A New Method for Accurate Noise Modeling of Microwave FET Transistors

Olivera Pronić, Vera Marković, Gordana Mitić, Jovana Ranđelović

Abstract - **A new procedure for noise parameter modeling of microwave MESFETs / HEMTs is proposed in this paper. The proposed modeling procedure presents a modification of Pospieszalski's noise model with the aim to improve the model accuracy. For this purpose, frequency-dependent error correction functions are determined and incorporated into the Pospieszalski's noise equations. Due to this, more accurate noise prediction is obtained. It will be shown that initially calculated error correction functions can be used for efficient transistor noise parameter prediction for various bias conditions.**

Keywords – **MESFET, noise modeling, error correction function**

I. INTRODUCTION

As the performance of modern communications systems improves, the noise of devices becomes the limiting factor for overall system. Therefore, much work has been done for developing noise models of microwave transistors that enable accurate estimation of noise behaviour.

There are different opinions about the most appropriate transistor noise model. Since the physical models are complex and may deviate from measured data, the empirical noise models are used more often, [1], [2], [3]. The two-parameters Pospieszalski`s model turns out to be the most suitable for implementation into the standard commercial circuit simulators, as Libra or ADS. Pospieszalski's noise model is based on simple expressions for noise parameters of transistor intrinsic circuit as the functions of transistor intrinsic circuit elements and two frequency independent parameters called equivalent gate and drain temperature. This model generally shows good agreement with measured data, but some deviations still can be observed. One of the ways for improving the accuracy is including some additional effects into the model.

In the original Pospieszalski's model, the correlation between two noise sources it completely ignored. However, it has been found that the inaccuracy caused by this approximation is not negligible at higher frequencies.

Olivera R. Pronić, Vera V. Marković, Gordana B. Mitić and Jovana B. Ranđelović are with the Faculty of Electronic Engineering, Niš, Beogradska 14, 18000 Niš, Serbia and Montenegro, E-mails:{oljap, vera, goca, jovanar}@elfak.ni.ac.yu.

In [4], the correlation is taken into account by defining the third equivalent temperature, called correlation temperature.

The other empirical noise models, like those proposed by Gupta [1] or Fukui [2], give the results for noise parameters that also deviate in some extent from experimental data. A procedure for improving the Fukui's empirical model by some correction functions is proposed in [5].

In this paper a simple procedure for more accurate noise modeling of MESFETs / HEMTs, starting from Pospieszalski`s model, is suggested. In order to achieve a better agreement between simulated and experimental data, the novel error correction functions are incorporated into the Pospieszalski`s equations for noise parameters. The possibility for using the same error correction functions for various bias conditions is investigated in this paper as well.

II. DESCRIPTION OF MODELING PROCEDURE

The schematic of GaAs FET package model equivalent circuit is shown in Fig.1. Transistor intrinsic circuit, which is common for the most of microwave models, is denoted by the dashed line. It consists of capacitor C_{gs}, resistors R_{gs} and R_{ds} and voltage controlled current source $g_m V$, where $g_m = g_{m0} e^{-j\omega\tau}$ is transconductance, and V is the voltage on C_{gs}. The remaining extrinsic elements, embedded in the circuit, represent parasitic effects of device. The equivalent circuit for MESFET / HEMT chip is denoted by dotted line.The effects of package are modeled by including transmission lines T_1, T_2 and T_3, capacitors C_{gsp}, C_{gdp} and C_{dsp} and inductances L_1, L_2 and L_3.

The resistors R_{gs} and R_{ds} determine thermal noise of intrinsic circuit. In MESFET noise model proposed by Pospieszalski, [3], equivalent gate noise temperature, T_g, and drain noise temperature, T_d, are assigned to these resistances. The noise contributions of these resistors are represented by voltage noise source e_{gs} and current noise source i_{ds}, respectively.

The noise parameters of intrinsic transistor circuit: minimum noise figure F_{min}, optimal source impedance $Z_{opt} = R_{opt} + jX_{opt}$ and noise resistance R_n can be calculated over wide range of frequencies as follows [3]:

$$F_{min} = 10 \log\left(1 + \frac{T_{min}}{T_0}\right), \tag{1}$$

$$T_{min} = 2\frac{\omega C_{gs}}{g_m}\sqrt{r_{gs}T_g g_{ds}T_d + \left(\frac{\omega C_{gs} r_{gs} g_{ds} T_d}{g_m}\right)^2} + 2\left(\frac{\omega C_{gs}}{g_m}\right)^2 r_{gs} g_{ds} T_d \ , \tag{2}$$

$$X_{opt} = \frac{1}{\omega C_{gs}} \ , \tag{3}$$

$$R_{opt} = \sqrt{\left(\frac{g_m}{\omega C_{gs}}\right)^2 \frac{r_{gs}T_g}{g_{ds}T_d} + r_{gs}^2} \ , \tag{4}$$

$$R_n = \frac{T_g}{T_0} r_{gs} + \frac{T_d g_{ds}}{T_0 g_m^2}\left(1 + \omega^2 C_{gs}^2 r_{gs}^2\right), \tag{5}$$

$$\Gamma_{opt} = \frac{Z_{opt} - Z_0}{Z_{opt} + Z_0} \ . \tag{6}$$

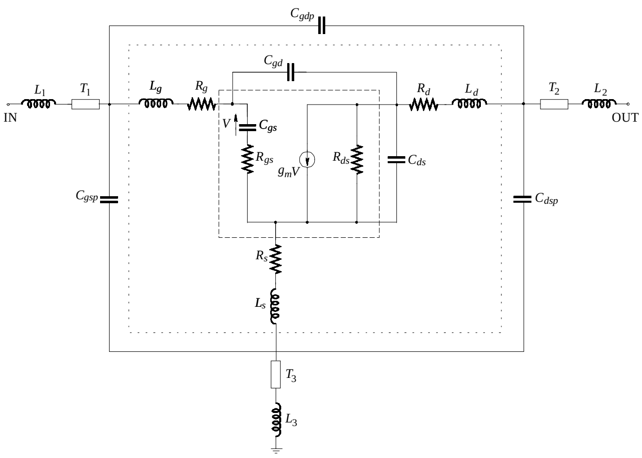

Fig.1. Equivalent circuit for FET packages

It is shown that noise parameters calculated in this way do not perfectly match measured noise parameters. In order to minimize deviations that exist between measured and modeled noise parameters, a correction procedure based on incorporation of frequency-dependent error correction functions into the Pospieszalski`s noise equations is applied.

At the beginning, for each of four noise parameters, the ratio of the experimental and simulated noise parameter values is calculated over the entire frequency range. Then, curve fitting procedure is applied on these sets of data, in order to obtain suitable frequency dependences. In this way, corresponding mathematical functions are chosen for all four noise parameters: F_{min}, $Mag(\Gamma_{opt})$, $Ang(\Gamma_{opt})$ and $r_n = R_n / 50$. These functions represent error correction functions for improving the Pospieszalski's noise model. Namely, standard noise equations (1-6) are modified by including error correction functions $y_1(f), y_2(f)$, $y_3(f)$ and $y_4(f)$. As a result, new equations for transistor intrinsic circuit noise parameters become:

$$F_{minnew} = F_{min} \cdot y_1(f), \tag{7}$$

$$Mag(\Gamma_{opt})_{new} = Mag(\Gamma_{opt}) \cdot y_2(f), \tag{8}$$

$$Ang(\Gamma_{opt})_{new} = Ang(\Gamma_{opt}) \cdot y_3(f), \tag{9}$$

$$r_{nnew} = r_n \cdot y_4(f). \tag{10}$$

It is shown that the most suitable form of error correction function for the minimum noise figure is the exponential one:

$$y_1 = m + ne^{-\frac{f}{l}} \ , \tag{11}$$

where *f* is the frequency, and *m*, *n* and *l* are the constants.

Error correction functions for $Mag(\Gamma_{opt})$, $Ang(\Gamma_{opt})$, and r_n has the form:

$$y_i = a_i + b_i f + c_i f^2 + d_i f^3 \ , \quad i = 2,3,4 \tag{12}$$

where a_i, b_i, c_i, d_i are the constants.

III. Numerical Example

Numerical results related to small-signal and noise modeling of HP GaAs FET packaged microwave transistor, type ATF 21186, are presented in this paper. All simulations are performed using microwave circuit simulator ADS (Advanced Design System), [6].

With the aim to predict the noise parameters using the proposed model, the equivalent circuit element values are determined at the beginning. The two-step optimization procedure is used for the efficient determination of circuit elements. Firstly, the extraction of equivalent circuit elements is done in order to achieve the best possible agreements between measured and modeled scattering parameters. Next, the equivalent noise temperatures T_g and T_d are extracted by fitting measured and modeled noise parameters. As referent data, manufacturer's *S* parameter and noise parameter data for various bias conditions in the frequency range (0.5 – 8) GHz, are used, [7]. Extracted component values, for ambient temperature equals 25°C and bias condition I_{ds}=20mA, V_{ds}=2V, are: R_{gs}=1.81Ω, τ=0.0099ps, L_s=0.084nH, L_g=0.772nH, L_d=0.388nH, R_s=0.61Ω, R_g=2.25Ω, R_d=0Ω, C_{ds}=0.156pF, C_{gd}=0.137pF, C_{gs}=0.326pF, g_{m0}=68.28mS, R_{ds}=101.4Ω, C_{dsp}=0.150pF, C_{gdp}=0.093pF, C_{gsp}=0.224pF, L_1=0.41nH, L_2=0.034nH, L_3=0.93nH. Transmission lines segments are characterized by following: physical lengths LNG_1=29.183mil, LNG_2=10.151mil, LNG_3=18.91mil, characteristic impedances Z_1=80.82Ω, Z_2=65.482Ω,

Z_3=63.86Ω, effective dielectric constant k=7, attenuation A=0.001dB/mil and scaling frequency for attenuation f=1GHz. The extracted equivalent noise temperatures are: T_d = 3244K, T_g = 246K.

The comparison of experimental (squares) and simulated S parameters(triangles) is shown in Fig. 2. It can be observed that, despite of a great number of variables, a satisfied agreement with referent data is achieved.

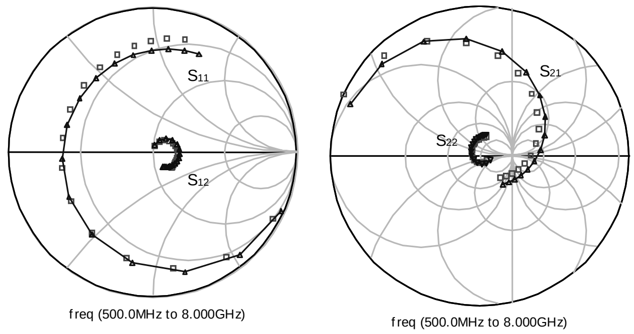

Fig. 2. Comparison between simulated and referent S-parameters

Noise parameter characteristics obtained by Pospieszalski's approach (denoted by MOD1), together with those based on measured data (denoted by MEAS) are presented in Fig. 3. Inaccuracy in noise modeling, specially for F_{min} and $Mag(\Gamma_{opt})$ can be observed.

In order to minimize deviations that exist between measured (MEAS) and modeled (MOD1) values of noise parameters, the error correction functions are included, as described in previous section. Evaluated constants in exponential function for minimum noise figure (Eq.(11)) are:

$$m=0.63,\quad n=3.95,\quad l=7.904\ 10^{7},$$

The parameters of polynomial functions (Eq.(12)) for $Mag(\Gamma_{opt})$, $Ang(\Gamma_{opt})$ and r_n are given in Table I.

TABLE I

	a	b	c	d
y_2	1.017	-5.93e-11	1.055e-20	0
y_3	0.973	5.643e-12	0	0
y_4	3.078	-1.7e-9	3.521e-19	-2.17e-29

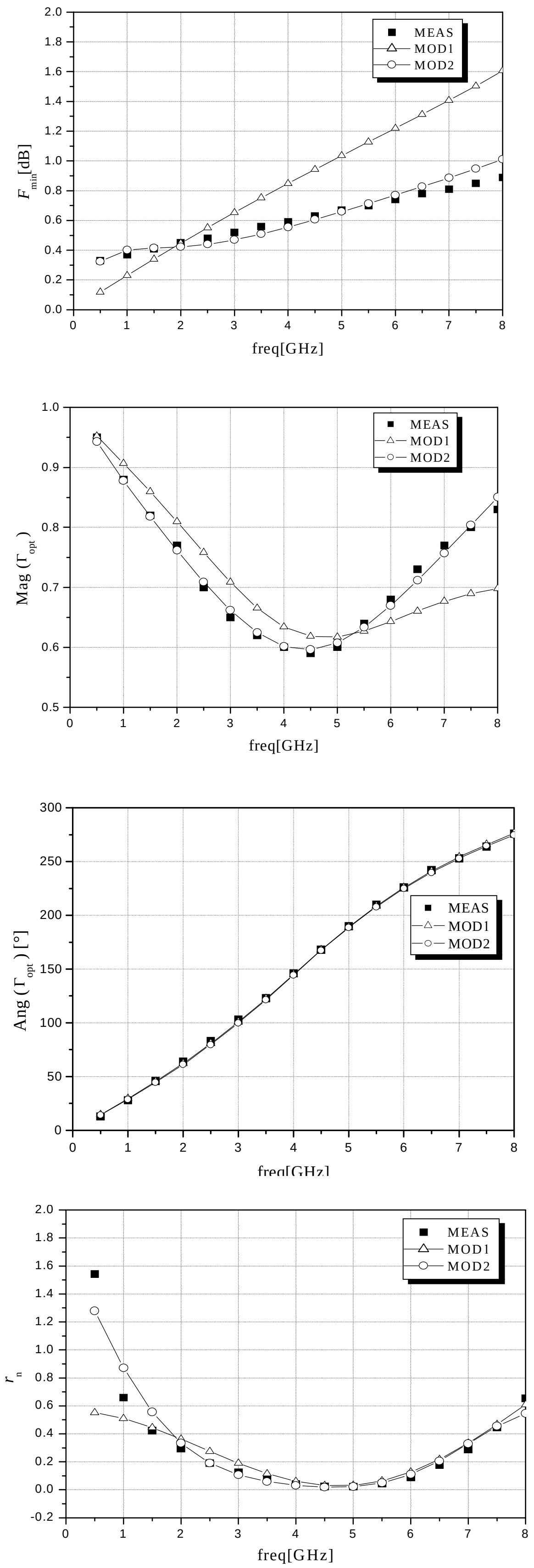

Fig. 3. Noise parameters for bias condition I_{ds}=20mA, V_{ds}=2V

Modified frequency dependences of noise parameters are also shown in Fig. 3. Corresponding curves are denoted by MOD2. It is obvious that significantly better agreement between measured and modeled parameters is now achieved.

The main advantage of the proposed model is that the error correction functions calculated for one bias condition can be used for efficient noise parameter modeling of the same transistor for other bias conditions. Since measured values of *S* parameters, as well as noise parameters, are different for various bias conditions, it is only necessary to repeat extraction procedure of equivalent circuit elements and equivalent temperatures. However, once determined error correction functions can be applied in the same form for various bias conditions.

As example, noise modeling of the same transistor is also done for new bias conditions: I_{ds}=15mA, V_{ds}=2V. Frequency dependences of the noise parameters obtained by proposed procedure using previously determined error correction functions (MOD2), are compared with measured values (MEAS) and shown in Fig. 4. A very good agreement is achieved in this case, too.

IV. CONCLUSION

New noise model of microwave FET transistors that presents modification of Pospieszalski's model is suggested in this paper. Modification is done by including the error correction functions to the Pospieszalski's standard noise equations. Due to this, deviations that exist between measured and modeled data are significantly reduced, and therefore better noise prediction is achieved. It is also shown that once determined error correction functions enable efficient noise modeling of the same transistor for various bias conditions. Proposed noise modeling procedure is applicable to any other MESFET / HEMT noise model presented in literature.

REFERENCES

[1] M.S. Gupta, O.Pitzalis, S.E.Rosenbaum, P.T.Greiling, "Microwave Noise Characterization of GaAs MESFETs: Evaluation by On-Wafer Low-Frequency Output Noise Current Measurement", *IEEE Trans. Microwave Theory Tech.*, vol. MTT-35, pp. 1208-1218, December 1987.

[2] H.Fukui, "Design of Microwave GaAs MESFET's for Broadband Low-Noise Amplifiers", IEEE Trans. Microwave Theory Tech., vol. MTT-27, pp. 643-650, July 1979.

[3] M.W.Pospiezalski, "Modeling of noise parameters of MESFET and MODFET and their frequency and temperature dependence" IEEE TransMicrowave Theory Tech, vol. MMT-37, pp.1340-1350, Sept. 1989.

[4] V.Marković, B.Milovanović, N.Maleš-Ilić, "MESFET Noise Model Based on Three Equivalent Temperatures", Proceedings of 27th European Microwave Conference, pp. 966-971, Jerusalem, Israel, Sept. 1997.

[5] P. Ratna and V.S.R. Kirty, A novel technique for accurate noise modeling, Proceedings of APMC2001, Taipei,Taiwan, pp.730-734.

[6] Advanced Desing System-version 1.5, Agilent Eesof EDA, 2000.

[7] Communications Components Desingner'ş Catalog, Hewlett Packard, 1997.

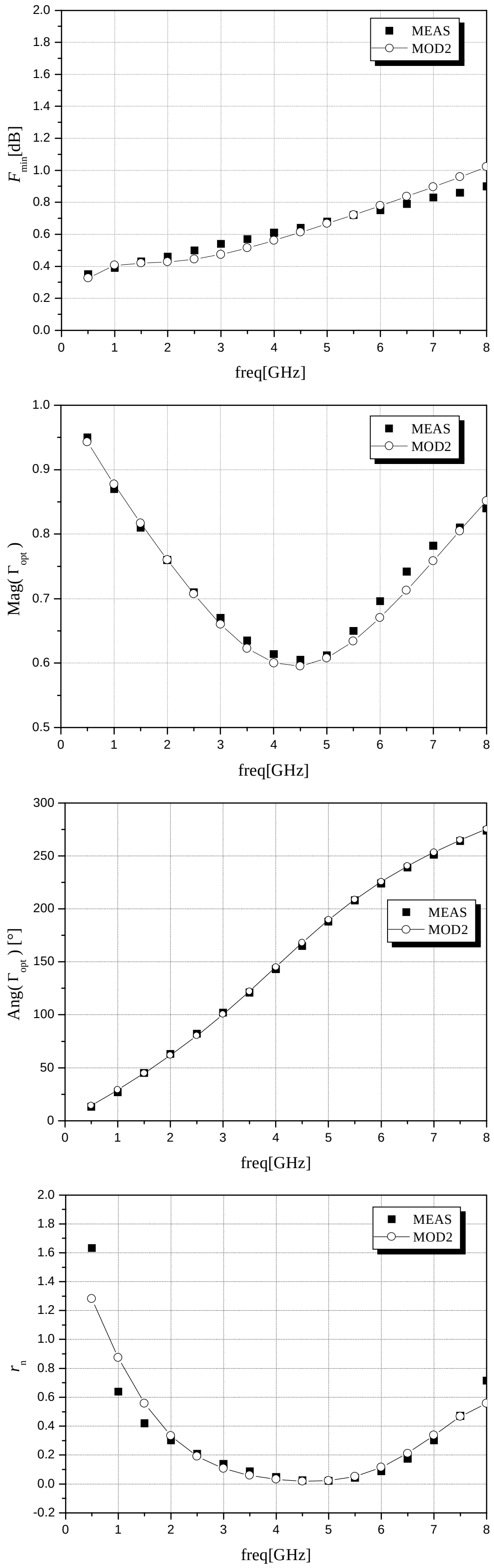

Fig. 4. Noise parameters for bias condition I_{ds}=15mA, V_{ds}=2V