Experimental Investigation of On-Wafer Noise Parameter Measurement Accuracy

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Abstract

The accuracy problem of noise parameter characterization of active microwave devices in highly mismatched systems is addressed. An experimental investigation is made to determine the dependency of noise parameter measurement uncertainty on the device's output mismatch. We have designed and fabricated five different structures of a new passive device, useful as a verification artefact, suited for on-wafer measurements. The main feature specifying this device is the same order of magnitude for input-output reflection coefficient and for noise parameters, as for low noise field effect transistors.

Introduction

The need of accurate and repeatable noise parameter measurements has become very important for the transistor technology development, and for the design of low noise microwave circuits and systems. Presently, some laboratories tend to develop on wafer calibration standards to provide traceability to national standards for microwave S-parameter measurements of GaAs MMIC circuits [1]. Meanwhile, to check accuracy of noise parameter test-sets, noise reference standards exist only for coaxial or waveguide media, for matched impedance measurements. For other test systems, using on wafer probe technique, users rely on a verification procedure to derive confidence in the measurements.
Previous studies on noise parameter measurement accuracy have dealt with the location of source reflection coefficient states and the instrumentation uncertainties using a simulation approach [2][3], with the influence of the noise parameter extraction algorithms [6][7], and with the sensitivity to the on-wafer S-parameter calibration methods [10]. Other studies have already addressed the issue of noise measurement verification using several different passive devices [3-7]. However, the characteristics of the proposed verification devices are not very close to the real test conditions of active transistors. We have introduced in a previous work [9], a new passive structure based on a Lange coupler, useful as a verification artefact, suited for on-wafer measurements due to its small size and wide operation bandwidth. Its characteristics of noise parameters and input-output reflection coefficients are same order of magnitude as for low noise FETs, field effect transistors.
This paper introduces five different new structures of the verification device which have been designed to study the effect of the DUT's output reflection coefficient on the noise parameter measurement errors.

Noise Verification Procedure

The verification procedure consists in comparing noise parameters calculated with measured S-parameters at a given physical temperature, and measured noise parameters of a simple lossy passive network. The differences, which are measurement residual errors, characterize a part of the accuracy of the test-set.
Lossy passive two-ports generate only thermal noise. The correlation matrix of lossy passive two-ports are for scattering matrix representation :

$$C_S = kT\,\Delta f\left(I - S.S^{+}\right) \qquad (1)$$

where k : Boltzmann's constant, T : physical absolute temperature of the two-port, I : an identity matrix, S : scattering matrix, + : the conjugate transpose, Δf : noise bandwidth.
The scattering noise correlation matrix representation is transformed into the chain representation using the general transformation formula :

$$C_A = T.C_S.T^{+} \qquad (2)$$

Transformation matrix T can be obtained by establishing relations between the noise amplitude of the original and resulting two-port, and by expressing these relations in matrix form [9].

Then, noise parameters are computed using the chain noise correlation matrix representation :

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$$C_A = 4kTo\,\Delta f \begin{bmatrix} Rn & \frac{Fmin-1}{2} - Rn.Yopt \\ \frac{Fmin-1}{2} - Rn.Y^*_{opt} & Rn.|Yopt|^2 \end{bmatrix} \quad (3)$$

where ***Fmin*** is the minimum noise figure, ***Rn*** the equivalent resistance and ***Yopt*** the optimum admittance.

Design and Fabrication of the New Devices

The new noise verification device is a microstrip Lange coupler loaded with a resistor at its isolated port, and an open stub at the direct port (Fig-1-). The noise parameters and input-output reflection coefficients, of this passive two-port, are comparable to those of active FETs, see figures 2 and 3.

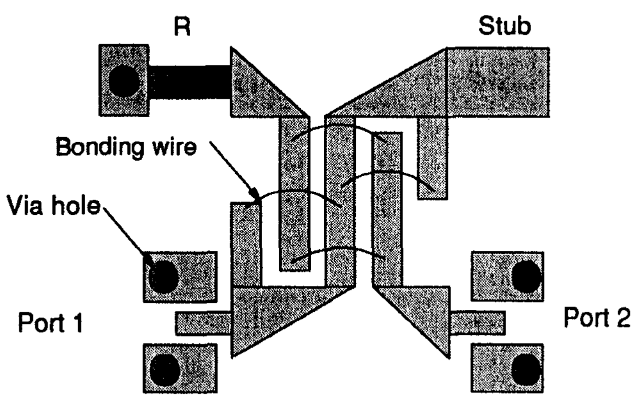

Fig-1-Design of the new noise verification device

In order to demonstrate the feasibility, we have designed and fabricated the new device, using a thin film technology on an alumina substrate. The frequency of operation and substrate thickness are such that the parasitic effects of via holes and bonding wires do not have a great influence on the mean device's characteristics [9].

Five new structures of the verification device were fabricated, their characteristics are resumed in table-1-. It shows the stub length, Ls, the resistor value, R, and indicates if the resistor is connected (C) or not connected (NC) to the ground. For these devices, the input reflection coefficient S_{11} remains nearly the same, while the output reflection coefficient S_{22} varies. The variation of the magnitude of S_{22}, that produces different output mismatch conditions during noise power measurements is also given.

Experimental Results

On-wafer microwave S-parameter measurements were performed with an HP8510B network analyzer, and noise parameter measurements with an ATN NP5 system. Several prototypes of the new verification device were tested in the frequency range of 2-18 GHz.

Figures 3 to 6 show the measurement errors, for each noise parameter, between the calculated parameter and the measured parameter, over the frequency range 2-18 GHz. These differences are mainly due to noise power measurement errors, which seem to affect more the two noise parameters, Fmin and Γopt magnitude, than *Rn* and Γopt phase. We can notice that a large error occurred at 6 GHz, around 50% for Fmin and 20% for Γopt magnitude.

Figures 7 and 8 show the measured Fmin and Γopt magnitude of a low noise Pseudomorphic HEMT, 0.2μm gate length and 6x15μm gate wide from PHILIPS PML technology, biased at Idss. We can notice ripples at 6, 9 and 18 GHz. The largest ripple occurred at 6 GHz, which is fully correlated with the previous verification device measurements. Also, we observed that large errors on Fmin and Γopt magnitude seem to be correlated, which has been verified with the new passive device measurements. This point is very important, since we could predict the bad measurement points, we could improve the determination of the transistor's small equivalent circuit and noise model.

Figure 9 shows the averaged RMS relative errors obtained for each noise parameter versus the DUT's output reflection coefficient magnitude. It confirms that Fmin is the most sensitive parameter, and that the Γopt phase seems to be less sensitive to noise power measurement errors.

Conclusion

Five structures of a new verification device, useful for on-wafer noise parameter measurement test-sets have been presented. The measurements performed with these devices, which were designed to study the DUT's output mismatch effect on noise parameter measurement accuracy, have shown an experimental estimation of the upper bound errors on the four noise parameters versus the DUT's output reflection coefficient magnitude.

Acknowledgement :

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N°	Ls (µm)	R (Ω)	GND	S22 Mag. min-max
1	300	50	NC	0.42-0.94
2	300	500	NC	0.59-0.96
3	300	500	C	0.39-0.77
4	300	50	C	0.04-0.22
5	800	500	C	0.30-0.59

Table-1- The characteristics of the 5 new devices

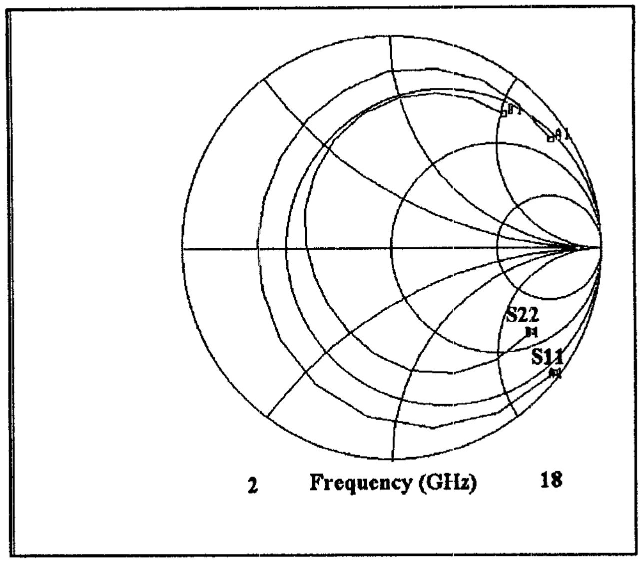

Fig-2- New verification device's input-output reflection coefficients (Device n°3)

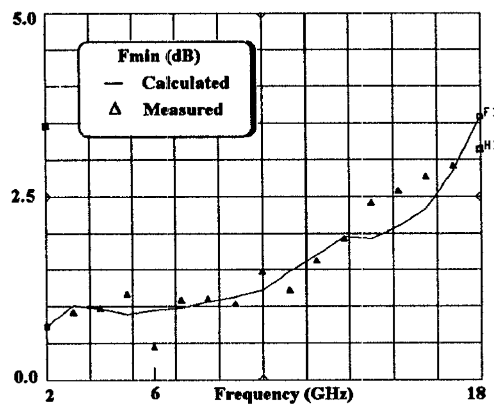

Fig-3- New verification device's Fmin (n°3)

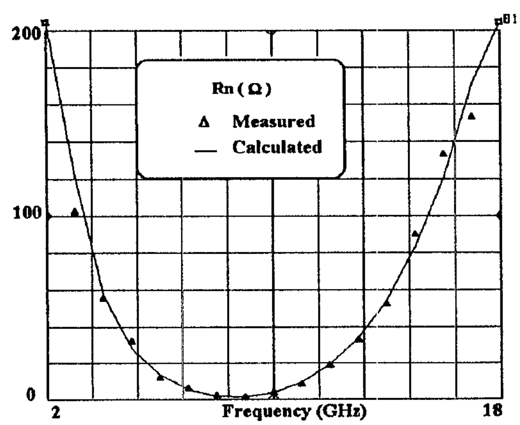

Fig-4- New verification device's Rn (n°3)

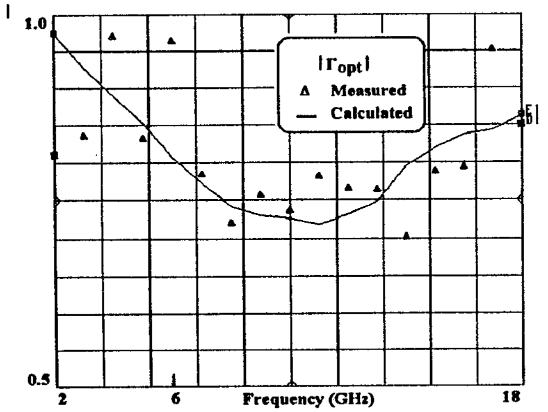

Fig-5-New verification device's Γopt magnitude

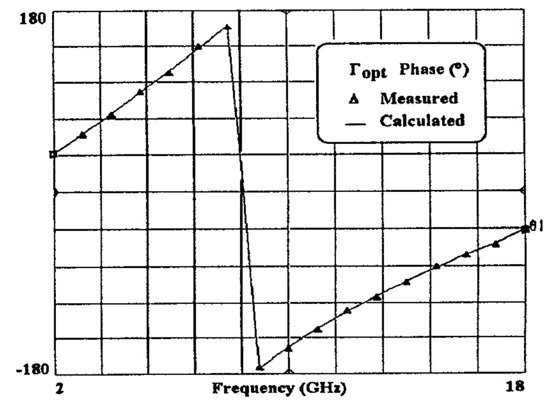

Fig-6- New verification device's Γopt phase

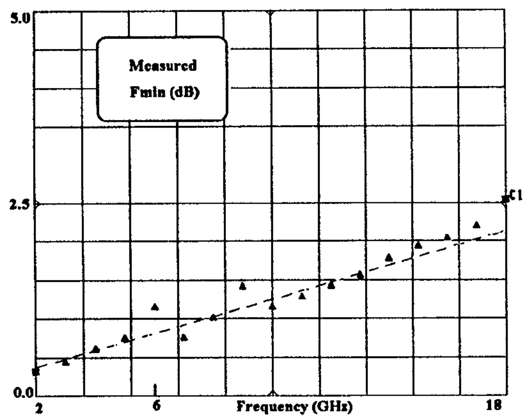

Fig-7- Mesured PHEMT's Fmin

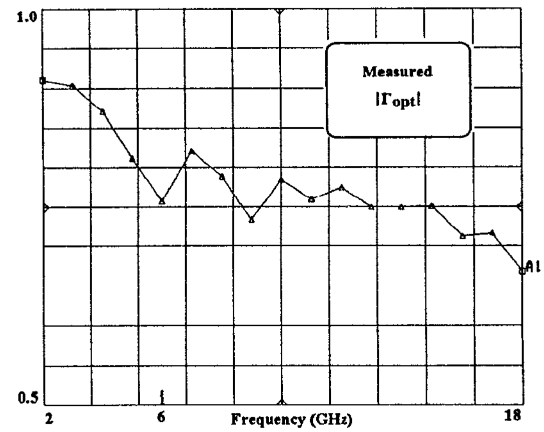

Fig-8- Mesured PHEMT's Γopt Magnitude

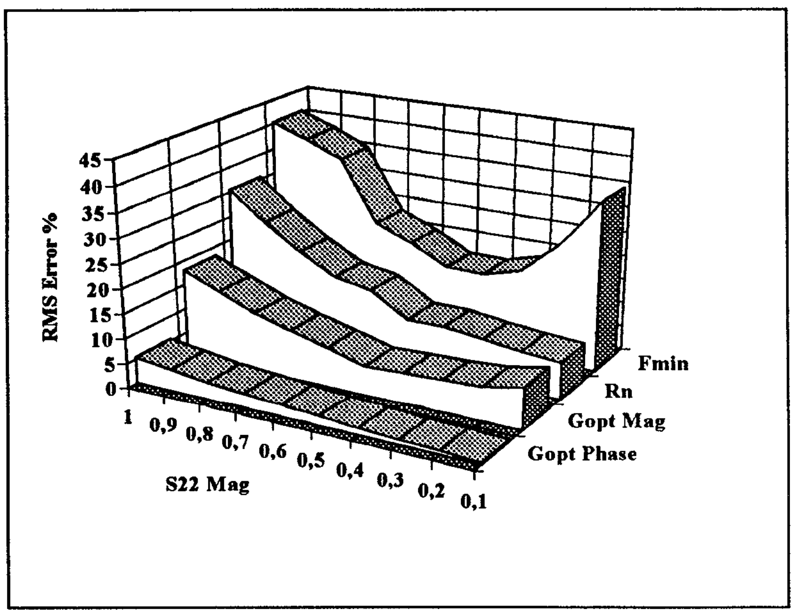

Fig-9- Averaged RMS relative errors of noise parameters vs S22 magnitude