PKI ANNs in Noise Wave Modelling of Microwave Transistors

Zlatica Marinković, Olivera Pronić - Rančić, Vera Marković

Abstract- **A new noise wave model of microwave field-effect transistors valid for various bias conditions is presented in this paper. The proposed model consists of an empirical noise wave model and a prior knowledge input artificial neural network trained to predict accurately transistor noise parameters. The inputs of the network are frequency, bias current and the noise parameters obtained by the noise wave model, which represent additional knowledge to the ANN. The validity of the presented model is exemplified by modelling of a specific MESFET device in packaged form.**

Keywords – **prior knowledge input artificial neural network, microwave transistor, noise model, bias dependence**

I. Introduction

Reliable and accurate small signal and noise models of microwave FETs (MESFETs, HEMTs) are necessary for the design of active circuits in modern communication systems. During the last few decades an extensive work has been carried out in the field of signal and noise modelling of these devices. Their physical models are complex and require many input technological parameters [1]-[2]. Therefore the empirical models, mostly based on equivalent circuits are often used [3]–[5].

The complete characterization of microwave transistors includes knowledge about device signal and noise parameters (scattering parameters and noise parameters: minimum noise figure, optimum source reflection coefficient and normalized noise resistance) which are frequency-, temperature- and bias-dependent. The measurements of these parameters, especially of the noise parameters, are complex and time-consuming procedures. Therefore, for accurate and efficient circuit design, models of active devices should include bias and/or temperature dependence. However, most of the existing transistor noise models are valid only for a single operating point.

The noise model [5] is considered to be very suitable for implementation into the standard commercial microwave circuit simulators. It is based on *H* representation of MESFET / HEMT intrinsic circuit with two uncorrelated noise sources. However, at microwave frequencies a treatment of noise in terms of waves seems to be more appropriate [6]-[7] because it allows the use of scattering matrices for the noise computations, leading to advantages in CAD of microwave networks. The wave approach is useful not only for noise modelling but also for measurement of microwave FETs [7].

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The noise wave modelling procedures of MESFETs / HEMTs and dual-gate MESFETs based on *T* representation of transistor intrinsic circuit are proposed in [8] and [9]. A new more accurate noise wave model of microwave FETs, including the error correction functions into the basic noise wave model is proposed in [10].

In order to include bias dependence in noise wave modelling of MESFETs / HEMTs, artificial neural networks (ANNs) have been used and the results are given in this paper. Once developed, an ANN provides fast response for various input values (even for those not seen by the ANN during model development). ANNs are very convenient to be used as a modelling tool and are especially useful for problems not fully mathematically described. There are many publications referring results of applications of ANNs in the microwave area, [11 – 16]. ANNs have been applied in modelling of either active or passive devices, in microwave circuit analysis and design, etc.

The most frequently used ANN is a standard multilayer perceptron (MLP) ANN, consisting of basic units (neurons) grouped into layers: an input layer, an output layer, as well as several hidden layers [11]. Each neuron is connected to all neurons from the adjacent layers, whereas there are no connections among neurons belonging to the same layer. Each neuron is characterized by a transfer function and each connection is weighted. Information flows forward from the input layer to the output layer.

An ANN learns relationship among sets of input-output data (training sets) by adjusting network connection weights and thresholds of activation functions. There is a number of algorithms for training of ANNs. The most frequently used are backpropagation algorithm and its modifications, e.g. Levenberg Marquard algorithm [11].

The model presented in this paper is a new bias dependant hybrid empirical-neural noise model of microwave FETs. The model consists of the empirical noise wave model [10] and an additional artificial neural network aimed to introduce bias dependence in the model. The used ANN belongs to the Prior Knowledge Input (PKI) ANNs [16] which have additional information about the problem being modelled at their inputs. The model and its development are described in the paper. An example of modelling the specific MESFET device in packaged form is provided as well.

II. Proposed PKI ANN Noise Model

The noise wave model of microwave MESFETs / HEMTs described in [10], similar to other empirical noise models, is valid only for one specific bias point. In order to include bias dependence in the noise modelling, a new hybrid model, which is shown in Fig.1, is proposed in this paper. The model consists of the empirical noise wave model [10] developed for one representative (reference) bias point and an ANN through which dependence on bias conditions is included in the model.

Since we considered the case where dc drain-to-source voltage is constant, bias conditions are defined by dc drain-to-source current. The inputs of the neural network are: bias current (I_{ds}) and frequency (f) as well as the prior knowledge - noise parameters for the reference bias point obtained from the noise wave model for that value of frequency (F'_{min} , $\mathrm{Mag}(\Gamma'_{opt})$, $\mathrm{Ang}(\Gamma'_{opt})$, r'_n). The ANN's outputs are device noise parameters (F_{min} , $\mathrm{Mag}(\Gamma_{opt})$, $\mathrm{Ang}(\Gamma_{opt})$, r_n).

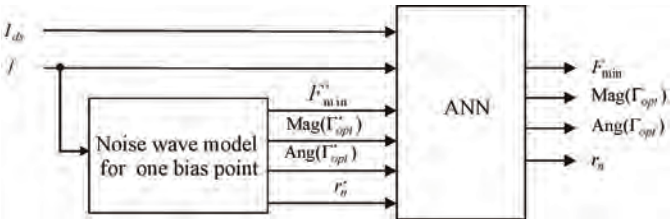

Fig. 1. Proposed PKI ANN model

The model is developed as follows: first, a reference bias point from the device bias operating range is chosen. Then, the equivalent circuit parameters for the noise wave model are extracted from the scattering (S-) parameters and noise parameters measured at several frequencies. For ANN training, it is necessary to acquire the measured values of noise parameters for certain number of bias points over the considered frequency range, and for each considered frequency to perform noise simulations using the developed noise equivalent circuit in order to obtain the noise parameters represent the ANN prior knowledge. To resume, the training set consists of samples, each containing the following: values of bias current, frequency, noise parameters obtained from noise wave model for that value of frequency and measured values of noise parameters as the network target values. After the training and evaluation of ANN, the mathematical expressions describing the ANN are further added on the mentioned device noise wave model schematic by means of a block dealing with variables and expressions (VAR). Inputs of the VAR block are the same as the inputs of ANN. The noise parameters calculated from these expressions are bias dependent values that have to be assigned to a device. Such schematics with added ANN can be used as a library element with the bias current as inputs.

After extraction of the elements of an equivalent circuit and training of the neural network, measured values are not requested for later determination of the noise parameters.

III. Numerical Example

Numerical results related to noise modelling of GaAs FET packaged microwave transistor, type ATF21186 by Agilent (HP), are presented in this paper. Measured values of S and noise parameters for biases (2V, 10mA), (2V, 15mA) and (2V, 20mA), in the frequency range (0.5 – 8) GHz, taken from the device datasheet, were used for the model development. All simulations were performed using microwave circuit simulator ADS, [17].

The small-signal equivalent circuit of the considered transistor is shown in Fig. 2. Transistor intrinsic circuit is denoted by the broken line and it is embedded in a network representing device parasitics. The noise of the device is described by means of the noise wave sources that emanate from the input port of the intrinsic circuit. The equivalent noise wave temperatures are assigned to the noise wave sources [10].

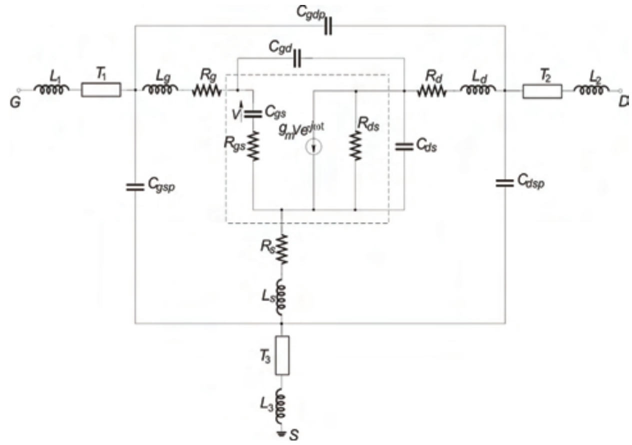

Fig. 2 Equivalent circuit of MESFET / HEMT package

At the beginning, the equivalent circuit parameters (equivalent circuit elements and noise wave temperatures) were extracted from the measured values of the device scattering and noise parameters for a bias point (2V, 15mA) and noise parameters are simulated. In order to eliminate deviations that exist between measured and modelled values of noise parameters, the error correction functions were determined and included in the transistor noise wave model. Namely, each intrinsic circuit noise parameter obtained by the basic noise wave approach is multiplied by the corresponding error correction function, [10]. In order to determine the error correction functions, for each of four noise parameters the ratio of the measured and simulated transistor noise parameters 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 determined for all four noise parameters. In this case, the error correction functions were determined for the minimum noise figure, magnitude of optimum reflection coefficient and noise resistance. All functions have the polynomial form. The simulated values for angle of optimum reflection coefficient are in excellent agreement with measured ones and there was no need to include any correction for that parameter in the noise model.

The extracted equivalent circuit parameters were used for simulation of the noise parameters used as the prior knowledge for the ANN training. After building of the training set in a way described in the previous section, the training of the ANN was performed. Since number of hidden layers and hidden neurons cannot be a priori set, in order to find the ANN with the best performance, ANNs with different number of hidden neurons were trained. After training and evaluation of the ANNs, a network with one hidden layer consisting of 15 neurons gave the best results. The mathematical expressions describing the ANN were then added on the equivalent circuit schematics and noise simulations have been performed. The most illustrative results are given below.

Frequency dependences of the minimum noise figure and magnitude of optimum reflection coefficient for bias point (2V, 15mA) obtained by the noise wave approach (dashed line), as well as by the proposed PKI ANN model (solid line) are compared with measured data (symbols) and shown in Fig. 3. The proposed PKI ANN model has better accuracy than noise wave model. It is obvious that almost perfect match between measured noise parameters and those obtained by the suggested PKI ANN model is achieved.

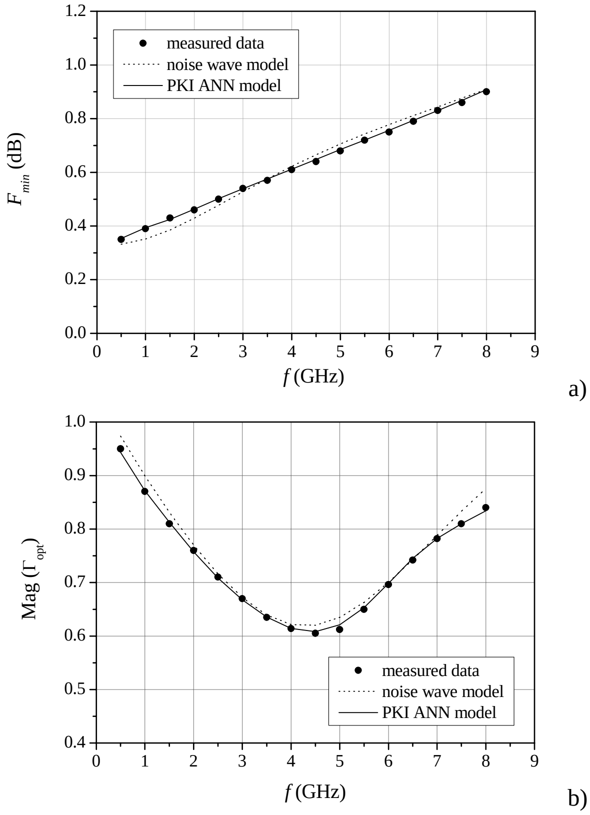

Fig. 3 Accuracy improvement in noise parameters modelling: a) minimum noise figure, b) magnitude of optimum reflection coefficient

In Fig. 4 and Fig. 5 there are plots of the noise parameters simulated by the proposed PKI ANN model and compared with the measured values. Comparison of measured and simulated values for the minimum noise figure, optimum source reflection coefficient and normalized noise resistance versus frequency is shown in Fig. 4. Circles denote the measured values and solid lines – the simulated ones obtained by the proposed PKI ANN model. It can be seen that the predicted noise parameter values match very well with the measured ones.

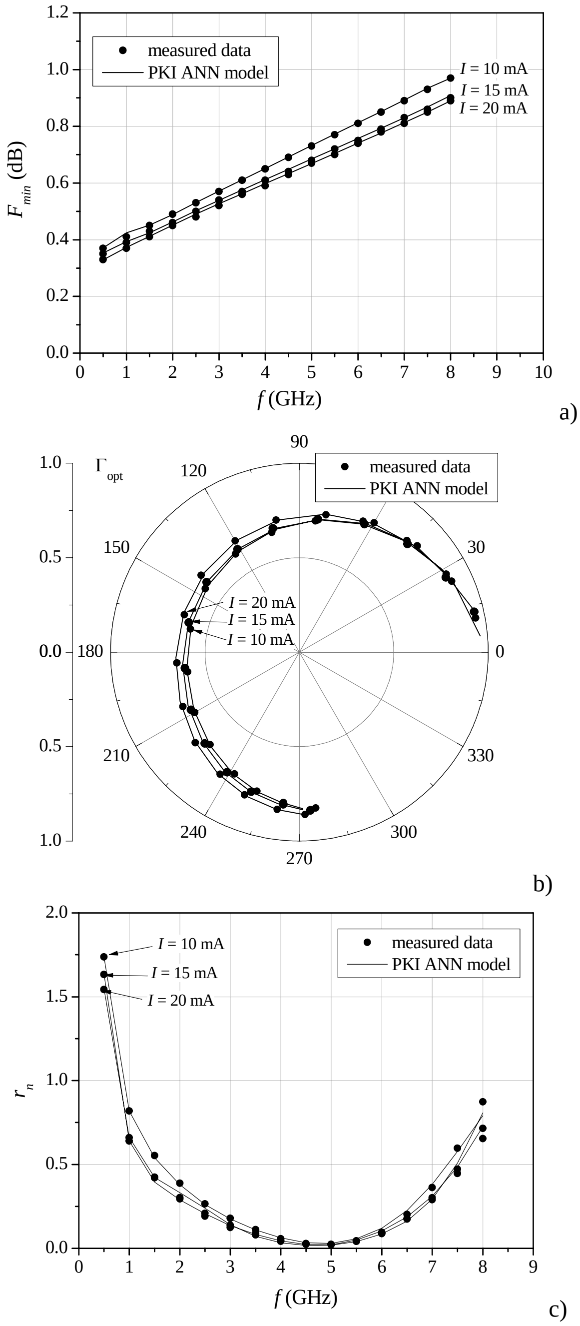

Fig. 4 Noise parameters versus frequency a) minimum noise figure, b) optimum reflection coefficient, c) normalised noise resistance

As a further illustration, the dependence of the minimum noise figure and the magnitude of optimum reflection coefficient on bias current is shown in Fig. 5. The presented data refer to frequencies (0.5, 2.5, 5 and 8) GHz. It can be observed that the simulated values match well the measured ones.

IV. Conclusion

Bias dependant noise parameters modelling of microwave FETs is proposed in the paper. The presented model consists of the empirical noise wave model, which does not directly

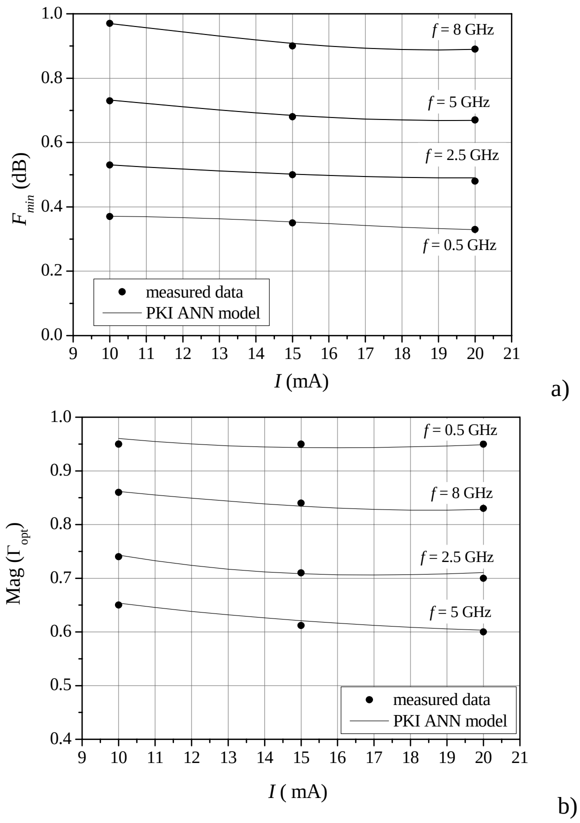

Fig. 5 Noise parameters versus bias current: a) minimum noise figure, b) magnitude of optimum reflection coefficient

incorporate the bias dependence, and ANN through which bias dependence is incorporated in the model. Besides the bias conditions and frequency, the ANN has as inputs the noise parameters simulated by the empirical model which represent additional knowledge about the modelled parameters. Therefore, this ANN is a PKI ANN.

Once developed, this model does not require any change in its structure or in values of its parameters. Extraction of the equivalent circuit parameters is performed only once, omitting in this way measurements and extraction procedures for each bias point. This makes bias-dependent noise modelling of microwave transistors less time consuming and more efficient.

The validity of the proposed bias dependant noise model is exemplified by modelling a specific MESFET device. The presented model has better accuracy than empirical noise wave model for the bias point used for the noise wave model development. Further, the presented model provides results that agree well with the measured characteristics in the considered bias and frequency operating range.

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