noise measurement, synthetic noise, lightwave components

ABSTRACT

A novel electrical noise source is proposed, based on lightwave components and internal shot-noise calibration, which offers an attractive alternative to conventional 50-Ω noise sources. This report describes the principle, and the experimental verification of various quality aspects like linearity, absolute accuracy, and impedance robustness.

1. INTRODUCTION

In order to carry out noise measurements on electrical amplifiers, various white noise sources are commercially available. Most of these sources are provided with fixed output impedance (50 Ω) and fixed on and off noise levels, and are calibrated with respect to thermal noise. An optical counterpart based on shot noise calibration has been recently introduced [1].

Combining a photodiode and a lightwave synthetic white noise source results in an accurate electrical noise source with attractive additional features including:

- variable noise over wide dynamic range (ENR: 0–40 dB)
- variable output impedance (Z: 0–100 kΩ//0.2 pF)
- output impedance invariant under variation of noise level
- absolute accuracy based on simple dc current measurements
- applicable as a "Noise-Tee."

This report describes the proposed setup, measurements on the linear relation between noise current and dc currents, and measurements on the absolute accuracy of the predicted spectral noise density.

2. DESCRIPTION OF THE EXPERIMENTAL SETUP

Figure 1 shows the proposed variable electrical noise source, which is composed of a photodiode illuminated by a lightwave synthetic noise source, and a reference receiver for calibration. A detailed description of this setup is reported in [1]. In the experiment, a delayed self-homodyne sweeper was used as a lightwave noise source [2] (white from LF up to 22 GHz). When connected to the noise head, the variable lightwave signal generates the variable electrical noise and associated dc current. When connected to the reference receiver the ratio between noise and dc current can be derived from a built-in weak shot noise source. A dedicated reference receiver was used to perform both low-noise and high-linearity performance [3]. The shot noise (4 pA/$\sqrt{\text{Hz}}$) was generated by an incandescent lamp that was switched on and off.

For the various currents, the following name conventions will be used:

Definition of dc currents in photodiodes (A)

I_{dd} = device dc current (noise head, sweeper)
I_{dr} = reference dc current (reference receiver, sweeper)
I_{dc} = calibration dc current (reference receiver, lamp)

Definition of associated spectral densities of noise currents (A/$\sqrt{\text{Hz}}$)

i_{nd} = device excess noise (noise head, sweeper)
i_{nr} = reference excess noise (reference receiver, sweeper)
i_{nc} = calibration excess noise (reference receiver, caused by the lamp)

For calibration, the lightwave signal was attenuated and adjusted to a value that causes the reference noise to be equal

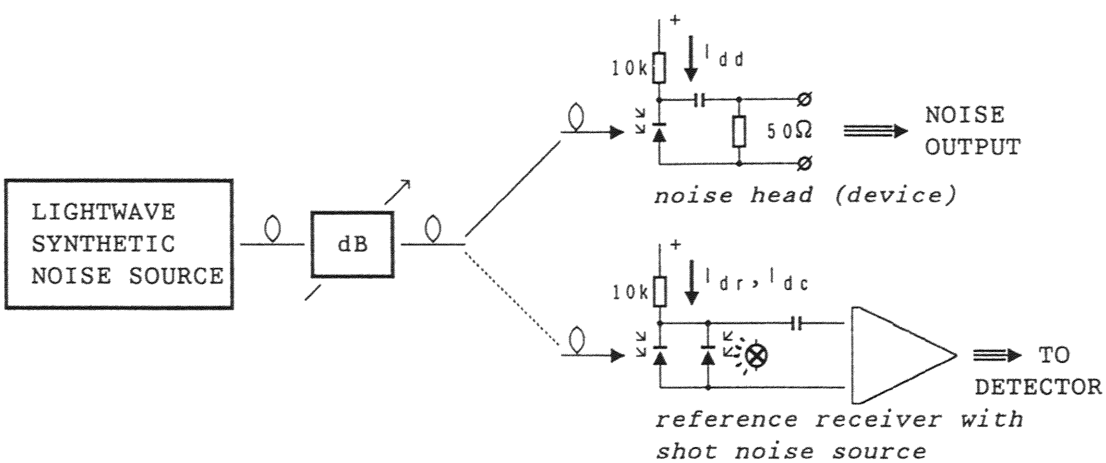

Figure 1 Basic setup of the wideband electrical noise source with shot-noise calibration

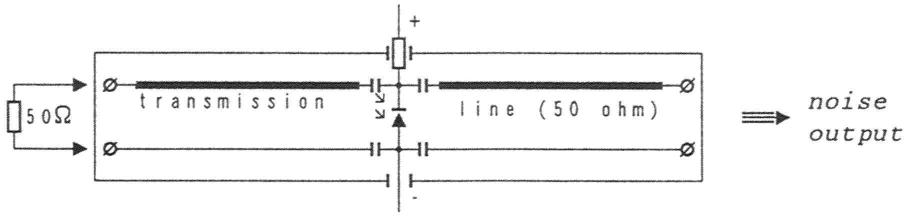

Figure 2 A noise head in tee configuration facilitates external modification of output impedance as well as the signal feedthrough

to the calibration shot noise. This can be checked with a spectrum analyzer or selective voltmeter by alternate switching of the synthetic noise source and the incandescent lamp on and off. The reference noise is then set to the value $i_{nr} = i_{nc} = \sqrt{2q \cdot I_{dc}}$, with q the charge of a positron.

When the associated dc current I_{dr} is measured, the adjustment is no longer relevant and the intensity of the lightwave signal can then be changed to generate the desired device excess noise in the noise head. The ratio $(i_{nd}:i_{nr})$ is equal to the ratio of the associated dc currents $(I_{dd}:I_{dr})$ and is independent of imbalance in the optical path and responsivity of the individual photodiodes. The device excess noise can be predicted from all dc-current measurements by

$$i_{nd} = (I_{dd}/I_{dr}) \times i_{nc} = (I_{dd}/I_{dr}) \times \sqrt{2q \cdot I_{dc}}\ (\mathrm{A}/\sqrt{\mathrm{Hz}}),$$

$$q = 1.6022 \cdot 10^{-19}\ (\mathrm{C}).$$

The calibration procedure used eliminates all nonlinearity errors and the influence of the system noise caused by the reference receiver and the spectrum analyzer. The calibration can be performed in a small frequency band (e.g., 50 MHz) because the spectral noise density of the lightwave source is frequency independent.

3. DESCRIPTION OF THE NOISEHEAD

The noise head was implemented as a "noise-tee" with an external 50-Ω resistor. Figure 2 shows this configuration based on a biased photodiode shunted to a short 50-Ω transmission line. The overall responsivity of this construction was flat up to 1.5 GHz, which was mainly limited by the internal photodiode capacity and serial inductance (1 pF and 2.5 nH).

The noise-tee configuration facilitates the external modification of output impedance as well as signal feedthrough. When the external resistor in Figure 2 is replaced by a one-port impedance tuner an attractive alternative to conventional setups with two-port impedance tuners is realized for the measurements of all four noise parameters of transistors.

Although the lightwave source generates white synthetic noise, the spectral density of the device noise is slightly affected by frequency-dependent variation in the photodiode

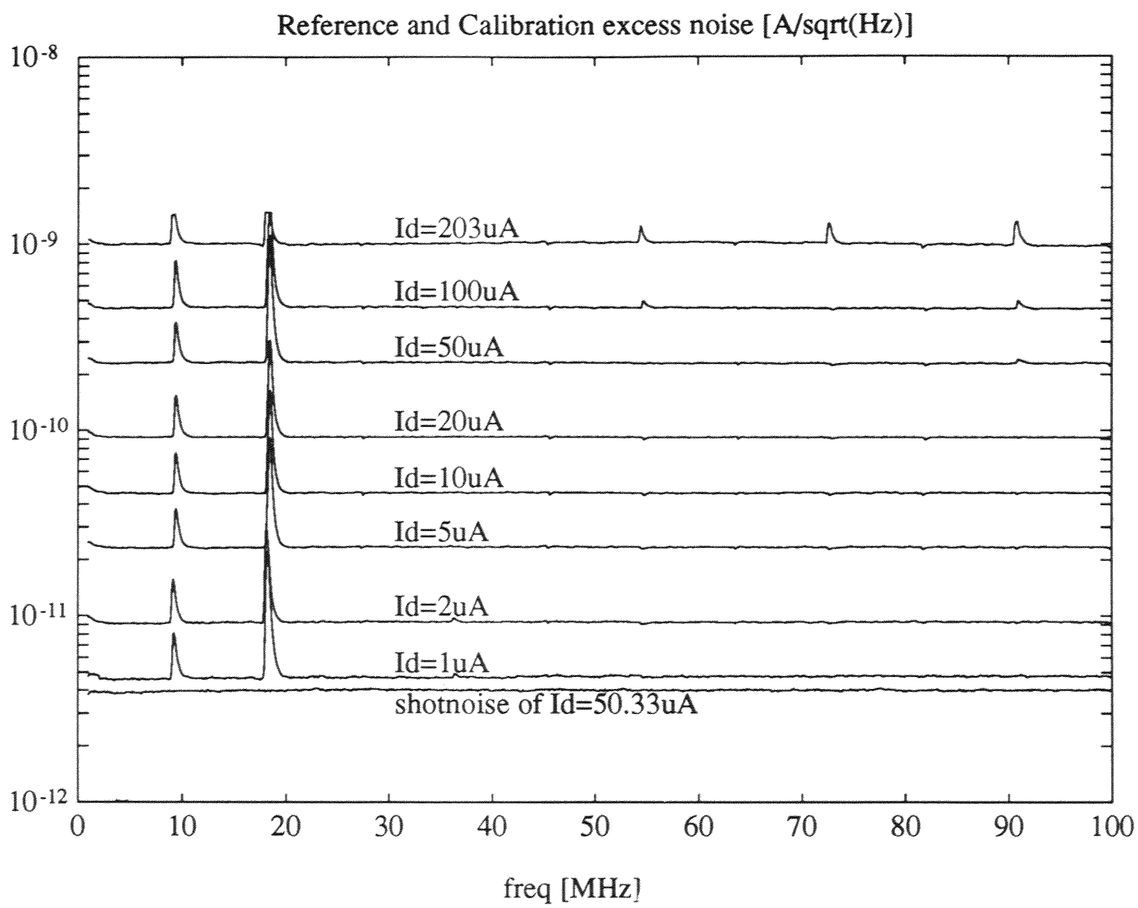

Figure 3 Reference and calibration excess noise in reference receiver

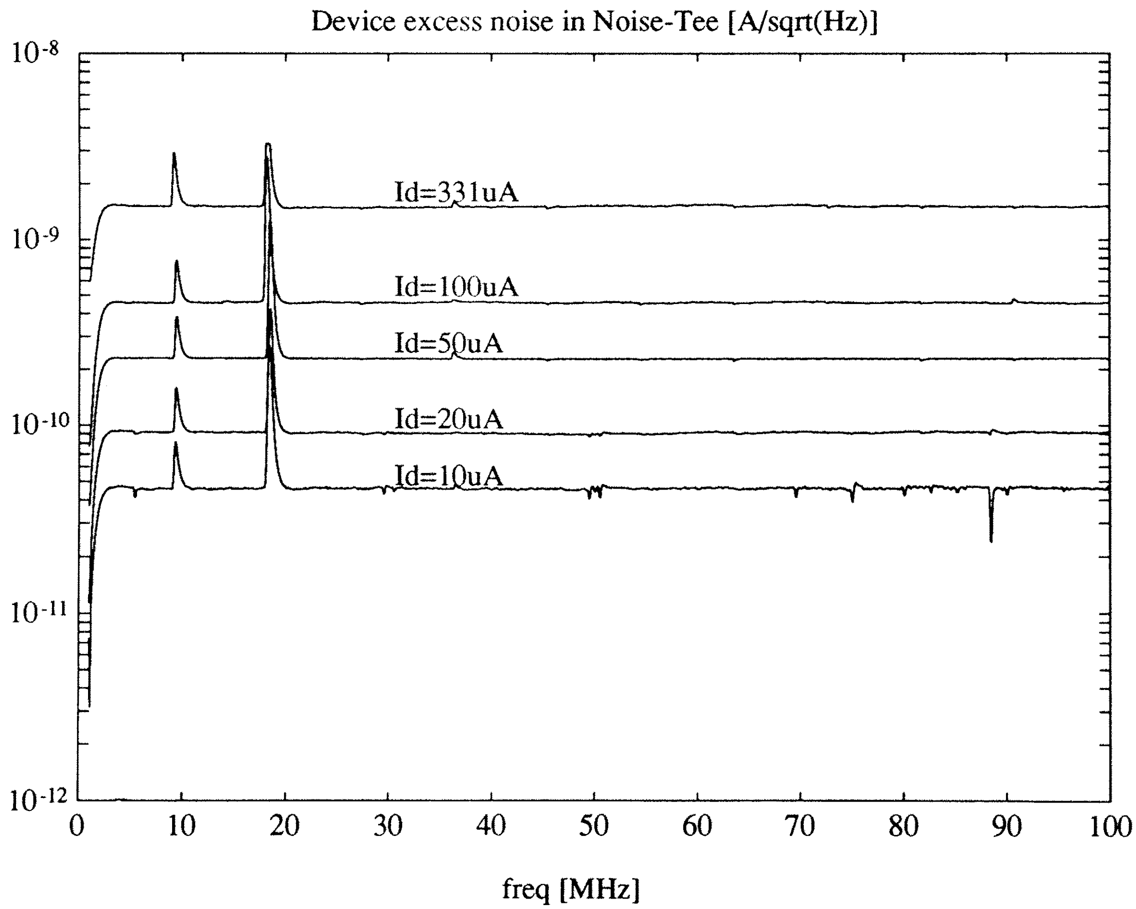

Figure 4 Device excess noise in noise-tee

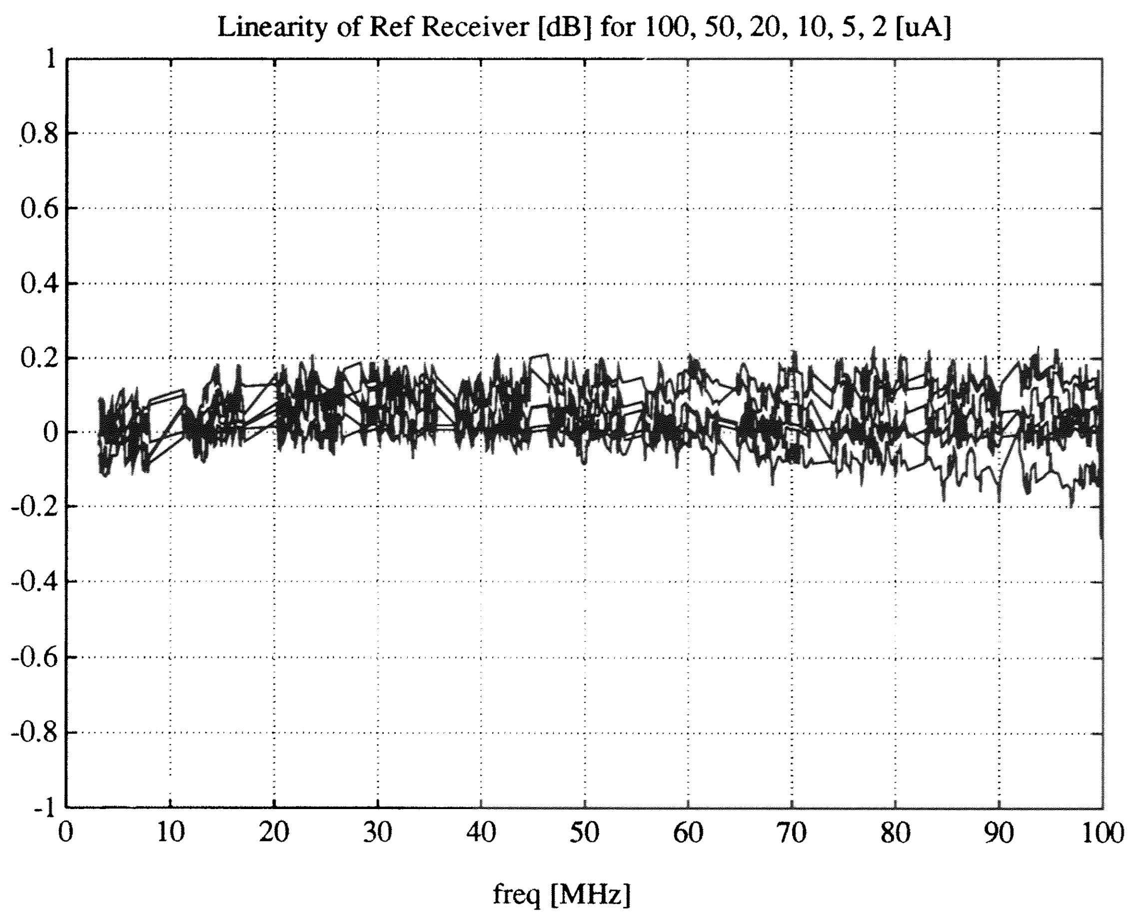

Figure 5 Deviation in the ratio noise current in decibels, measured for 100, 50, 20, 10, 5, and 2 [μA] reference dc current in the reference receiver

responsivity. While this is a *relative* correction to the absolute calibration at lower frequencies, these variations can be measured accurately with any lightwave component analyzer and supplied to the noise head as a correction table.

4. EXPERIMENTAL VERIFICATION OF LINEARITY

The linear dependence of the noise current density to the dc photo current was verified experimentally below 100 MHz.

The noise signals were measured with a HP8566b spectrum analyzer (attenuator 0 dB, resolution bandwidth 100 KHz, video bandwidth 1 Hz, and sweep time reduced to 50 sec). The device noise was preamplified using a power amplifier (minicircuits ZHL-1-2W, 500 MHz, 2 W, 29 dB). These measurements are best carried out at low signal levels, using amplifiers with wide dynamic range, using a spectrum analyzer with sufficient spectral purity and a self-calibration procedure to avoid problems with system nonlinearity.

All measured raw spectra were unwrapped, equalized, and scaled to absolute values as described in [1]. Figures 3 and 4 shows the various excess noise currents generated in the photodiodes of the reference receiver and the noise-tee. The spectra of the reference noise and the calibration shot noise are highly frequency independent, which demonstrates the flat frequency response of the photodiodes below 100 MHz and the validation of the unwrapping and equalizing procedure.

The spikes in the reference noise are principal aspects of the delayed self-homodyne sweeper signal and are a consequence of its internal 9-MHz modulation. The ratio of the dc diode current and the spectral noise density ($I_{dr}/i_{nr} \approx \sqrt{47\text{ GHz}}$) is constant, and is useful as a figure of merit for the lightwave synthetic noise source. This ratio is indicative of the usable synthetic noise bandwidth and results from the calibration process. Figures 5 and 6 show the deviation of this ratio for various noise densities and demonstrates that the overall linearity of the experimental setup was better than ± 0.2 dB. This is within the specified measurement accuracy of the spectrum analyzer used and demonstrates that an even higher linearity is plausible. Spikes at multiples of 9 MHz were removed in these plots.

5. EXPERIMENTAL VERIFICATION OF ABSOLUTE ACCURACY

To verify the accuracy of the proposed variable noise source, the device noise was compared at 60 MHz with a commercially available calibrated noise source (HP346C, ENR = 13 dB) and a noise figure meter (HP8970a). The calibration dc current was measured to be 49.67 μA, and thus associated with 4.00 pA/$\sqrt{\text{Hz}}$ shot noise. The reference noise was set to the same value and the associated dc current was measured to be 0.858 μA. The device DC current was set to 20 μA, and thus the associated device excess noise was predicted to be $(20/0.858) \times 4.00\text{ pA}/\sqrt{\text{Hz}} = 93\text{ pA}/\sqrt{\text{Hz}}$. This device noise was then fed to the noise figure meter that indicated $\text{NF} = 13.75\text{ dB} = 20 \cdot \log(i_{hot}/i_{cold})$. This is equivalent to 85.3 pA/$\sqrt{\text{Hz}}$ excess noise.

The prediction of the device excess noise, based on shot-noise calibration, appeared to be about 9% higher than the indicated value by the noise figure meter. This deviation was systematic and reproducible. The assumed but ignored influence of the parasitic shot noise of the device and reference

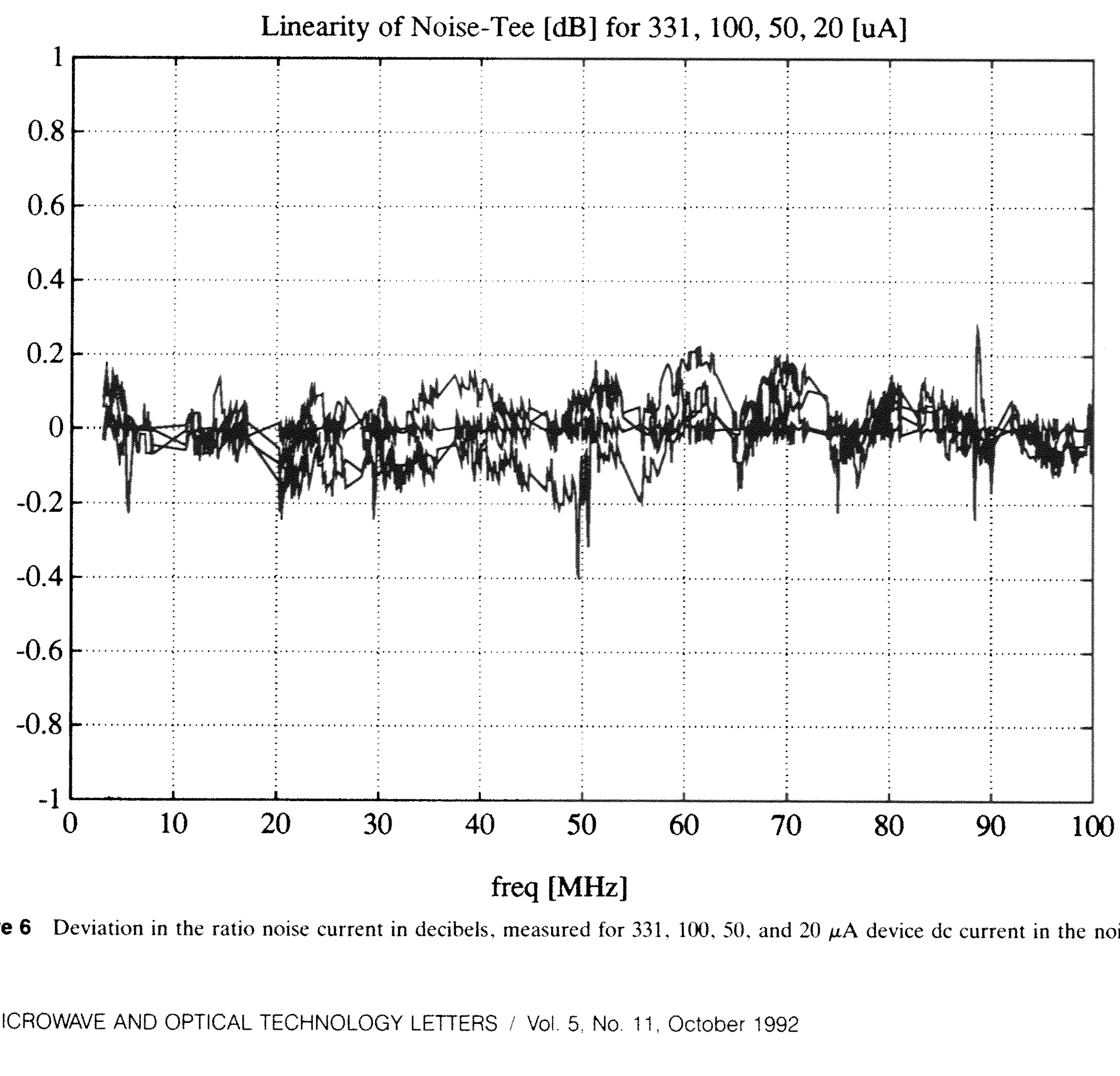

Figure 6 Deviation in the ratio noise current in decibels, measured for 331, 100, 50, and 20 μA device dc current in the noise tee

dc currents is less than 0.8% in this example, and therefore not responsible for this deviation.

When the shot noise source is responsible for this discrepancy, then its noise was less than 92% of its theoretical value. This is unlikely because this is incompatible with the general accepted shot noise limit of the sensitivity of fiber-optic transmission links.

When the noise figure meter is responsible for this discrepancy, then the excess noise ratio (ENR) of the noise source is about 1 dB too low. This is unlikely too, because the accuracy of these sources are specified to 0.1 dB typical and to 0.3 dB worst case and is in conformity with two other calibrated noise sources.

There were no other means available to verify this contradiction, which forms an item for further investigation. Yet the linearity and reproducibility are high, which enables accuracy improvement by precalibrating the assumed error of the shot noise source with a noise standard.

6. VERIFICATION OF CONSTANT IMPEDANCE

The output impedance of commercially available noise sources are liable to changes of 20% when switched on and off (HP346C: $Z_{\text{hot}} = 46.5\,\Omega$, $Z_{\text{cold}} = 55.8\,\Omega$, below 100 MHz). Due to this impedance variation the noise contribution and the gain of the amplifier under test is subject to (unknown) variations and will result in measurement errors.

In many situations the change in output impedance of the proposed noise-tee is negligible. When shunted by a 50-Ω load, variations of less than 0.1 dB were measured at 2 GHz when the lightwave noise source was switched on and off, and less than 0.5 dB when the bias voltage of the photodiode was reduced from 20 to 10 V.

7. CONCLUSIONS

A novel electrical noise source is proposed, based on lightwave components, that offers an attractive alternative to conventional 50-Ω noise sources: The noise and output impedance are easily variable. The impedance of the photodiode is invariant under noise variations and orders of magnitude higher than 50 Ω; this quality facilitates a noise-tee configuration. The built-in shot noise calibration enables high absolute accuracy by simple dc-current measurements. The high accuracy is proven by means of linearity tests, absolute calibration tests, and impedance variation tests. A contradiction was observed between pure shot noise calibration and the calibration of commercially available noise sources.

REFERENCES

1. R. F. M. van den Brink, E. Drijver, and M. O. van Deventer, "Novel Noise Measurement Setup with High Dynamic Range for Optical Receivers," *Electron. Lett.*, Vol. 28, 1992, pp. 629–631.
2. J. Wang, et al., "Measurement of Frequency Response of Photoreceivers Using Self-Homodyne Method," *Electron. Lett.*, Vol. 25, 1989, pp. 722–723.
3. R. F. M. van den Brink, "Optical Receiver with Third-Order Capacitive Current-Current Feedback," *Electron. Lett.*, Vol. 24, 1988, pp. 1024–1025.

Received 5-15-92

Microwave and Optical Technology Letters, 5/11, 549–553

CCC 0895-2477/92/$4.00