EXTRACTION OF MICROWAVE NOISE PARAMETERS OF FET DEVICES

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ABSTRACT

A technique is proposed for the extraction of the noise parameters of on-wafer, chip-mounted or packaged MESFETs and HEMTs. The approach includes the characterization of the device's small-signal equivalent circuit employing DC and RF measurements. A few microwave noise measurements are associated with computer fitting procedures to determine the noise coefficients P,R and C which completes the method. The procedure is used to determine the optimum source impedance of a Toshiba S8818A 0.3 µm gate length MESFET and the obtained parameters are compared with experimental results.

INTRODUCTION

The optimum design of low-noise microwave amplifiers requires the use of the active device's noise parameters, specially its noise impedance. This is one of the parameters that is very difficult and cumbersome to measure directly, unless modern but expensive microwave computer controlled tuner is employed. Thus, a simple, fast and accurate method of determining the noise impedance of MESFET or HEMT devices is desirable.

A simple solution to this problem has been previously proposed (1), which consists in deriving the noise parameters for a simplified model characterized by S-parameters and F_{min} in function of frequency. Recently, a more rigorous approach was reported in the literature (2), which relies on characterizing the device's low frequency power spectral density and assuming it is frequency independent in the microwave range, thus allowing its application on the noise parameters derivation. However, these approaches either employs simplified models which may limit their application to low microwave frequencies or are not applicable to HEMT devices.

The objective of the present paper is to propose an alternative approach to obtain the noise parameters of MESFETs and HEMTs, with no simplifications on the noise model and no restrictions on the device environment, i.e. on-wafer, chip-bonded or packaged styles. The method requires characterization of the device linear model and measurement of F_{min} at three distinct frequencies. A simple computer program was developed to fit the measured F_{min} to those given by the transistor model and by the noise coefficients P,R and C, which defines the device noise parameters.

TRANSISTOR NOISE MODEL

The conventional noise model for a FET (3) plus parasitics can be represented by the equivalent circuit of figure 1 and described by nodal analysis. Employing this type of representation, any other element can easily be added, and so does other noise sources. This means this model is quite general, since it can be applied to FETs with different noise sources. In the particular case of MESFETs and HEMTs the noise mechanisms are similar (4) and so does their representation.

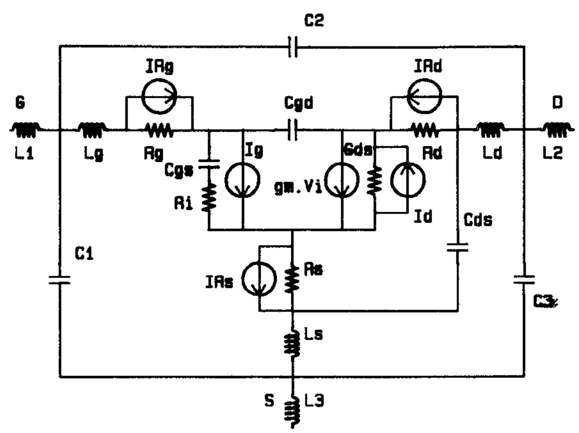

Fig. 1 - Transistor noise model

The thermal noise sources are defined by the Nyquist formula given by equation

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[1], and the channel drain noise source and the induced gate noise source given respectivelly by equations [2] and [3].

$$\overline{I_i^2} = 4.k.T.G_i.\Delta f \qquad i=g,d,s \qquad [1]$$

$$\overline{I_d^2} = 4.k.T.g_m.P.\Delta f \qquad [2]$$

$$\overline{I_g^2} = 4.k.T.(w.C_{gs})^2.R.\Delta f/g_m \qquad [3]$$

Where,

k = Boltzmann constant
T = Absolute temperature
w = Angular frequency
G_i = Conductance
g_m = Transconductance
Δf = Bandwidth
P,R = Dimensionless (4) noise coefficients depending on the device geometry and bias.

The gate and drain noise sources are fully correlated due to the capacitive coupling from drain-to-gate, by means of a coefficient C defined by equation [4].

$$j.C = \overline{I_g^*.I_d} \;/\; (\overline{I_g^2}.\overline{I_d^2})^{1/2} \qquad [4]$$

For engineering purposes, it is more practical to express the noise figure F of a device, for any generator impedance Yg, in terms of four noise parameters represented in equation [5].

$$F = F_{min} + R_n.|Y_g - Y_{opt}|^2/G_g \qquad [5]$$

Where,

F_{min} = Minimum noise figure
R_n = Noise equivalent resistance
Y_{opt} = Optimum noise admittance
G_g = Generator conductance
Y_g = Generator admittance

The noise parameters can be obtained from the set of nodal equations describing the circuit of figure 1 , by application of noise figure definition, followed by calculation of derivatives of noise figure in function of the generator admittance. The resulting four noise parameters expressed as function of the coefficients P, R and C and of the small-signal equivalent circuit have been derived elsewhere (3). Thus, if one of the noise parameters are measured in function of frequency, say F_{min} , then a curve fitting procedure may be applied to obtain the coefficients P, R, and C, which in turn defines all other parameters. The drain noise coefficient P, can also be obtained by an approximate expression (4) given by equation [6].

$$P = I_{DS}/(V_{Dsat}.g_m) \qquad [6]$$

where,

V_{Dsat} = Drain saturation voltage
I_{DS} = Quiescent drain current

DETERMINATION OF THE NOISE PARAMETERS

The determination of the noise parameters is carried out as follows:

1 - <u>DC Measurements</u>. In this step, static measurements are made to determine the device's parasitic resistances, the I_{DS} xV_{DS} and I_{DS} xV_{GS} curves, the maximum saturation current and the threshold and drain saturation voltages.

According to the approximate expression [7] for F_{min} (4), the optimum bias point for noise performance can be obtained, by searching on the static characteristics the point where the relation $(IDS)^{1/2}/g_m$ is minimum.

$$F_{min} = 1+2[I_{DS}/V_{Dsat}]^{1/2} w.\frac{C_{gs}}{g_m}.(R_s+R_g)^{1/2} \qquad [7]$$

2 - <u>Low Frequency S-Parameters Measurements</u>. Making these measurements in the frequency range .1 - 1 GHz it is possible (5) to express the model parameters directly in function of S-parameters. Thus, the dynamic g_m and g_d as well as all capacitances can be determined with good accuracy.

3 - <u>High Frequency S-Parameters Measurements</u>. These measurements are made for the fitting of the measured S-parameters to the ones calculated by the model.

4 - <u>Noise Figure Measurements</u>. A set of noise figure measurements are made in order to determine F_{min} in function of frequency. Observations on the general shape of this characteristic for several MESFETs and HEMTs devices, allows one to conclude they are similar, and in fact only 3 measurements within the operating bandwidth are necessary to obtain this function, which is described by equation [8].

$$F_{min}(dB) = a.f^2 + b.f + c \qquad [8]$$

Where,
a, b and c are coefficients to be determined and f is given in GHz.

This step is completed by a curve fitting procedure for the determination of R and C, and an optimization on the value of P determined by equation [6].

APPLICATION EXAMPLE

The procedure was applied to the characterization of a 0.3 um MESFET packaged device, type S8818A by Toshiba, which presents a F_{min} of 2.1 dB at 18 GHz with an associated power gain of 8 dB.

The characterization of the small-signal equivalent circuit, as well as the determination of the optimum bias for noise performance were obtained carrying out steps 1 to 3. The resulting parameters from these steps are listed on table I.

Intrinsic & Extrinsic Elements		Package Parasitics
g_m =34.50 mS	L_d = 0.46 nH	C_1 = 0.19 pF
g_{ds}= 4.60 mS	L_g = 0.34 nH	C_2 = 0.001 pF
C_{gs}= 0.27 pF	L_s = 0.095nH	C_3 = 0.25 pF
C_{gd}= 0.025pF	R_g = 2.00 ohms	L_1 = 0.17 nH
C_{ds}= 0.08 pF	R_d = 1.00 ohms	L_2 = 0.18 nH
R_i = 1.50 ohms	R_s = 2.35 ohms	L_3 = 0.021 nH

TABLE I - Parameters of the small-signal equivalent circuit, at V_{DS} = 3.0 volts; I_{DS} = 13 mA, with V_{Dsat} = 0.34 volts; I_{DSS} = 62 mA and V_T = -1.56 Volts.

The fourth step concerns with the measurement of the minimum noise figure at three distinct frequencies within the bandwidth. This was done using a microstrip tuner which had its losses taken into account in the noise figure readings. The obtained values after measuring and fitting are on table II and table III.

F(GHz)	F_{min}(dB)
4.0	0.73
6.0	0.92
12.0	1.86

TABLE II - Noise measurements

Quadratic Coefficients	Noise Coefficients
a = 0.0077	P = 0.85
b = 0.0179	R = 0.135
c = 0.535	C = 0.7002

TABLE III - Noise coefficients

Now one is able to completely determine all noise parameters at any frequency for this device. The mimimum noise figure was calculated for the frequency range 1 to 25 GHz and the results are on figure 2. For the sake of comparison the results supplied by the manufacturer are plotted on the same figure. It can be seen that there is a good agreement between both results.

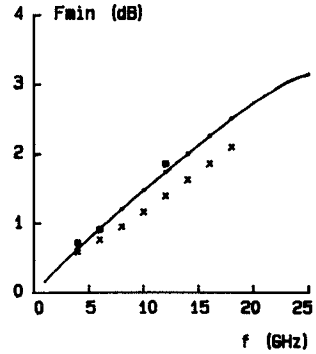

Fig. 2 - F_{min} in function of frequency
(——) Calculated from model
(xxx) Manufacturer datasheet
(ooo) Measured results

The calculated optimum generator impedance for the same frequency range is plotted in the Smith Chart of figure 3. Again, for comparison purposes the manufacturer results are on the same chart. A careful measurement of the optimum noise impedance was done at 4, 6, 8.3 and 12 GHz by means of the microstrip tuner and the results are plotted on the same figure. Again, a good agreement was obtained with the proposed procedure, whose results were confirmed by measurements.

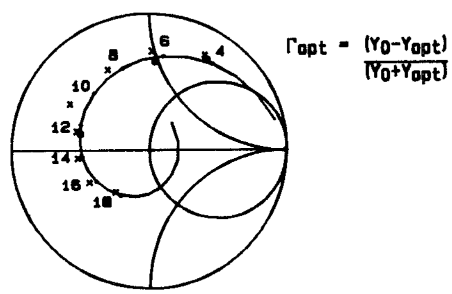

Fig. 3 - Optimum generator impedance
(——) Calculated from model
(xxx) Manufacturer datasheet
(ooo) Measured results

Finally, The equivalent noise resistance for this device is plotted in figure 4 as a function of frequency. It decreases with frequency according to previous published results (5) up to 15 GHz. Then, it increases up to 25 GHz, probably due to the packaged parasitics, which also affects the noise impedance shown in figure 3.

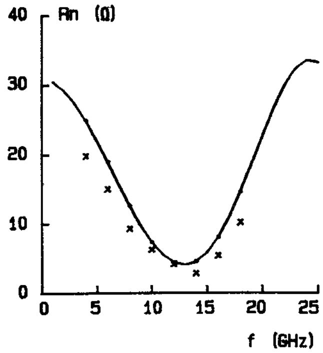

Fig. 4 - Equivalent noise resistance
(——) Calculated from model
(xxx) Manufacturer datasheet

The calculated noise parameters are in a good agreement with the manufacturer's data sheet and were confirmed by measurements of noise impedance at 4, 6, 8.3 and 12 GHz. An interesting feature of this procedure is its ability to extrapolate results beyond the measured frequency range of F_{min} (12GHz) and S-parameters (18GHz). For instance, the calculated noise impedance at 18 GHz is very close to the results measured by the manufacturer.

CONCLUSIONS

It is felt that the objectives of this paper has been fulfilled, i.e. to present an alternative approach to the noise parameter extraction of FET devices, that is accurate, reliable and relatively fast. The method applies equally well to MESFETs and HEMTs and is capable of accounting for the parasitics associated with the mounting of chip devices and with the packaged devices. It is also applicable to on- wafer characterization, if microwave probes are employed. Application of the method to HEMTs presents an additional advantage on determining the uncertainty on the value of R_S which is frequency dependent. In this case F_{min} is measured directly at microwave frequencies, so that this effect is encompassed by the parameters P,R and C.

Finally, the application of the method to a low noise MESFET has been demonstrated and showed results that are in a good agreement with experimental measurements and are quite close to the parameters supplied by the manufacturer.

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