Implementation of Microwave Transistor Neural Noise Models into Standard Microwave Simulators

Vera Marković, Zlatica Marinković[1]

Abstract – **Authors of this paper have proposed efficient transistor noise models based on neural networks. In this paper, implementation of proposed neural noise models into standard microwave simulators, such as Libra or ADS is presented. For a specified bias point, a microwave transistor can be described within the simulator by an $s2p$ file containing transistor signal and noise data. Using proposed neural models such $s2p$ file can be generated and assigned to the two-port circuit representing the transistor.**

Keywords – **Neural network, microwave transistor, noise parameters, S-parameters, microwave simulator**

I. Introduction

In the last decade, neural networks have been widely applied in many areas such as pattern recognition, speech and image processing, control process applications, etc. Neural network based methods belong to the class of so-called ”black box” methods since only sources and responses are considered [1]. Since a neural network itself has no any knowledge about the problem to be solved, it has to be trained. In the training process, known input-output combinations related to the problem are presented to the neural network, and network parameters are adjusted. Once trained, neural network is expected to generate correct responses for all inputs even they are presented to the network during the training or not. Neural network ability to give correct response for the inputs not included in the training set, called generalization, is the strongest motive for the further research activities in the filed of neural networks.

As highly nonlinear structures, neural networks are able to model nonlinear relations between different data sets. Owing to this ability, they have been applied in a wide area of problems. Especially, they are interesting for problems not fully mathematically described. Once trained they can predict response with quite a good accuracy, even for input values not presented in the training process, without changes in their structure and without additional knowledge of considered problem. Neural models are simpler than physically based ones but retain the similar accuracy. They require less time for response providing; therefore using of neural models can make simulation and optimization processes less time-consuming, shifting computation efforts from on-line optimization to off-line training.

Recently, neural networks have been applied in the microwave area [2]. Neural models of passive components are presented in [3-5]. There are some neural models that refer to the important parts of many modern communication systems – microwave transistors. Very good results are obtaining in noise modeling of microwave transistors, considering transistor bias condition as well, [6-9]. In this paper, implementation of the developed neural models into the standard microwave simulators, such as Libra or ADS, will be presented.

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II. Transistor Signal And Noise Characteristics

Microwave transistors are usually represented as a two-port circuit characterized by its scattering ($[S]$) matrix, that contains four complex scattering parameters, $S_{ij}, i, j = 1, 2$ described by their magnitudes and phases. It is common that the manufacturers provide S-parameters' data at certain number of frequencies from the specified frequency range, where these data are related to one or a few bias conditions. S-parameters define so-called signal performance of the transistor.

In addition to the signal performance, transistor noise performance is of a great importance for the low noise applications. Any two-port noisy component can be characterized by a noise figure F, which is a measure of the degradation of the signal-to-noise ratio between input and output of the component, [10], and can be expressed as

$$F = F_{\min} + \frac{4R_n|\Gamma_g - \Gamma_{opt}|^2}{Z_0(-|\Gamma_g|^2)|1 + \Gamma_{opt}|^2}, \qquad (1)$$

where $F_{\min}$ is a minimum noise figure, R_n is an equivalent noise resistance, Γ_{opt} is the optimum reflection coefficient, and finally, Z_0 is normalizing impedance. The optimum reflection coefficient refers to the optimum source impedance that results in minimum noise figure, $F = F_{\min}$. The set of four noise parameters: $F_{\min}$, magnitude and angle of Γ_{opt} and R_n describe inherent behavior of the component, independent of a connected circuit and are not a direct or physics-based representation of the noise produced by the device, but play an important role in describing the performance of the noise figure as a function of the generator reflection coefficient.

III. Multilayer Perceptron (MLP) Neural Network

The basic idea of neural network application in microwave transistor noise modeling is developing of appropriate noise models that can predict transistor noise parameters accurately in a wide frequency range for all bias points from the operating range. As a first step, transistor noise parameters dependence on biases and frequency is modeled using multilayer perceptron network - MLP. A standard MLP neural network is shown in Fig. 1. [1].

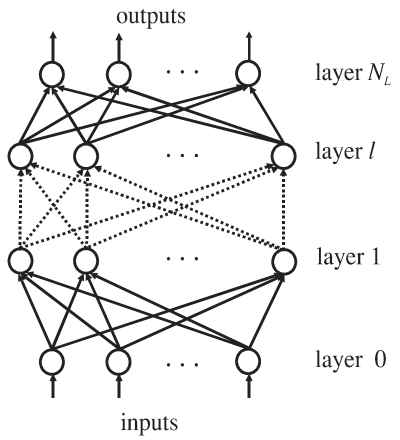

Fig. 1. MLP neural network

This network consists of neurons (circles) grouped into the layers. The input signal is presented to the neurons from the input layer. Each neuron from one layer is connected to all neurons from the next layer. The output layer neurons represent outputs of the network. The layers not directly connected to the outside environment are hidden layers. Neurons are characterized by their activation functions. Here, a linear function for input and output layer and a sigmoid function for hidden layers are chosen. The connections between neurons are characterized by weighting factors.

Input vectors are presented to the input layer and fed through the network that then yields the output vector. Network training is a process of adjusting of network parameters (activation function thresholds and connection weights) in order to minimize the difference between a network response and reference values. This process is iterative and it proceeds until errors are lower than the prescribed goals or until the maximum number of epochs (epoch – the whole training set processing) is reached. Here, for training purposes, *Levenberg-Marquardt* algorithm (a modification of "backpropagation" algorithm) is used.

IV. Transistor Modeling Using Neural Networks

MLP networks are applied with the aim to model the HEMT transistor noise parameters dependence on frequency and bias conditions (dc drain-to-source voltage and dc drain-to-source current). The used MLP network structure has four layers (i.e. two hidden layers). There are three neurons in the input layer:

- dc drain-to-source voltage V_{dc},
- dc drain-to-source current $I + dc$ and
- frequency f.

The output layer consists of four neurons corresponding to:

- minimum noise figure,
- magnitude of optimum reflection coefficient,
- angle of optimum reflection coefficient and
- normalized equivalent noise resistance (50 Ω normalizing impedance).

This approach is presented in Fig. 2 and denoted by "bf" (the mark is related to the network inputs – bias and frequency).

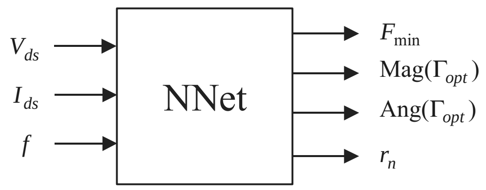

Fig. 2. Neural model for noise parameters dependence on bias conditions and frequency (bf approach)

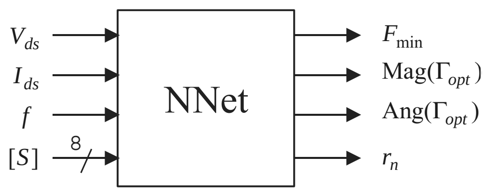

Fig. 3. Neural model for noise parameters dependence on bias conditions, frequency (sbf approach)

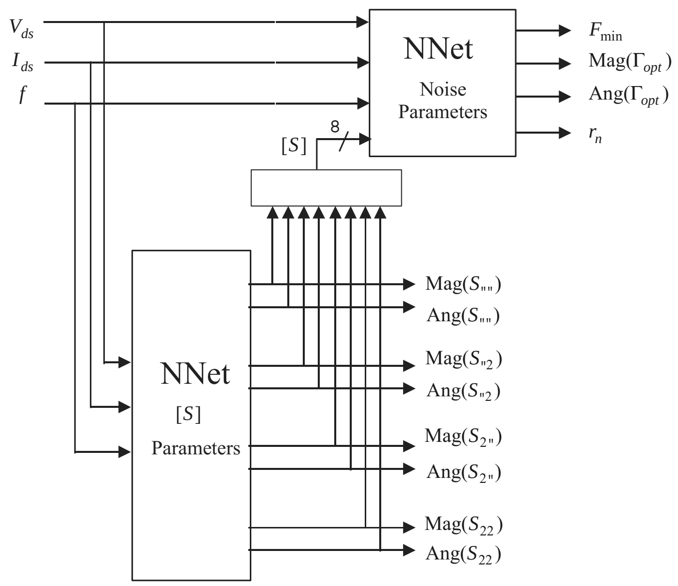

Fig. 4. Neural model for accurate noise parameters prediction

Obtained models are able to predict noise parameters for a given bias point even in the case of the bias point not presented in the training process, without additional computation or change in the network structure.

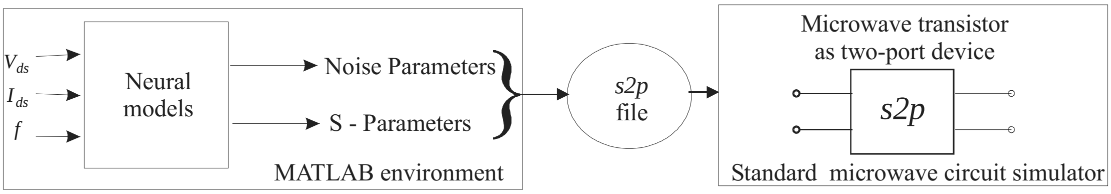

Fig. 5. $s2p$ file generating using transistor neural noise models

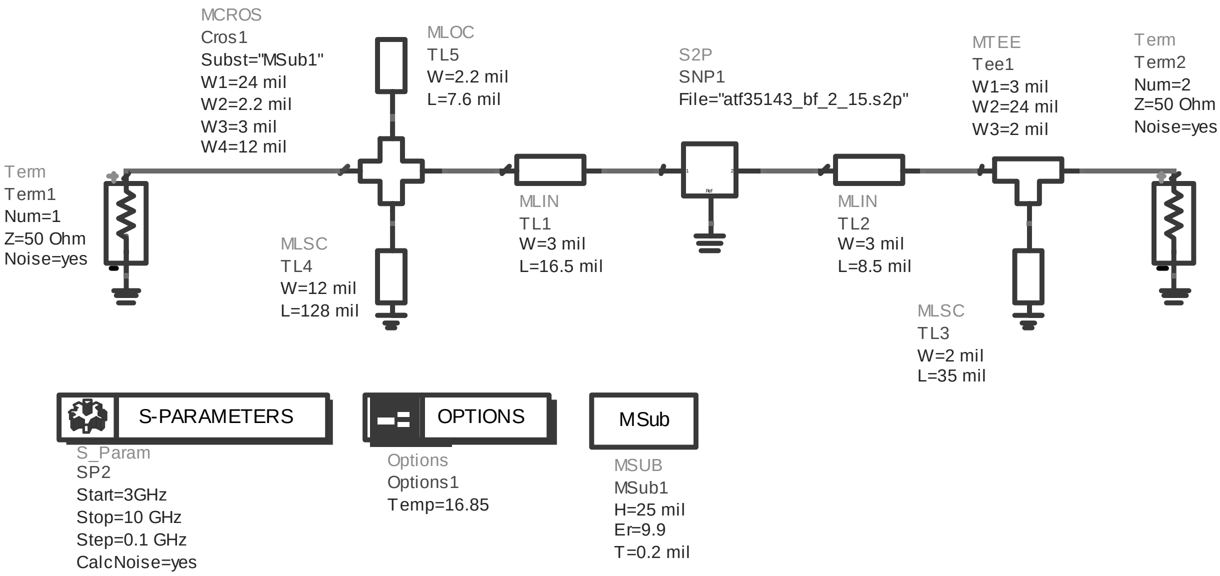

Fig. 6. One-stage microwave amplifier

Further, in order to improve the modeling, transistor scattering parameters are introduced as additional inputs of the neural network, as it is shown in Fig. 3 [6].

Although S-parameters easier to be measured than noise parameters much time can be saved using neural models of S-parameters as well. At that way, all noise parameters can be predicted with high accuracy without additional measuring of S-parameters or their determination by simulation. This approach is presented in Fig. 4 [9].

V. Neural Model Implementation Into The Standard Circuit Simulator

In the microwave community several powerful software packages for analyzing, optimization and design of microwave circuits are popular and widely used, like Libra [11], ADS [12], etc. These software packages are often called microwave simulators. Within microwave simulators, one transistor can be represented as a two-port circuit described by using so-called $s2p$ file. This file contains table values of S-parameters and, in the case of low-noise transistors, the noise parameters as well. $s2p$ file is formed according specified syntax. The data is related to one specified combination of biases, and organized in the following way: after text header there are magnitudes and arguments of four S-parameters (S_{11}, S_{12}, S_{21} and S_{22}) at a number of frequency points. These data are followed by noise parameters' values: minimum noise figure $F_{\min}$, magnitude and angle of optimum reflection coefficient Γ_{opt} and, finally, normalized equivalent noise resistance (where the normalization resistance value is 50 Ω). The noise parameters are given at either the same frequencies or the different frequencies as S-parameters are given at.

The basic idea is forming the $s2p$ file according to the existing syntax using data generated by the transistor neural models of S- and noise parameters for the specified bias conditions. Then, this file is assigned to the two-pot circuit that describes the transistor in the microwave simulator.

In this way, extraction of elements of transistor equivalent circuit and/or model parameters, that is necessary in the existing transistor signal and noise models, is avoided. Here, on-line optimization is shifted in off-line training of neural networks. Once trained, neural models provide signal and noise data prediction practically instantaneously. Therefore, it should compute neural models' responses for specified bias conditions and form $s2p$ file, Fig. 5. This could be done efficiently in the environment used for neural network training, like MATLAB program package environment used here.

VI. Modeling Example

The procedure described above can be illustrated by an example of implementation of transistor neural models in ADS, the standard software tool for microwave design. Noise performance analysis for a microwave amplifier realized as hy-

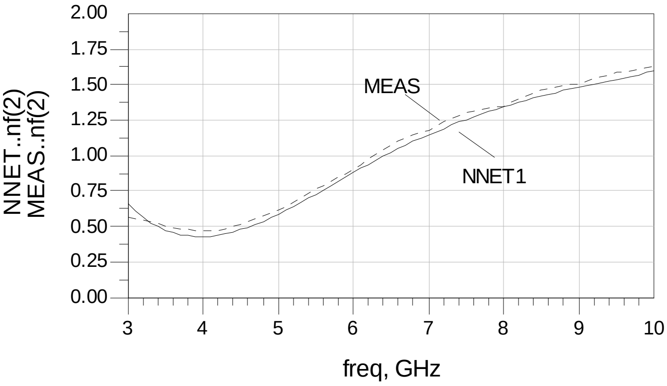

Fig. 7. Noise figure of the microwave amplifier vs. frequency

brid microwave circuit is performed. Schematic design of this amplifier in ADS simulator is shown in Fig. 6. This is a simple one-stage amplifier consisting of active component and input and output matching network realized in microstrip technology. As active component, a microwave pHEMT transistor *Hewlett Packard* ATF35143 is used. First, appropriate signal and noise models for this transistor have been developed, [9]. The models are trained using the data from the manufacturer's catalogue over the (0.5-10) GHz frequency range and for different bias conditions. The both of developed neural models, sp_10_10 model for S-parameters and bf_10_10 model for noise parameters, have ten neurons in each of two hidden layers. Using data generated at the different bias conditions, standard $s2p$ files corresponding to these bias conditions are formed. Further, within ADS, these $s2p$ files can be simply assigned to two-port circuit corresponding the transistor in the amplifier circuit, and amplifier performance analysis (including noise) could be done. Also, optimization of matching networks could be performed if necessary.

In order to verify the proposed approach, not only $s2p$ files generated using neural models but also corresponding $s2p$ files given by the manufacturer are used, and the amplifier analyses simulation results are compared.

It is very interesting to compare results for transistor biases different form the biases used for the training of neural models. As an illustration, Fig. 7 shows noise figure at the amplifier output at the bias point (2 V, 15 mA). The data related to this bias point were not used in the training of neural models. Noise figure obtained in the case of $s2p$ file generated using transistor neural models is denoted by solid line (NNET), and in the case of $s2p$ file given by the manufacturer by doted line (MEAS). It could be seen that these two lines are very close, verifying the proposed procedure.

VII. Conclusion

Using available data of S-parameters and noise parameters of a microwave transistor in operating frequency range and for different bias conditions, neural networks that model dependences of these parameters on biases and frequency could be trained. The trained neural models can predict S- and noise parameters in the whole operating range without their changes. This is their main advantage comparing to most of the existing transistor signal and noise models, which are valid for only one bias condition. Within microwave simulator a microwave transistor can be represented as two-port circuit with assigned file containing information about S- and noise parameters for several frequencies. Since this file can be obtain very easily for any transistor bias conditions using transistor neural models, the proposed approach provides very efficiently representing of the transistor in the whole operating range.

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