SCATTERING AND NOISE MEASUREMENTS OF PSEUDOMORPHIC HIGH ELECTRON MOBILITY TRANSISTORS

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Abstract

In the characterization of the transistors at microwaves, scattering and noise parameters are used in circuit design and, in particular noise measurements, for quality and reliability assessment. Results presented in literature are discussed, and the measurements of the scattering and noise parameters of some PHEMTs between 2 GHz and 26 GHz are published.

Noise analysis

Noise generated by microwave transistors was studied into three frequencies regions, so that it was named: low frequency noise; between 1 Hz and 100 KHz, radio frequency noise; between 1 MHz and 150 MHz, and microwave noise, measured between 4 GHz and 18 GHz.

Low frequency noise.

Although microwaves transistors are not employed at these frequencies, low frequency noise can be up converted at microwaves and degrade noise performances of circuits. Besides, this noise is linked with the technological parameters of devices and, from its measurement versus frequencies, the energies and the corner frequencies of the generation-recombination centres (g-r) can be calculated. Noise can in fact be written as a sum of the 1/f or flicker noise and of the contribution given by the different noisy g-r processes like:

$$S_v(f) = A/f + \sum_{i=1}^{n} \frac{c_i/f_{0i}}{1+(f/f_{0i})^2} \qquad (1)$$

The values of A/f, that represents the 1/f or flicker noise contribution, the constants Ci and the corner frequencies f0i of the g-r processes can be calculated by the best fit with the measurements of the noise versus frequencies. Besides, capture and emission energies of generation centres can be evaluated by measuring devices noise at different temperatures [1].

It was discovered that at these frequencies among MESFETs, HBTs, HEMTs and PHEMTs, HEMTs are the noisiest devices. Their g-r centres are the DX centres at the interface between AlGaAs and GaAs. The effect of these impurities is particularly evident at low temperature where it can produce the collapse of the I-V characteristics.

It is possible that transistors performances at low temperatures [2], will become even more worth of measuring because the environment of circuits could become colder with the diffusion of superconductor materials [3] that, after many years of researches, are now approaching critical temperatures [4] that are easier and more economic to be reached (250 K).

Radio frequency noise

At frequencies higher than the so called excess noise corner frequency, noise is dominated by the diffusion high frequency noise and not by the low frequency 1/f or excess noise. At radio frequencies, excess noise corner frequencies of 30 MHz for MESFETs, 50 MHz for PHEMTs and 100 MHz for HEMTs were measured [1] so that, according to these data, at radio frequencies MESFETs are the less noisy devices.

Microwave noise

Transistors performances at microwaves are expressed by noise and scattering parameters values. Noise parameters are derived from a circuital representation of the device like a two port, free of noise sources and with an external voltage generator in series and a current generator in parallel with the input port. Voltages and currents are expanded in Fourier series or expressed in the Fourier integral form. Noise characteristics are taken into account considering the set of orthogonal functions in the Fourier analysis to be obtained from a series of ideal measurements on an ensemble of systems with identical statistical properties or on the same system at uncorrelated time intervals. Employing the relation between the mean square noise voltage fluctuation, the spectral density and the Fourier amplitude; a relation between the four noise parameters and the noise frequency factor or noise figure was drawn [5].

This relation, expressed in terms of the reflection coefficients is [6, 7]:

$$F(\Gamma_s) = F_0 + 4N_n \frac{\left|\Gamma_s - \Gamma_{on}\right|}{\left(1 - \left|\Gamma_s\right|^2\right)\left(1 - \left|\Gamma_{on}\right|^2\right)} \qquad (2)$$

Where F is the ratio between the total noise power per unit bandwidth available at the output port when the input termination is standard (290 K), to the portion of this power generated by the input termination. Γs is the

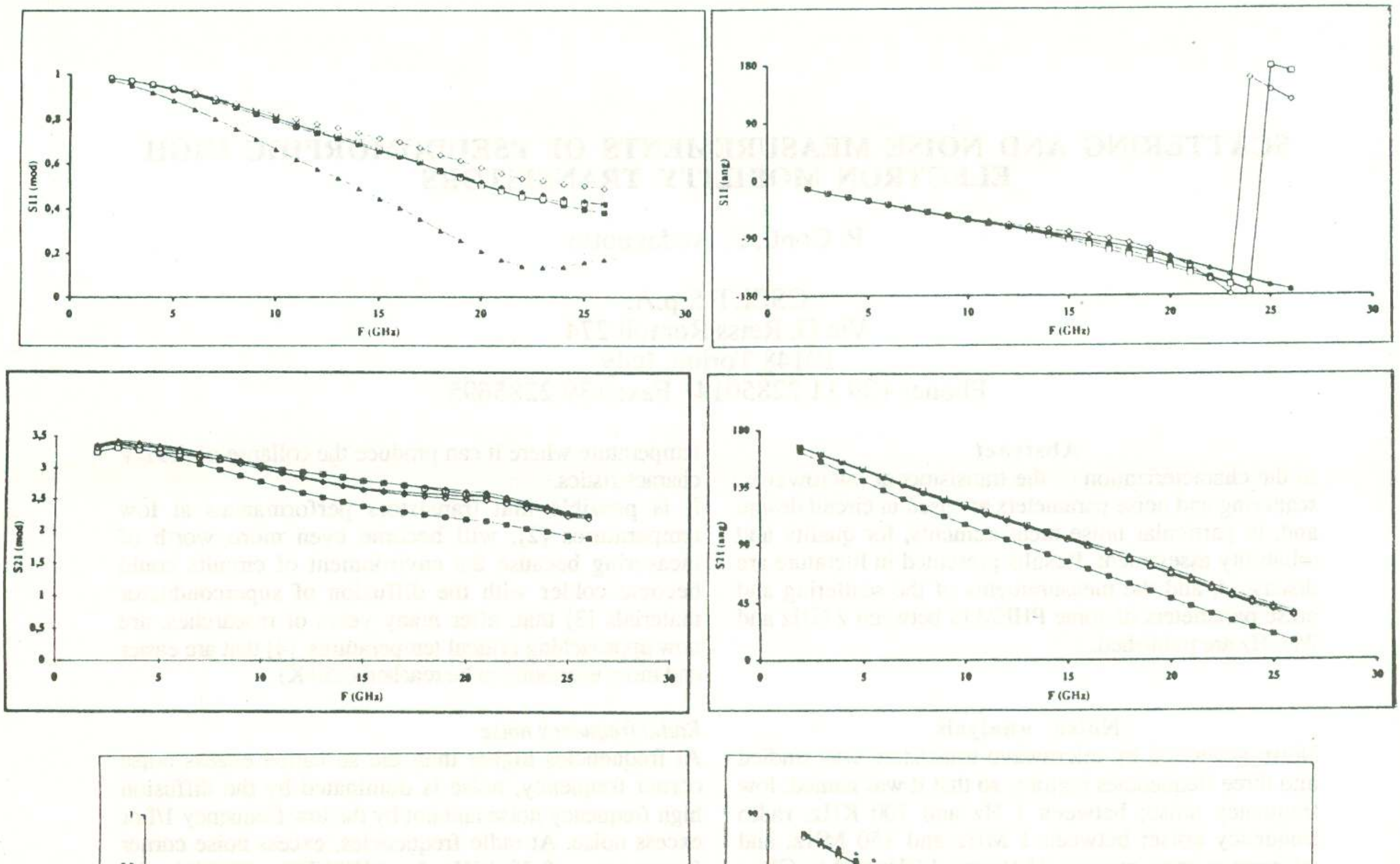

Fig.1 - Scattering parameters of five single gate low power PHEMTs between 2 GHz and 26 GHz (T = 297 K Vds=3V Ids=10 mA).

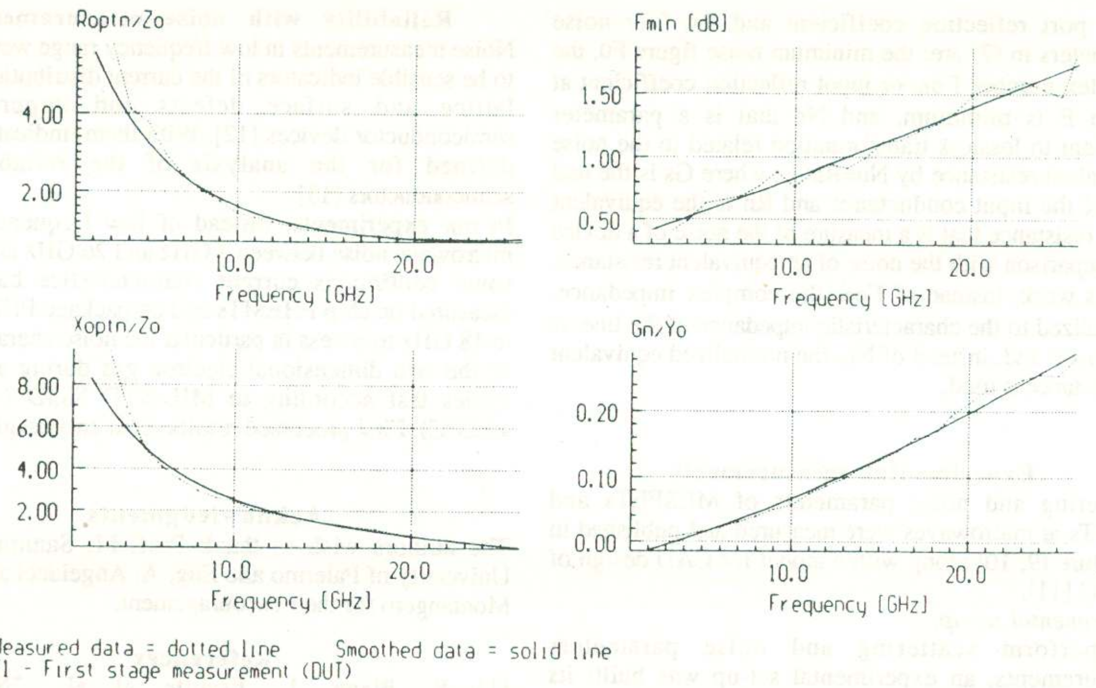

Fig. 2 - Noise parameters of a single gate low power PHEMT between 2 GHz and 26 GHz (T = 297 K Vds = 3V Ids=10 mA).

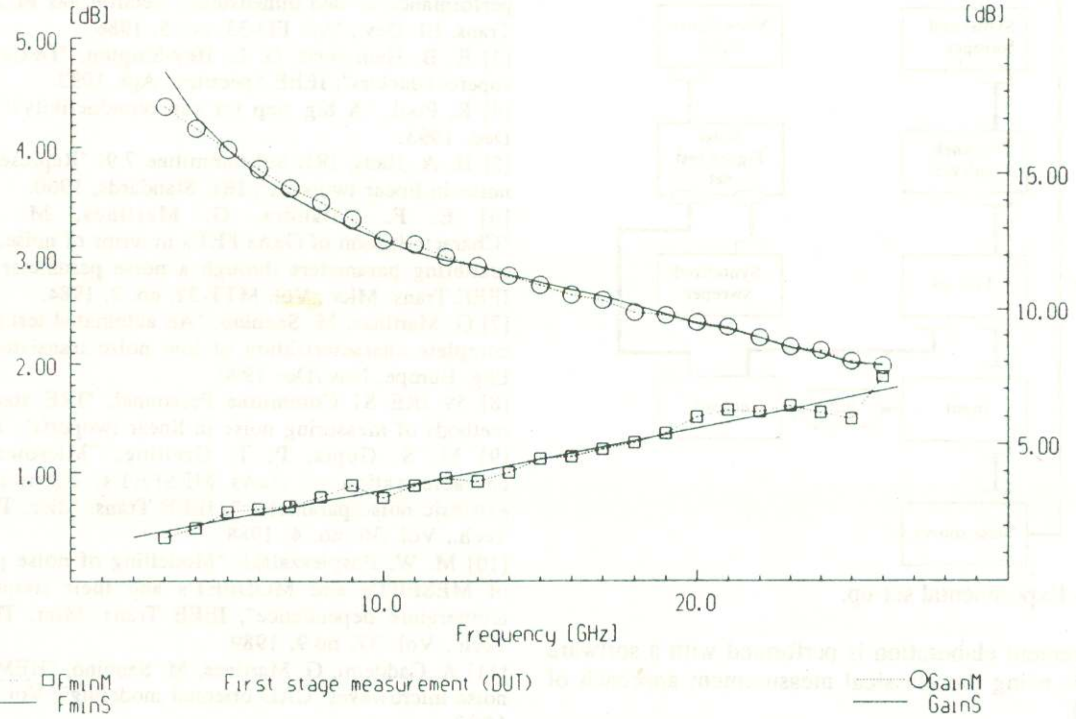

Fig. 3 - F0 and Gain of a single gate low power PHEMT between 2 GHz and 26 GHz (T = 297 K Vds = 3V Ids=10mA).

input port reflection coefficient and the four noise parameters in (2) are: the minimum noise figure F0, the complex number Γ_{on}, or input reflection coefficient at which F is minimum, and Nn that is a parameter invariant to lossless transformation related to the noise equivalent resistance by Nn=RnGs; where Gs is the real part of the input conductance and Rn is the equivalent noise resistance that is a measure of the noise of a device in comparison with the noise of an equivalent resistance. In this work, instead of Γ_{on}, the complex impedance, normalized to the characteristic impedance of the line, is employed and, instead of Nn, the normalized equivalent conductance is used.

Experimental measurements

Scattering and noise parameters of MESFETs and HEMTs at microwaves were measured and published in literature [9, 10] along with a model for CAD design of MMIC [11].

Experimental set-up.

To perform scattering and noise parameters measurements, an experimental set-up was built; its block diagram is drawn in figure 4. It makes use of an instrumentation that can measure scattering and noise parameters of devices between 45 MHz up to 26.5 GHz.

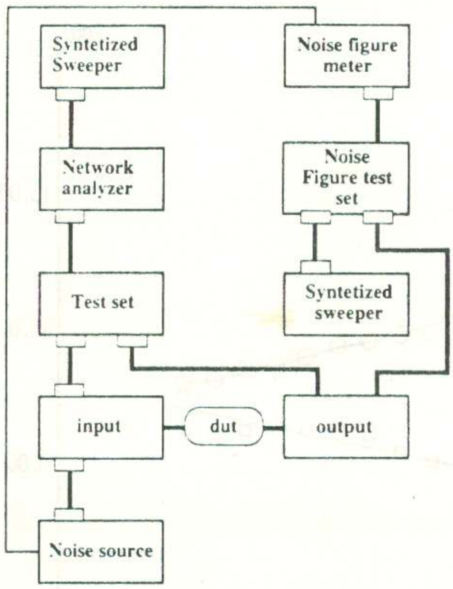

Fig. 4 - Experimental set-up.

Measurement elaboration is performed with a software Cascade using the classical measurement approach of IRE [8].

Scattering and noise parameters of in chip PHEMT (Pseudomorphic High Electron Mobility Transistors) between 2 GHz and 26 GHz are presented in figures 1, 2, 3.

Reliability with noise measurements

Noise measurements in low frequency range were shown to be sensible indicators of the current distribution and of lattice and surface defects and impurities in semiconductor devices [12]. With them, indicators were defined for the analysis of the reliability of semiconductors [13].

In our experiments, instead of low frequency noise, microwave noise between 2 GHz and 26 GHz along with some continuous current characteristics have been measured on chip PHEMTs and on package PHEMTs up to 18 GHz to access in particular the noise characteristics of the two dimensional electron gas during a thermal cycles test according to MIL-STD 883D (-55 °C / +125°C). First processed results seem encouraging.

Acknowledgments

The authors wish to thank Prof. M. Sannino of the University of Palermo and Eng. A. Angelucci and Dr. P. Montangero for their encouragement.

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