EM-ANN MODELS FOR VIA INTERCONNECTS IN MICROSTRIP CIRCUITS

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Abstract

A novel approach for accurate and efficient modeling of MMIC components by using electromagnetically-trained Artificial Neural Network (EM-ANN) software modules is presented. The approach has been verified by developing models for microstrip via and stripline-to-stripline interconnects in multilayer circuits. Implementation of the approach is demonstrated by integrating the EM-ANN models in a commercial microwave circuit simulator.

I. INTRODUCTION

Efforts to lower the cost and reduce the weight/volume of MMICs have resulted in high-density and multilayer circuits where a large number of via interconnects are used. With this increased complexity and higher operating frequencies, an accurate and efficient characterization of via interconnect discontinuities must be carried out in order to achieve accurate simulation results [1]. Several recent efforts have focused on the analytical and numerical evaluation of via discontinuities using quasi-static and full wave techniques [1-8]. Quasi-static models are valid only at low frequencies. Full-wave characterization can lead to accurate results, but at a much higher computational expense which prevents their use in practical interactive CAD.

This paper presents a new methodology for accurate modeling of via interconnects using Electromagnetically-Trained Artificial Neural Networks (EM-ANNs). In the past, Artificial Neural Networks (ANNs) have been used only to a very limited extent in the microwave engineering area. Applications reported in literature include: automatic impedance matching [9], microstrip circuit design [10], and microwave circuit analysis and optimization [11]. We make use of the ANN approach for component modeling. The proposed technique uses the Design of Experiments (DOE) methodology to identify various component parameter values for which electromagnetic simulations need to be carried out in order to capture important input-output relationships. Use of the DOE approach allows for a minimum number of EM simulations that need to be performed. Simulation results are then used to train the ANN model, using physical parameters as inputs, to provide the correct S-parameter response over the desired frequency range. Since ANNs have been shown to have the ability to model highly nonlinear relationships, as well as provide excellent interpolative capabilities [12,13], the trained model is valid for the entire ranges of the input variables. Once the EM-ANN model has been trained, it is easily inserted into a commercial microwave circuit simulator. These models prove to be extremely useful in situations where an element is used many times with varying geometrical dimensions. An application of this methodology for modeling broadband shunt via elements in microstrip circuits is presented.

II. Methodology

2.1 ANN Modeling

The ANN architecture used in this work is shown in Fig.1 and consists of an input layer, an output layer, and one hidden layer. It is a multilayer, feed-forward ANN, utilizing the error backpropagation learning algorithm [14]. The hidden layer allows modeling of complex input-output relationships.

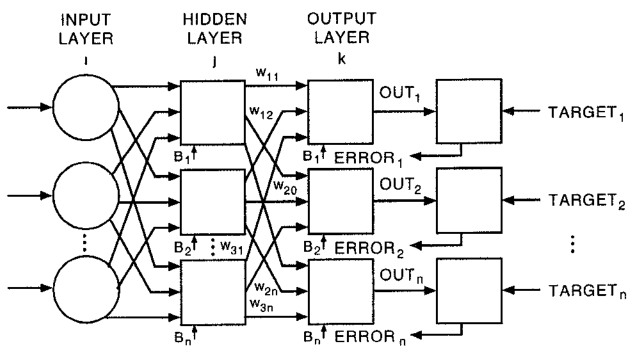

Fig. 1 Artificial neural network architecture used for modeling.

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The ANN learns relationships among sets of input-output data which are characteristic of the component under consideration. First, input vectors are presented to the input neurons and output vectors are computed. ANN outputs are then compared to desired outputs and errors are computed. Error derivatives are then calculated and summed up for each weight until all training sets have been presented to the network. These error derivatives are then used to update the weights for neurons in the model. Training proceeds until errors are lower than prescribed values. Details of the training algorithm are given in [13].

2.2 DOE Methodology

In order to train the EM-ANN models, a number of EM simulations need to be performed. These simulation points need to be chosen so that important input-output relationships are presented to and learned by the EM-ANN model. Simple models require less simulation points, while highly nonlinear models require an increased number of simulations.

Although DOE methods had been developed for regression analysis, they can be used to determine simulation points which effectively cover the region of interest. When building a model, one would like to perform as few EM simulations as possible for achieving the desired accuracy. This implies starting with a low-order experimental design and sequentially building up to higher-order designs by adding additional simulation points.

The central composite procedure for design of experiments [14], shown in Fig. 2 for a case with two design parameters, is used in this work to obtain the initial structures to be simulated for EM-ANN modeling. If it is found that the input-output relationships of the component have not been sufficiently captured, additional simulation points are added to fit the higher-order nonlinearities.

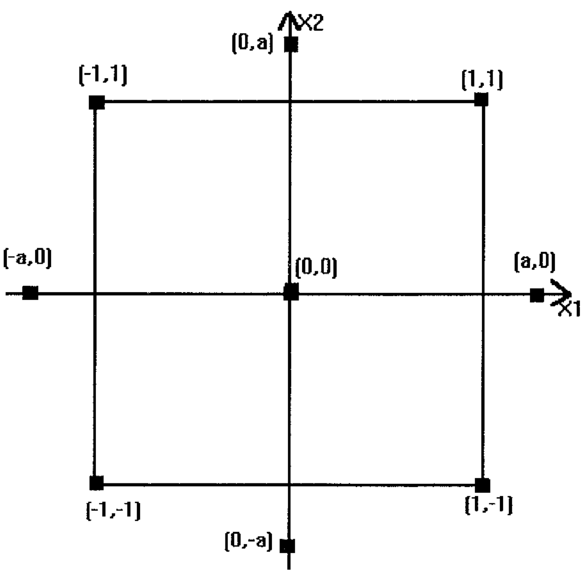


Fig. 2 Distribution of simulation points for a central composite experimental design when the number of design variables is only two (x1 and x2).

III. Results for Broadband GaAs Microstrip Via

Figure 3 shows the structure and some parameters of the via under consideration. The height of the substrate, the dielectric constant, and all loss parameters are considered constant for this example. The width of the incoming microstrip line, W_l, the width of the via pad, W_p, and the diameter of the via hole, D_{via}, are variable design parameters. Input variables for the EM-ANN and their ranges are given in Table 1.

EM simulations were performed from 5 to 55 GHz in 10 GHz steps using a commercially available full-wave electromagnetic simulator (HP-Momentum [15]). Via structures for 15 DOE central composite points, as well as for 14 additional training/testing points spaced midway between the previous points, were simulated. In addition, 16 structures were simulated for independent verification of the model after completion of the training.

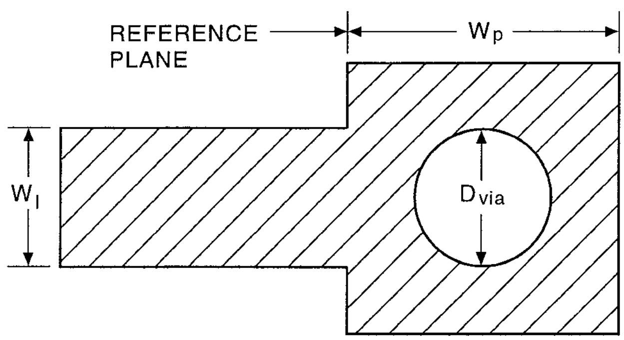
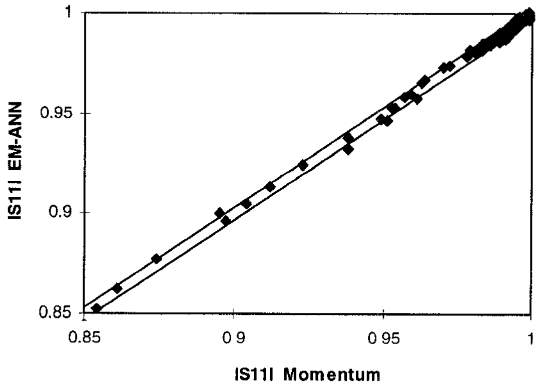


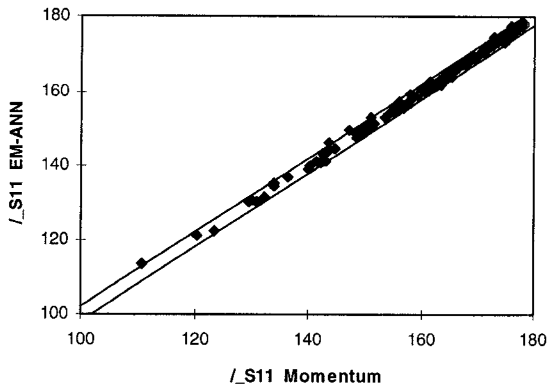
Fig. 3 GaAs microstrip ground via geometry. Substrate thickness = 4 mil, ε_r=12.9, tanδ=0.002, σ_{metal}=4.1e7, and t_{metal} = 0.1 mil.

Input Parameter	Minimum Value	Maximum Value
Frequency	5 GHz	55 GHz
W_l/W_p	0.3	1.0
D_{via}/W_p	0.2	0.8
W_l/H_{sub}	0.1	2.0

Table 1 Variable input parameters for GaAs microstrip ground via modeling.

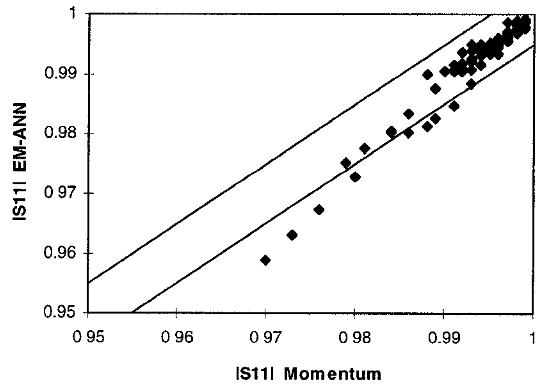


(a)

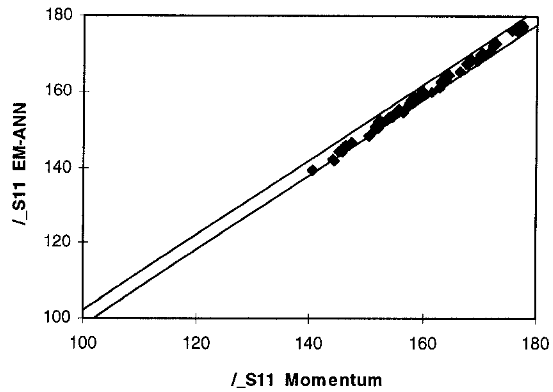


(b)

Fig. 4 Comparison of EM-ANN model results with full-wave analysis of a microstrip via for training data set.
(a) magnitude response with ±0.003 error bounds
(b) phase response with ±2 degree error bounds



(a)



(b)

Fig. 5 Comparison of EM-ANN model and full-wave results for GaAs microstrip via verification data set. (Note the expanded scale compared to that in Fig. 4(a))
(a) magnitude response with ±0.005 error bounds
(b) phase response with ±2 degree error bounds

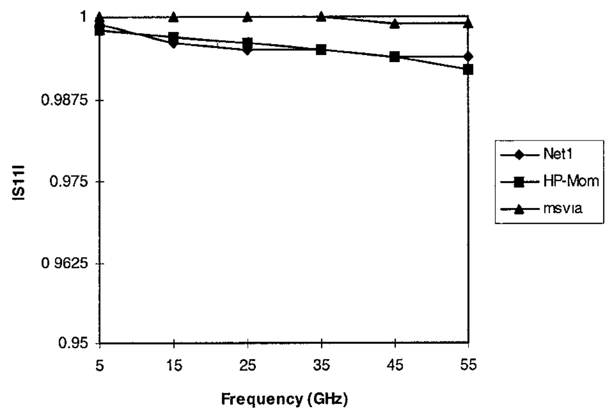
Best results were obtained by using the 15 central composite points and the 14 interior points for training the network. This training required a total of 50 minutes time on a 486 computer. Fig. 4 and Fig. 5 show the results for the training and verification sets, respectively. Shown are EM-ANN results versus HP-Momentum results, which should be linear for a perfect fit. It may be noted that the EM-ANN via model is able to achieve accuracy comparable to EM simulation over the entire 5-55 GHz range. Since a full-wave analysis is used, all the dielectric, conductor, and radiation losses , as well as all parasitic effects, are included. The developed model may now be used in linear analysis and in nonlinear analysis where harmonic frequency components are generated.

IV. Integration of EM-ANN Model with a Circuit Simulator

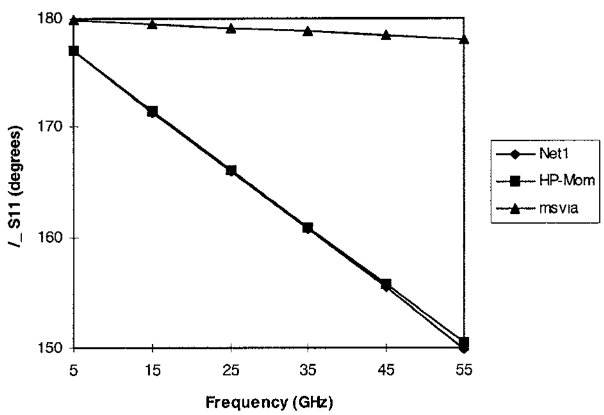
After training, the EM-ANN models were integrated into a microwave network simulator (HP-MDS [16]). Fig. 6 compares the new EM-ANN via model (NET1) with HP-Momentum results and the current *msvia* element available in HP-MDS. Excellent results are achieved by the EM-ANN models when compared to HP-Momentum simulations. Simulation times for NET1, *msvia,* and HP-Momentum are shown in Table 2. Note that the new EM-ANN model does not require a significant increase in simulation time over the current HP-MDS model.

V. Concluding Remarks

We present a novel approach for accurate and efficient modeling of MMIC components by using electromagnetically-trained ANN software modules. The approach has been verified by developing models for microstrip via and stripline-to-stripline interconnects in multilayer circuits and integrating these models ın a commercially available microwave circuit simulator. Other applications of the approach will be presented at the symposium.



(a)



(b)

Fig. 6 Comparison of Net1 model, HP-Momentum, and HP-MDS via element, *msvia*. GaAs via with ε_r=12.9, H_{sub}= 4 mil, t_{metal}=0.1 mil, σ_{metal}=4.1e7, $\tan\delta$=0.002, W_l/W_p=0.65, D_{via}/W_p=0.5, and W_l/H_{sub}=1.05.

Model	Simulation Time
HP-MDS, *msvia*	0.30 sec
HP-Momentum	12.48 min
Net1	0.33 sec

Table 2 Comparison of simulation times for the GaAs via described in Fig. 6.

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