# New Approach to Applying the Transistor Neural Models within Microwave Circuit Simulators

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*Abstract*- **This paper deals with the implementation of microwave transistor signal and noise neural models into standard microwave circuit simulators. Models based on neural networks were proposed earlier and presented in the previous authors' papers. Models were implemented as user-defined library elements and are valid for the whole operating range of transistor biases.**

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

## I. INTRODUCTION

The development of reliable small-signal and noise device models is very important task required for the design of microwave circuits, especially for the wireless applications, [1].

A drawback of most existing empirical or physical models is that they are limited to one bias point. Authors of this paper have been proposed new transistor models valid in the whole operating range of biases and frequencies, [2]-[5]. Neural networks have been chosen as a modeling tool because they have capability to extract very complex relationships between two sets of data, which is very interesting for problems not fully mathematically described, [6]. They have found application in many areas. Recently, an interest in neural networks has arisen in the microwave area as well [7].

This papers deals with implementation of the proposed transistor models into standard microwave simulators.

## II. MULTILAYER PERCEPTRON (MLP) NEURAL NETWORK

MLP neural network [6] is most often used neural network structure for modeling of microwave devices. MLP network consists of an input layer, output layer and a number (usually one or two) of so-called hidden layers. Each neuron from one layer is connected to all neurons from the next layer. Neurons are characterized by their activation functions. 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. The *l*-th layer output is:

$$\mathbf{Y}_l = F(\mathbf{W}_l \mathbf{Y}_{l-1} + \mathbf{B}_l) \quad (1)$$

where $\mathbf{Y}_l$ and $\mathbf{Y}_{l-1}$ are outputs of *l*-th and (*l*-1)-th layer, respectively, $\mathbf{W}_l$ is weight matrix between (*l-1)*-th and *l*-th layer and $\mathbf{B}_l$ is bias matrix between (*l-1)*-th and *l*-th layer. Function *F* is an activation function of each neuron and, in our case, is linear for input and output layer and sigmoid for hidden layers: $F(u) = 1/(1+e^{-u})$ .

Network training is an iterative 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. Here, for training purposes, *Levenberg-Marquardt* algorithm (a modification of "backpropagation" algorithm) is used.

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 (generalization ability).

## III. TRANSISTOR SIGNAL AND NOISE CHARACTERISTICS

A microwave transistors is usually represented as a two-port circuit characterized by its scattering ([*S*]) matrix, that define so-called transistor signal performance, and 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 only one or, infrequently, to a few bias conditions. 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, [8], and can be expressed as

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

where $Z_0$ is normalizing impedance. In (1), minimum noise figure $F_{\min}$, equivalent noise resistance $R_n$ , and magnitude and angle of the optimum reflection coefficient $\Gamma_{opt}$ represent a set of four noise parameters that describe inherent behavior of the component and their frequency dependences are required for low-noise circuit design.

## IV. MICROWAVE LOW-NOISE TRANSISTOR MODELING USING NEURAL NETWORKS

The basic idea of neural network application in microwave transistor modeling is developing models that can predict transistor signal and noise performance accurately in a wide frequency range for all bias points from the operating range.

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MLP networks were applied with the aim to model the HEMT transistor S and noise parameters dependence on frequency and bias conditions (*dc* drain-to-source voltage and *dc* drain-to-source current), as it is presented in Figs 1 and 2, respectively, [3].

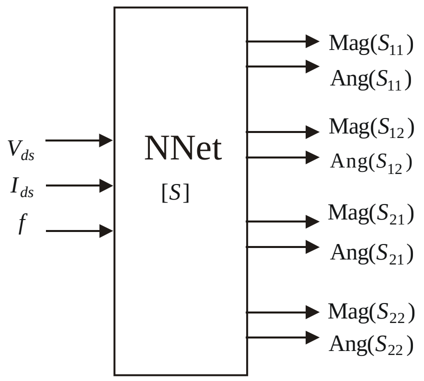


Fig. 1. *Neural model for S- parameters dependence on bias conditions and frequency*

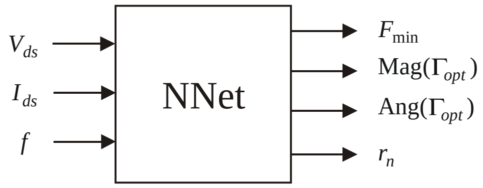


Fig. 2. *Neural model for noise parameters dependence on bias conditions and frequency*

Both neural networks have three neurons in the input layer corresponding to

- dc drain-to-source voltage $V_{ds}$,
- dc drain-to-source current $I_{ds}$ and
- frequency *f*.

The output layer of a network that models S-parameters has eight neurons corresponding to magnitudes and phases of all four scattering parameters.

The output layer of a network which models noise parameters 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).

The number of hidden neurons can be one or two, depending on the number of training data.

The proposed models are able to predict signal and noise parameters for any bias point including those not presented in the training process, without additional computation or change in the network structure.

Further, with the aim to increase the accuracy of modeling additionally, some improvements in model structure have been introduced, as it has been reported in [2]-[5].

## V. New Approach to Neural Model Implementation into a Standard Circuit Simulator

Practical using of once developed neural models for transistor signal and noise parameters requires their implementation in some of standard packages for analyzing, optimization and design of microwave circuits, like Libra [9], ADS [10], etc.

One possible way is to represent a low-noise transistor within the circuit simulator as a two-port circuit with assigned so-called *s2p* file. An *s2p* file contains table values of S-parameters in the operating frequency range and the noise parameters in a number of frequency points as well. This approach is shown in Fig 3, and described in detail in [11].

The procedure is as following: *S*- and noise parameter data are generated using transistor neural models, and an *s2p* file is formed according to the specified syntax. It can be done within the environment where neural models were trained (e.g. MATLAB environment).

Since one s2p file corresponds to only one specified bias point, it is necessary to go back to "training environment" and generate a new *s2p* file for any other bias point. This is the main drawback of this procedure.

Here, a new way of neural network implementation is proposed, Fig 4, where the prediction of transistor signal and noise parameters is completely performed in the microwave simulator. Namely, instead of generating *s2p* files, the sets of equations are generated in the "training environment". Actually, these equations are mathematical representation of the developed neural models, according to Eqn (1).

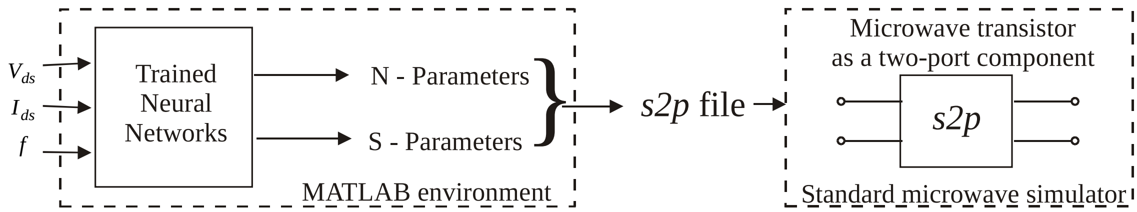


Figure 3. Implementation of signal and noise neural models by *s2p* file generating

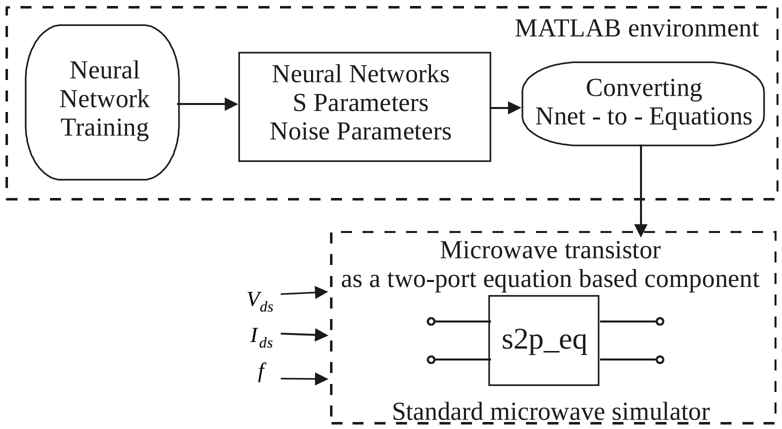


Figure 4. Implementation of signal and noise neural models by equation generating

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Further, these equations are used in the VAR blocks within the microwave simulators. The outputs of these VAR blocks, magnitudes and phases of S-parameters and four noise parameters, are assigned to specified, so-called S2P_EQN, item. This item represents a two-port component whose S-parameters and noise parameters are equation based. In that way, signal and noise characteristics, for any operating bias point and any frequency from the operating range can be obtained within the simulator, i.e. model can be used apart from the "training environment".

## VI. Modeling Example

The proposed procedure can be illustrated by an example of implementation of transistor neural models in ADS, the standard software tool widely used for microwave design. A *Hewlett Packard* microwave pHEMT transistor ATF35143 has been modeled.

First, appropriate signal and noise neural models for this transistor have been developed, [3]. The models were trained within MATLAB program package environment 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. A procedure for generating mathematical equations corresponding to neural models has been developed within MATLAB environment as well. Using this procedure, models, sp_10_10 and bf_10_10 were converted to blocks of equations that have been further used within the appropriate VAR blocks in the simulator.

In the ADS simulator, the transistor is defined as a new user-defined library element, ATF35143_bf_sp, Fig. 5. Schematic design of the library element structure is shown in Fig. 6.

The neural model incorporated within ADS package enables fast and efficient simulation of *S* and noise parameters for different bias conditions, for instance for optimization purposes.

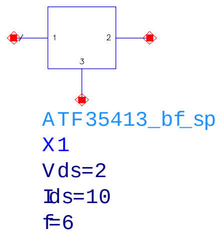



Fig. 5. Transistor model as user defined library element

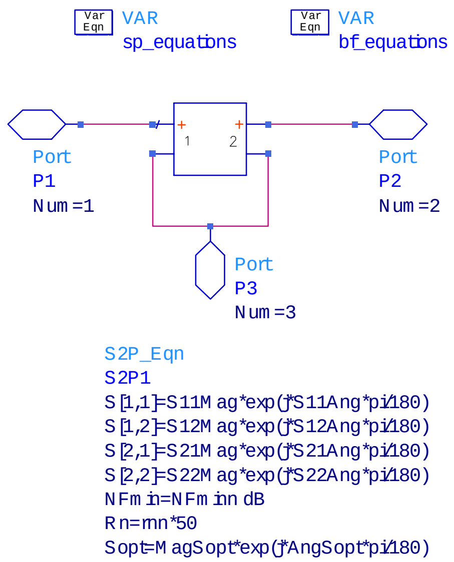



Fig. 6. Transistor model - Schematic Design

For illustration, the minimum noise figure characteristics for the considered pHEMT for two bias points are presented in Fig.7. It can be seen that predicted data (solid line) are very close to referent data not only for bias point used for network training (crosses) but also for bias point not used for network training (squares). Further, the results of simulation of the parameter $S_{21}$, minimum noise figure, and optimum reflection coefficient for several different biases conditions are presented in Fig. 8 (a), (b) and (c), respectively.

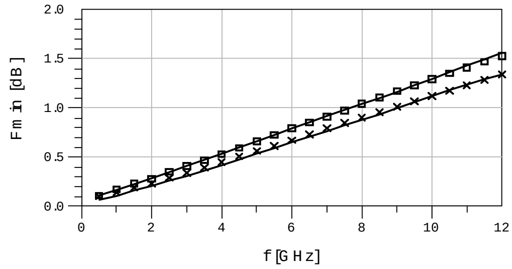
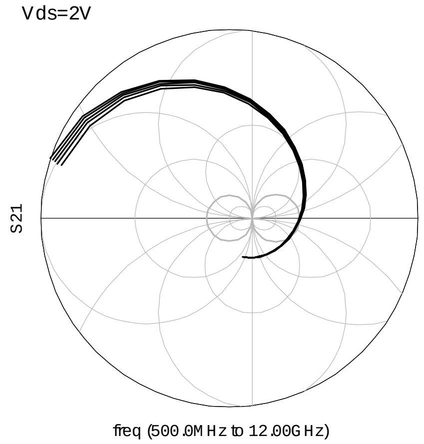
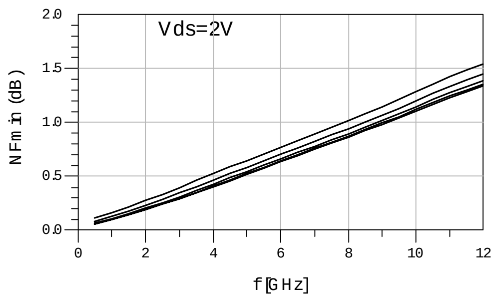


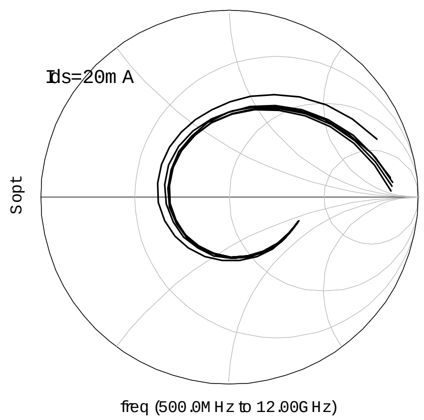

Fig. 7 Prediction of the minimum noise figure by the neural model for two bias points, comparing with the referent data




(a) Parameter $S_{21}$ for $V_{ds}$ =2V and $I_{ds}$ =(10-40) mA




(b) Minimum noise figure for $V_{ds}$ =2V and $I_{ds}$ =(10-40) mA




(c) $\Gamma_{opt}$ for $I_{ds}$ =20mA and $V_{ds}$ =(2-4) V

Fig. 8 Prediction of some transistor parameters for different bias points

## VII. Conclusion

Neural networks can be successfully used for microwave low-noise transistor modeling. Once trained neural models can predict transistor *S* - and noise parameters in the whole operating range without changes in model structure. This is their main advantage comparing to most of the existing transistor signal and noise models, which are valid for only one bias condition. Namely, the extraction of elements of transistor equivalent circuit and/or model parameters, that is necessary in most of the standard transistor models, is avoided, i.e. on-line optimization is shifted in off-line training of neural networks.

The developed models can be implemented in microwave simulator in two ways. The first one is forming an *s2p* file in the training environment and its assigning to a two-port circuit representing the transistor. The disadvantage of this approach is a need for going back from the simulator to the training environment for each bias point not used before, in order to form *s2p* file. The approach suggested here is converting neural models to corresponding mathematical expressions and their direct implementation into the simulator. In this way, a completely new library element for transistors that include bias conditions can be defined. All computations for any new bias point will be done within the simulator, which enables very efficient further analysis of circuits containing this active device.

## Acknowledgement

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