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ELECTROMAGNETIC MODELING AND OPTIMIZATION USING NEURAL NETWORKS

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ABSTRACT

Electromagnetic modelling and optimization is important for designing high-frequency electronic circuits used in computers and wireless communications. Wireless technologies at higher frequency bands from radio-frequency (RF) to microwave and millimeter-waves are being explored. The push for bandwidth in wireline communication drives the signal speed to multi-gigabits per second and beyond. At such high-frequency/high-speed, the electromagnetic effects in components and systems must be accurately handled during design. However electromagnetic simulation and optimization is still computationally prohibitive for many practical problems today.

This paper describes an emerging computational approach utilizing artificial neural networks (ANN) for fast modeling and optimization of electromagnetic components in high-frequency electronic design [1]. ANNs can be trained to learn electromagnetic behaviors from component data. Trained ANNs can be used in high-level circuit and system design allowing fast optimization including electromagnetic effects in components. Work in this area in recent years have led to the application of ANNs in a variety of circuit modeling and design such as modeling microstrip lines, vias, spiral inductors, transistors, VLSI interconnects, coplanar waveguide discontinuities, printed antennas, and embedded passives for circuit synthesis, optimization, and yield analyses. Research and developments in the area are continuing in developing ANN based methodologies for advanced linear/nonlinear microwave modeling and design.

Let $\boldsymbol{x}$ be a vector of input parameters of an electromagnetic model, such as geometrical/physical parameters of a passive component. Let $\boldsymbol{y}$ be a vector of responses of the RF/microwave component under consideration, e.g., electromagnetic scattering parameter (S-parameters) of a passive component. The original electromagnetic theoretical model for this relationship is computationally too intensive for online circuit design. A fast ANN model is to be developed to represent this $\boldsymbol{x}$-$\boldsymbol{y}$ relationship. We define an ANN, such as multilayer perceptron network [1], with input neurons representing $\boldsymbol{x}$, and output neurons representing $\boldsymbol{y}$. The ANN is trained to learn the electromagnetic problem through samples of ($\boldsymbol{x}$, $\boldsymbol{y}$) data called training data. The data can be generated by measurement and/or simulation of the original electromagnetic problem. The purpose of ANN training is to adjust ANN internal parameters such that

the ANN model outputs best match that in the data. After training, the ANN model can be tested with a separate set of data called test data. The test data can be generated by the same data generator as the training data, but sampled differently such that the test data has not been used during training. The ANN model is ready to be used if the error between the ANN and the test data is small.

As an example, we illustrate the use of ANN for electromagnetic modeling of a spiral inductor shown in Fig. 1, which is a component often used in RF/microwave communication circuits. This modeling example was originally introduced in [2]. Although 3D-electromagnetic simulators can be used to analyze spiral inductors, they are computationally prohibitive especially if the inductor's geometrical/physical parameters need to be repetitively changed during computer-aided design. Our neural network model is defined to have 4 input neurons (conductor width W, spacing between different turns in the inductor S, dielectric constant of the substrate material ε, and frequency f),, and 4 output neurons (real and imaginary parts of the scattering parameters S_{11} and S_{21}). Two types of electromagnetic simulators, a 2.5 dimensional (2.5D)-electromagnetic simulator [3], and a 3 dimentional (3D)-electromagnetic simulator [4], are used to generate training data for ANN training. After training is finished, the model is tested with a separate test data, also generated from electromagnetic simulation. The error between ANN model and test data is within 1%, which means the ANN model is very accurate for engineering design. The CPU time for simulating 32 structures of the spiral inductor (with different W, S, ε and frequency) using the 3D electromagnetic simulator is 10 hours. Using the trained ANN to perform design optimization and statistical simulation with 1000 structures of the spiral inductor takes less than 1 second. This demonstrates that once trained, the ANN can be used for fast modeling and optimization with substantial speedup over the conventional electromagnetic based design of the RF/microwave communication circuits.

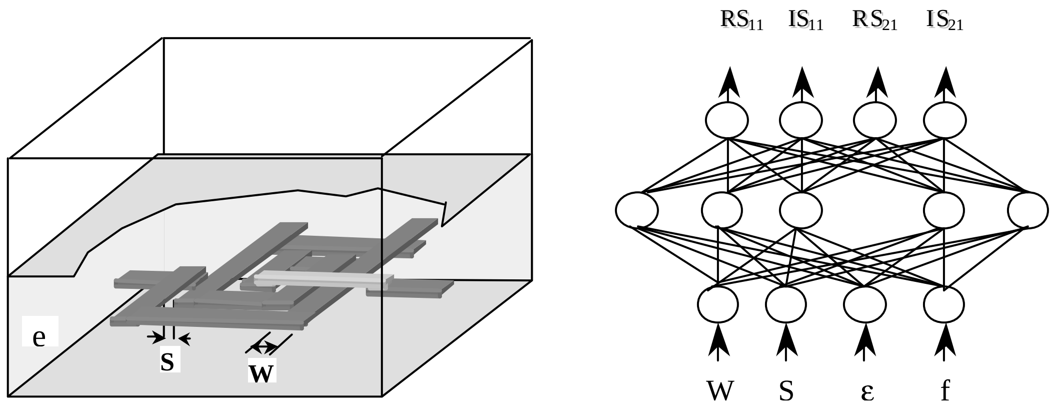

Fig. 1. A spiral inductor and its ANN model which is trained with electromagnetic data.

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[2] V.K. Devabhaktuni, B. Chattaraj, M.C.E. Yagoub and Q.J. Zhang, "Advanced microwave modeling framework exploiting automatic model generation, knowledge neural networks and space mapping," *IEEE Transactions on Microwave Theory and Techniques*, vol. 51, pp. 1822-1833, 2003.

[3] *Sonnet v*.7.0, Sonnet Software, Inc. Liverpool, NY, USA.

[4] *Ansoft HFSS v*.8.0, Ansoft Corp., Pittsburg, PA, USA.