A New Procedure for Extraction of Noise Wave Parameters of Microwave FETs

Vladica Đorđević[1], Zlatica Marinković[2], Vera Marković[2] and Olivera Pronić-Rančić[2]

Abstract – **A new procedure for extraction of noise wave parameters of microwave FETs is presented in this paper. A neural network is trained to predict intrinsic noise parameters for given equivalent circuit parameters, transistor total noise parameters, frequency and ambient temperature. Determination of noise wave parameters is carried out based on the extracted intrinsic noise parameters by using existing formulas. The proposed procedure enables avoiding complex optimization procedures in microwave simulators, which are used for the determination of the noise model parameters, for different ambient temperatures. The detailed validation of the proposed procedure was done by comparison of the transistor total noise parameters obtained using extracted noise wave parameters and measured transistor total noise parameters.**

Keywords – **MESFET, HEMT, noise parameters, noise wave parameters, artificial neural network.**

I. Introduction

Microwave FETs (MESFETs, HEMTs) are an essential part of low-noise communication devices. Therefore, it is very important to have knowledge about characteristics of microwave FETs. Their characterization includes knowledge about scattering parameters and noise parameters. The measurements of these parameters are complex and require a lot of time. This is because these parameters are frequency, temperature and bias dependent. For this reason, microwave transistors are usually represented by appropriate models in microwave computer-aided design (CAD). These models can be physical or empirical. The physical transistor models are quite complex and require many input technological parameters [1-2]. Empirical models of the transistors are much simpler and therefore, they are commonly used [3-5]. Most of the empirical models are based on the equivalent circuit representation. In the case of microwave FETs, equivalent circuits that are used to analyze the characteristics of the noise are based on the small-signal equivalent circuits.

Several FET noise models that are based on the equivalent circuit representation are developed. These noise models consist of a small-signal equivalent circuit and assigned noise sources. Those noise sources are usually equivalent voltage and/or current sources. In recent years, Pospieszalski's noise model is widely used in commercial microwave circuit simulators [5]. This model is based on H representation of device intrinsic circuit with two uncorrelated noise sources, one on the gate side and other at the drain side. However, at microwave frequencies, it is more suitable to use noise wave modeling procedure of MEFETs / HEMTs because the treatment of noise in terms of waves seems to be more appropriate [6-11]. It is important to note that noise wave model provides advantages in CAD of microwave networks, because it allows the use of scattering matrices for the noise computations.

A noise model usually refers to the intrinsic part of the transistor. Therefore, a noise model provides relationships between noise model parameters and the intrinsic noise parameters, N_{int}. This means that noise model parameters can be calculated on the basis of known N_{int}, and vice versa. Based on the extracted noise model parameters, the total noise parameters, N_{total}, are calculated in the circuit simulator taking into account effects of the extrinsic circuit elements.

A new procedure for extraction of microwave FETs noise wave parameters is presented in this paper. Extraction of these parameters is carried out based on the extracted N_{int}. For the purpose of extracting the N_{int}, previously proposed approach based on artificial neural network (ANN) [12] is used.

Neural-network computational approach has proven to be a very useful modeling tool in the area of microwaves, e.g. for the purpose of modeling of microwave transistors [13-19]. Namely, the process of optimization of microwave circuits based on the use of CAD tool can be very time-consuming. By using neural networks, the whole process of microwave circuits analysis becomes more efficient, because once developed neural models give responses almost instantaneously. This stems from the fact that responses of neural networks are based on performing basic mathematical operations and calculating of elementary mathematic functions. The main feature of neural networks is their ability to determine response even for input combinations that are not used for the process of learning, i.e. they have a great generalization capability. In that way, the developed neural models can be used over a wide range of input parameters.

The proposed procedure, which is based on the developed neural model and existing formulas for the noise wave model, enables avoiding complex optimization procedures in microwave simulators, which are conventionally used for the determination of the noise model parameters. This is reflected in a significantly shorter time required for the extraction of the noise wave parameters.

The paper is structured as following: after Introduction, in Section II the noise wave model of microwave FETs is described. In Section III the proposed artificial neural network based procedure is described. In Section IV the numerical

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results of extraction of noise wave parameters of microwave FETs are presented and discussed. The main conclusions are given in Section V.

II. Noise Wave Model of Microwave FETs

The noise wave model of the microwave FET devices in packaged form is considered in this paper. Equivalent circuit of packaged MESFET / HEMT is shown in Fig. 1. It consists of intrinsic and extrinsic part. The intrinsic equivalent circuit is framed with a broken line, and intrinsic noise parameters are referred to it. The remainder of the equivalent circuit (extrinsic circuit) may be different, depending on the included parasitic effects. The total noise parameters are used to characterize the noise of the entire transistor, which is represented by the equivalent circuit shown in Fig. 1.

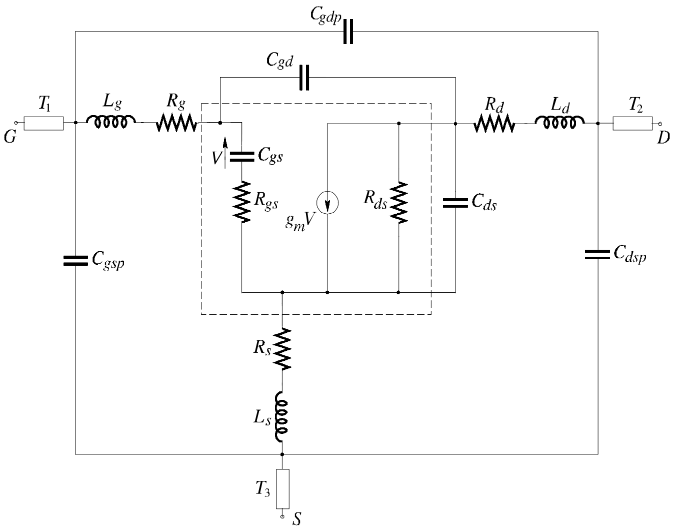

Fig. 1. Equivalent circuit of packaged MESFET / HEMT

Since, the transistor intrinsic circuit is linear noisy two-port network, it can be considered as a noiseless two-port defined by transfer scattering parameters $[T]$ and two noise wave sources, a_n and b_n, referring to the input, as shown in Fig. 2. The matrix equation describing this representation of the noisy two-port follows, [8]:

$$\begin{bmatrix} a_1 \\ b_1 \end{bmatrix} = \begin{bmatrix} T_{11} & T_{12} \\ T_{21} & T_{22} \end{bmatrix} \begin{bmatrix} b_2 \\ a_2 \end{bmatrix} + \begin{bmatrix} a_n \\ b_n \end{bmatrix}. \tag{1}$$

where a_i and b_i, i =1, 2, are incident and output waves at the i-th port.

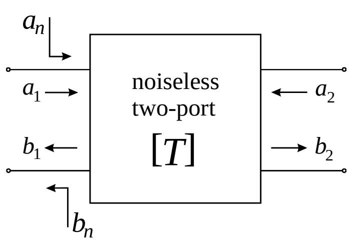

Fig. 2. Two port noisy network

The elements of the noise source vector are correlated and characterized by correlation matrix $\boldsymbol{C_T}$:

$$\boldsymbol{C_T} = \begin{bmatrix} \langle |a_n|^2 \rangle & \langle -a_n b_n^* \rangle \\ \langle -b_n a_n^* \rangle & \langle |b_n|^2 \rangle \end{bmatrix}, \tag{2}$$

where $\langle\ \rangle$ indicates time average of the quantity inside and $*$ indicates complex conjugation. The noise wave model is characterized by its parameters called noise wave temperatures. It is very convenient to use these temperatures as empirical model parameters [6]. The correlation matrix $\boldsymbol{C_T}$ can be expressed by noise wave temperatures as:

$$\boldsymbol{C_T} = k\Delta f \begin{bmatrix} T_a & |T_c| e^{j\varphi_c} \\ |T_c| e^{-j\varphi_c} & T_b \end{bmatrix}, \tag{3}$$

where k is the Boltzmann's constant and Δf is the noise bandwidth (Δf=1Hz is assumed). In this way the noise performance of any two-port network can be completely characterized by two real temperatures T_a and T_b and a complex correlation temperature T_c. These temperatures can be expressed in terms of the noise parameters of transistor intrinsic circuit (F_{mini} – minimum noise figure, Γ_{opti} – optimum source reflection coefficient (complex value which is usually represented in polar form, as a magnitude, Mag(Γ_{opti}), and an angle, Ang(Γ_{opti})) and R_{ni} – noise resistance) as follows:

$$T_a = T_0 (F_{mini} - 1) + \frac{4 R_{ni} T_0 \left|\Gamma_{opti}\right|^2}{Z_0 \left|1 + \Gamma_{opti}\right|^2}, \tag{4}$$

$$T_b = \frac{4 R_{ni} T_0}{Z_0 \left|1 + \Gamma_{opti}\right|^2} - T_0 (F_{mini} - 1), \tag{5}$$

$$T_c = \frac{4 R_{ni} T_0 \Gamma_{opti}}{Z_0 \left|1 + \Gamma_{opti}\right|^2}, \tag{6}$$

where Z_0 is the normalization impedance (50Ω) and T_0 is the standard reference temperature (290K).

III. Proposed Procedure Based on ANN

As already mentioned, the optimization procedures for determination of the noise model parameters can be very complex. Instead, the determination of the noise model parameters can be simplified if they are calculated from the intrinsic noise parameters. For the purpose of obtaining the intrinsic noise parameters, ANNs approach proposed in [12] is used.

The proposed procedure for extraction of noise wave parameters (noise wave temperatures) is illustrated in Fig. 3. The noise wave temperatures are the functions of the intrinsic noise parameters, N_{int}, as given by Eqs. (4-6). The intrinsic noise parameters are obtained by using neural model defined by the following expression:

$$N_{int} = f(ECPs, N_{total}, f, T_{amb}) . \quad (7)$$

Namely, a neural network is trained to predict intrinsic circuit noise parameters, N_{int}, (F_{mini}, r_{ni} (normalized noise resistance), Mag(Γ_{opti}) and Ang(Γ_{opti})) for given small-signal equivalent circuit parameters, *ECPs*, transistor total noise parameters, N_{total}, (F_{min}, r_n, Mag(Γ_{opt}) and Ang(Γ_{opt})), frequency, *f*, and ambient temperature, T_{amb}. T_{amb} is included in the model because the noise of the resistive elements depends on the temperature.

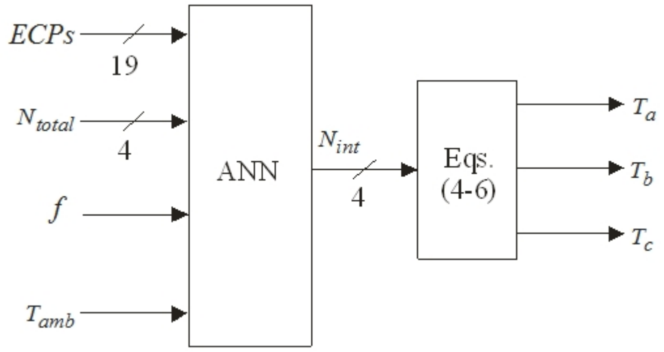

Fig. 3. Proposed procedure for extraction of noise wave temperatures based on ANN

IV. Numerical Results

The proposed modeling procedure was applied to a packaged HEMT, type NE20283A, and some of the obtained results are presented in this paper. All simulations are performed using microwave circuit simulator ADS (Advanced Design System), [20]. Measured *S* and noise parameters were available in the frequency range (6 – 18) GHz over the temperature range (233 – 333) K (step 20 K). They have been obtained earlier at the University of Palermo, Italy, by a convenient measurement procedure, [21].

A neural network that is an integral part of the proposed procedure is developed in [12], for the purpose of extraction of intrinsic noise parameters. It consists of two hidden layers, with 9 neurons in the first, and 12 neurons in the second layer. Extraction of noise wave temperatures is carried out based on the extracted intrinsic noise parameters by using Eqs. (4-6).

The proposed procedure for extraction of noise wave temperatures is validated by comparison of the measured total noise parameters and total noise parameters obtained for extracted values of noise wave temperatures calculated by the proposed procedure. Small-signal *ECP*s and N_{total} of the transistor, at ambient temperature of 293K, at frequencies from 6 to 18 GHz, were used to obtain the values of noise wave temperatures by using proposed procedure. The values of extracted noise wave temperatures are then used to obtain the total noise parameters within the software package ADS. In Table I, there are the corresponding test results. In this case, average test error (ATE) and correlation coefficient, *r*, were used as the measure of the quality of prediction [13].

TABLE I
PROPOSED PROCEDURE TESTING

	ATE [%]	*r*
F_{min}	3.74	0.9949
r_n	6.25	0.9902
Mag(Γ_{opt})	6.24	0.9986
Ang(Γ_{opt})	3.09	0.9998

In addition, test results of the transistor total noise parameters, N_{total}, are shown in Figs. 4 and 5.

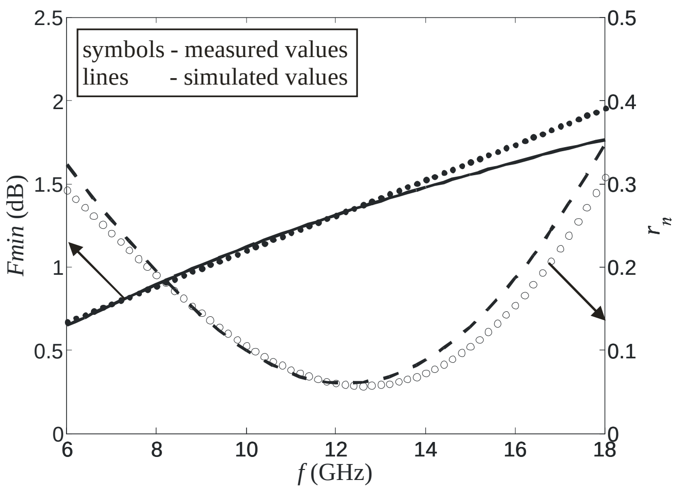

Fig. 4. Measured and simulated values of F_{min} and r_n, depending on the frequency, at 293K

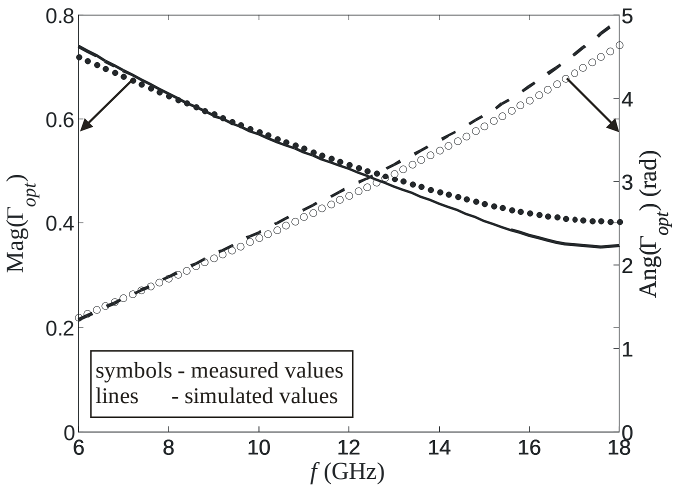

Fig. 5. Measured and simulated values of Mag(Γ_{opt}) and Ang(Γ_{opt}), depending on the frequency, at 293K

As can be seen in Fig. 4, the target values of F_{min} and r_n are well approximated by the curves representing the values of these parameters obtained by using proposed procedure in a large part of the observed frequency band. In support of this fact, there are results obtained for ATE and *r* during the testing of proposed procedure (Table I), which can be considered as quite satisfactory.

The results of neural network testing for the parameter Γ_{opt} are shown in Fig. 5. The obtained values of ATE and *r*, for Mag(Γ_{opt}) and Ang(Γ_{opt}), are also shown in Table I. Based on these results, it can be seen that the target values of Mag(Γ_{opt}) and Ang(Γ_{opt}) are well approximated by the curves representing the values of these parameters obtained by using the proposed procedure.

V. CONCLUSION

This paper presents development and validation of a new procedure for extraction of noise wave temperatures of microwave FETs based on artificial neural networks. The purpose of extraction of noise wave temperatures is to avoid complex optimization procedures in microwave circuit simulators, which are conventionally used for the determination of the noise model parameters. By using the proposed procedure, the process of determination of noise wave parameters becomes more efficient.

The proposed procedure was applied to a specific HEMT device in a packaged form. Determination of noise wave temperatures was carried out based on the extracted intrinsic noise parameters by using existing formulas. For the purpose of extracting the intrinsic noise parameters, previously proposed ANNs approach was used. Based on the obtained noise wave temperatures, the corresponding total noise parameters were calculated in the circuit simulator. A good agreement between simulated total noise parameters and measured total noise parameters proves validity of the proposed procedure.

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