A Practical Large-Signal Global Modeling Simulation of a Microwave Amplifier Using Artificial Neural Network

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***Abstract*—We present a new technique to obtain large-signal global modeling simulation of a MMIC amplifier. The active device is modeled with a neural network trained with data obtained from a full hydrodynamic model. This neural network describes the nonlinearities of the equivalent circuit parameters of a MESFET implemented in an extended Finite Difference Time Domain (FDTD) mesh. We successfully represented the transistor characteristics with a one-hidden-layer neural network whose inputs are the gate voltage V_{gs}, and the drain voltage V_{ds}. Small-signal simulation is performed and validated by comparison with HP-Libra. Then, the large signal behavior is obtained, which demonstrates the successful use of artificial neural network (ANN) in the FDTD marching time algorithm.**

***Index Terms*—Artificial neural network, extended-FDTD, global modeling.**

I. Introduction

MICROWAVE circuits are becoming more and more integrated. In the millimeter-wave band, the radiation and the coupling effects can no longer be neglected. The aim of the "Global Modeling" techniques is to unify both the electromagnetic analysis of passive structures and the semi-conductor theory used to obtain physical models of transistors. At very high frequencies, the active device model must be accurate enough to predict the behavior of sub-micrometer gate devices. Alsunaidi *et al.* [1] have used a full hydrodynamic model coupled with Maxwell's equations to predict the interactions between the carriers and the propagating wave inside the device. Recently, this full hydrodynamic model has been used to demonstrate the global modeling approach [2]. However, it suffers from time consuming techniques such as nonuniform meshing and time domain diakoptics.

Artificial neural network (ANN) is a new trend in millimeter-wave CAD that dramatically reduces the computation time of electromagnetic (EM) models, replacing the expensive EM model with ANN trained by EM simulation results [3]. This new approach has been successfully used [4] to model passive devices. ANN's have also been used to model the high nonlinearities of transistors obtained by measurements [5].

In this letter, we propose to model the steady state solution of the hydrodynamic equations by an artificial neural network that accurately and efficiently predicts the behavior of the simulated MESFET. The transistor is implemented in an extended finite difference time domain (FDTD) [6] code to simulate an amplifier. The nonlinearities of the MESFET are predicted by the ANN, which updates the circuit parameters values according to the electromagnetic field computed across the lumped elements inserted in the FDTD mesh.

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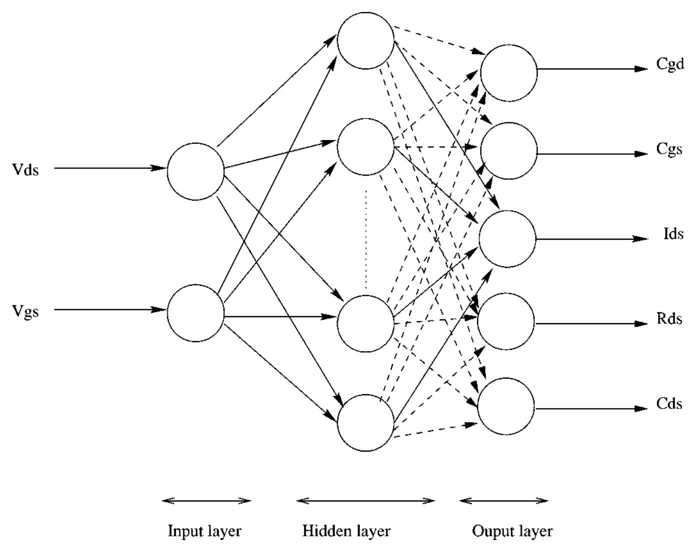

Fig. 1. Artificial neural network architecture.

II. Methodology

The hydrodynamic model is based on the moments of the Boltzmanns transport equations obtained by integration over the momentum space. This model has been successfully used to obtain a full wave analysis of the transistor [1], [2]. However, this approach is computationally very expensive to be used in an iterative design scheme. The training property of the ANN is used to accelerate the full wave analysis, in order to efficiently characterize the large signal behaviors of microwave circuits.

A MESFET is simulated using the hydrodynamic equations. Then, the intrinsic parameters are extracted from the results and can be used to train the ANN. Physical dimensions as well as doping profiles could also be used as inputs of the ANN, but one has to compute the training data. In this work, we restricted ourselves to two inputs: V_{GS}, V_{DS}, and five outputs C_{gs}, R_{ds}, C_{ds}, C_{gd} and I_{ds}. Fig. 1 shows the architecture of an ANN with one hidden layer, two inputs and five outputs. The input of each neuron in the hidden layer is the sum of all the outputs of the

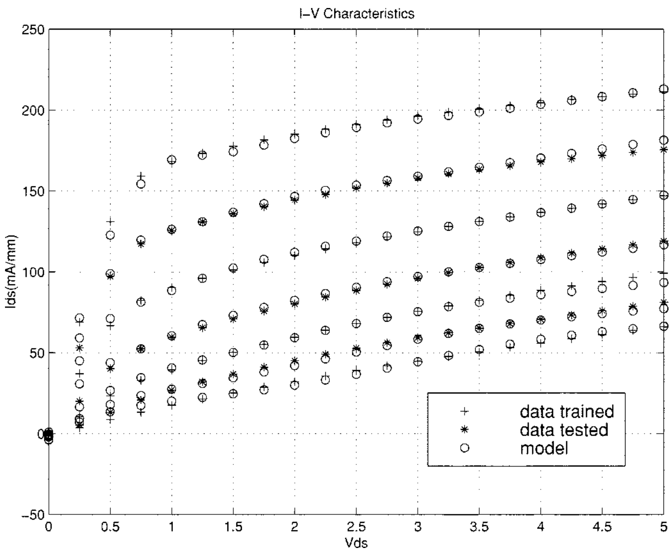

Fig. 2. I–V characteristics of the simulated MESFET.

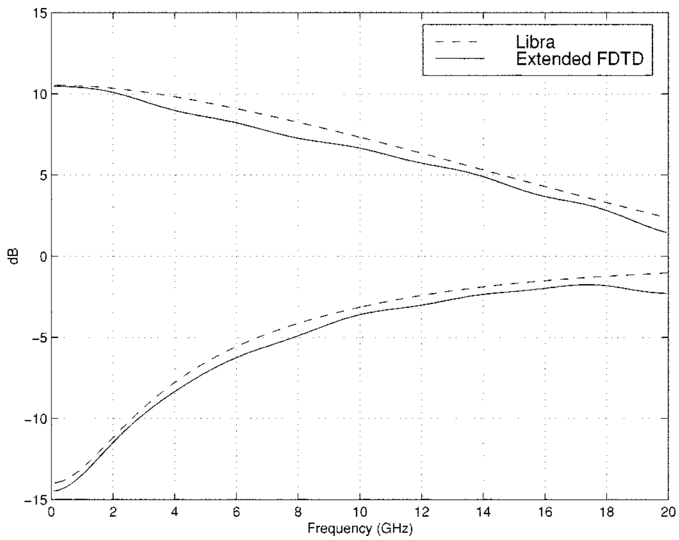

Fig. 3. Small-signal S-parameters of the MESFET.

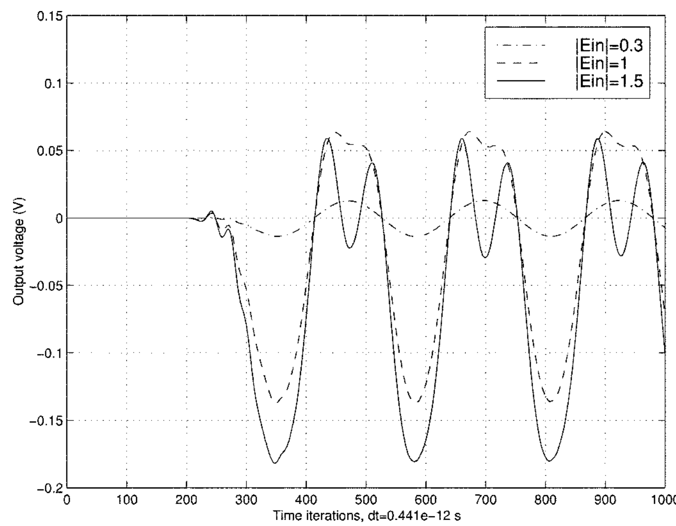

Fig. 4. Large-signal simulation results.

input layer multiplied by a set of weighting factors. The output is given by a so-called activation function, which is a nonlinear function applied to the input in order to model our data.

A 3-D FDTD code is modified to include lumped elements that describe the intrinsic parameters of the equivalent circuit of a unilateral transistor. These lumped elements are distributed across multiple FDTD cells. At each time step, the V_{GS} and V_{DS} voltages are computed from the electric field which are then fed back to the neural network to compute the new intrinsic parameters. Hence, updating of the equivalent circuit parameters is almost instantaneous and does not require the hydrodynamic model to be solved during the FDTD simulation.

III. Results

A typical MESFET was simulated according to the hydrodynamic model. Then, a three layer neural network was trained to model the nonlinearities of C_{gs}, R_{ds}, C_{ds}, C_{gd} and I_{ds}. Six neurons were used in the hidden layer. Fig. 2 shows the I–V characteristics of the simulated MESFET and the results obtained after training of the ANN. Four different I–V drain-voltage sweeps were used for training using a total of 84 training points. The testing was performed for three I–V drain-voltage sweeps (63 points), embedded in the ones used for training. We used a back-propagation ANN using the *Levenberg–Marquardt* method for the optimization. The agreement between both sets of data used for training-testing, and the hydrodynamic model initial data, is very good.

The accuracy is better than 1%. At a given V_{gs}, the drain current can be computed for the full range of V_{ds} almost instantaneously. This has to be compared with the 45 min necessary to compute 21 points using the hydrodynamic model on the same computer. We simulated the transistor without any matching network to validate the method. Fig. 3 presents the small-signal S-parameters.

The dielectric constant of the substrate is $\varepsilon_r = 2.2$, and the height of the substrate is $h = 0.794$ mm. The amplifier is assumed to be biased at $V_{GS} = -0.6$ V and $V_{DS} = 3$ V. At this bias point, $C_{gs} = 0.5$ pF, $C_{ds} = 17$ fF, $R_{ds} = 120\,\Omega$ and $g_m = 120$ mS. These results are compared with a simulation performed using HP-Libra. The trends of S_{21} and S_{11} are very close to the FDTD results.

The neural network has been used to take into account the nonlinearities of the intrinsic parameters. The structure is excited by a sinusoidal wave of amplitude $E_{\rm in}$, and frequency $f = 10$ GHz. Fig. 4 presents the output voltage for three different cases. As the amplitude of the signal is increased, the device approaches saturation, generating harmonics in the frequency domain. This shows that the ANN can be used to describe the nonlinearities of the MESFET.

IV. Conclusions

Millimeter-wave CAD requires a full-wave analysis of MMIC's to accurately predict wave-device interactions, and the performance of new active devices inside a particular microwave topology. An ANN is used to model the non- linearities of a MESFET based on a full-hydrodynamic model. This ANN is used to update the intrinsic parameter values of the transistor implemented in the FDTD marching time algorithm as lumped elements. The ANN reduces dramatically the computation time in comparison with a complete global modeling approach. This approach provides an efficient and accurate first order large-signal global modeling approximation.

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