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A PROCEDURE FOR ACCURATE NOISE MEASUREMENTS OF ONE PORT DEVICES WITH HIGH REFLECTION COEFFICIENTS

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ABSTRACT

This work presents a procedure to reduce effectively the uncertainty of noise measurements of highly reflective one-port DUT's. This procedure consists of inserting an attenuator between the calibration reference plane and the DUT. The measurement RSS uncertainty has been calculated analytically and an excellent improvement of the accuracy and repeatability has been obtained when attenuations of moderate values were used.

INTRODUCTION

In the noise characterization of one port DUT's with high reflection losses a high degradation of the measurement accuracy is observed [1],[2]. In addition, one-port devices do not provide any gain, as a transistor or an amplifier, and this requires severe specifications to the one-port noise measurement system in terms of system noise, gain and power sensitivity. These problems make the noise characterization of devices such as Schottky diodes particularly difficult at the IF frequencies normally used for millimeter wave mixing operation, since these devices present a high reflection coefficient for both low and high bias currents in this frequency range.

Therefore, an accurate measurement procedure is needed to validate models of highly reflective one-port devices. An improved accuracy in the noise measurement of these devices may be obtained if the DUT is matched to the measurement system. A matching procedure utilizing a non reflective attenuator connected between the calibration reference plane and the DUT is proposed. This effectively reduces the magnitude of the reflection coefficient at the calibration reference plane in a fairly broad range of frequencies and bias currents. The DUT noise temperature is then extracted from the measurement of the noise temperature at the calibration reference plane, at which the reflection coefficient is lower. This results in a considerable improvement of the measurement accuracy, if moderate values of the attenuation are used.

NOISE MEASUREMENT UNCERTAINTY

Figure 1 shows the experimental setup used for the measurements of highly reflective one-port DUT's. This setup is based on the method originally proposed by Gasquet et al. [3].

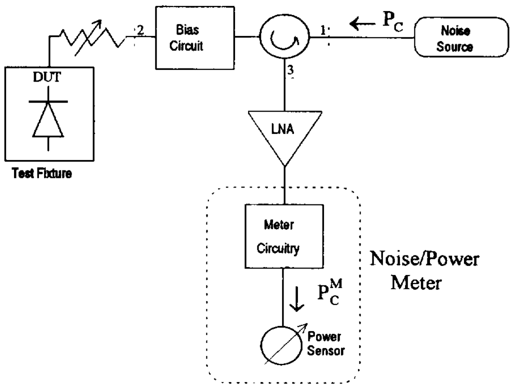

Figure 1

A calculation of an analytical expression for the RSS uncertainty of the noise temperature measurement was made in [2] and showed how the accuracy is affected by factors like the available gain and noise of the measurement system, the ENR of the noise source and the DUT reflection coefficient. Two assumptions were made in this calculation: 1) the circulator physical temperature and the source cold noise temperature are the same, and 2) the source reflection coefficient is zero at both the cold and hot states. This leads to the following expression for the noise temperature at the calibration reference plane:

$$T_N(\rho, P_C^M, G_{AV}, T_{SYS}, T_C) = \frac{1}{1-\rho}\left(\frac{T_O P_C^M}{G_{AV}} - (T_{SYS} + \rho T_C)\right) \quad (1)$$

where T_O is the standard temperature (290 K), T_{SYS} the measurement system noise temperature, T_C the noise source cold temperature, ρ the square of the reflection coefficient magnitude measured at port 2, G_{AV} the measurement system available gain and P_C^M the measured power when the source is in its cold state normalized to the noise floor. Assuming that the attenuator is perfectly matched to the system, the DUT noise temperature may be extracted from (1) through the expression

$$T_{DUT} = \frac{T_N - T_R(1-A_{AT})}{A_{AT}} \tag{2}$$

where A_{AT} is the power attenuation of the attenuator, and T_R the attenuator physical temperature. The RSS uncertainty of the DUT noise temperature is then

$$\varepsilon^2_{T_{DUT}} = \frac{\varepsilon^2_{T_N} + (1+A^2_{AT})\varepsilon^2_{T_R} + 0.053(T_R^2+T_N^2)\varepsilon^2_A}{A^2_{AT}} \tag{3}$$

where ε_A is the uncertainty of the attenuator losses expressed in dB, ε_{T_R} is the uncertainty of the room temperature measurement, and ε_{T_N} is the RSS uncertainty of the noise temperature measured at port 2 in K, already calculated in [2], and given by

$$\varepsilon_{T_N} = \sqrt{\Psi_\rho^2 + \Psi_P^2 + \Psi_G^2 + \Psi_T^2} \tag{4}$$

where Ψ_ρ, Ψ_P, Ψ_G and Ψ_T are the contributions to the overall error of the uncertainty of the DUT reflection coefficient, the meter resolution, the system available gain and the system noise temperature, respectively.

If no attenuation is used between the bias network and the DUT, the uncertainty of the DUT noise temperature approaches to infinity as the DUT reflection coefficient approaches to unity. This is illustrated with a practical example, in which the expressions obtained were applied to the experimental measurements of Schottky barrier devices at the intermediate frequency of 1.5 GHz. Schottky diodes are widely used at this frequency for mixing applications in the range of millimeter and submillimeter waves [4], [5].

Figure 2 shows the calculated measurement uncertainty as a function of the DUT reflection coefficient for different values of the attenuation, in comparison with the uncertainty calculated without using any attenuator.

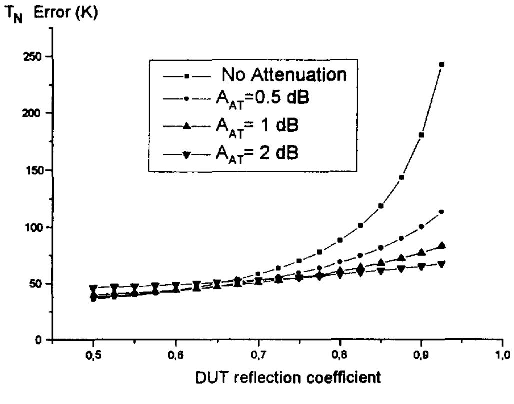

Figure 2

The DUT noise temperature was 150 K, and the measurement system had 100 K of overall noise temperature and 2 dB of overall available gain. In this gain the internal attenuators of the noise meter input must be considered.

The improvement of the accuracy at high reflection coefficients is made at the expense of slightly increasing the uncertainty at low reflection coefficients. A number of DUT's present a reflection coefficient that varies from zero to one, depending on the bias current. This is the case for a Schottky barrier diode. For these devices, the use of a fixed attenuator degrades the accuracy when the device is nearly matched. This loss of accuracy may be avoided with the use of a variable attenuator, which allows the introduction of the attenuation only when the DUT presents a reflection coefficient close to unity.

EXPERIMENTAL MEASUREMENTS

The setup shown in figure 1 was used to measure the IF noise of a Schottky barrier device. Both the reflection coefficient and noise temperature are shown in figure 3 as a function of the bias current. These measurements are in good agreement with noise models of Schottky diodes previously published [6]-[9]. The theory predicts a device noise temperature equal to the physical temperature when the device is at zero bias, and a reduction of the noise to a value given by the shot noise mechanism at intermediate values of the bias current, which is nearly the half of the room temperature multiplied by the ideality factor, η. Additional noise mechanisms like the hot electron effects, intervalley scattering and traps increase the DUT noise at large currents. The characterization of these mechanisms is particularly difficult, since at large currents the device reflection coefficient becomes close to unity.

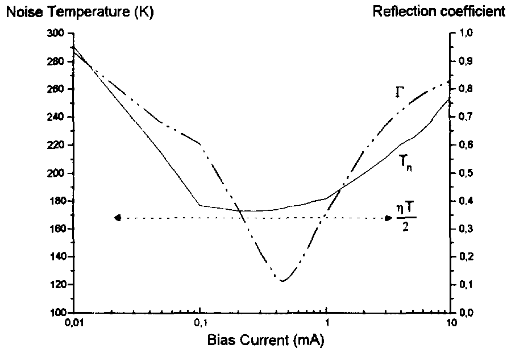

Figure 3

A high improvement of the measurement repeatability was also observed with the inclusion of the attenuator. This allowed the reduction of the measurement averaging, and therefore the time needed to make the measurements. A reduction of the measurement time is particularly important when the device is biased at large currents, since the corresponding increase of the device temperature introduces errors in the noise measurement.

CONCLUSIONS

A simple procedure of reducing the uncertainty in one-port noise measurements when the device presents a high reflection coefficient has been presented. An expression for the RSS uncertainty of the DUT noise temperature for the modified setup has been obtained and compared with the uncertainty of the measurements made with the original setup. A practical example in which noise measurements of a Schottky barrier device were made has illustrated the degree of improved accuracy that may be obtained.

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