Estimating far-field emissions from simulated near-field data using neural networks

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***Abstract* — In this paper, a procedure for estimating the electromagnetic fields radiated far from their source based on near-field simulation is considered. The near-fields radiated from the sources are modeled with the Transmission Line Matrix method. The so-called far-fields are estimated with the help of different artificial neural networks. Comparison with results based on theoretical equations and software simulations substantiate the validity of the proposed hybrid method.**

***Index Terms*— Antennas and propagation, Computational electromagnetics, Transmission line matrix methods, Neural networks.**

I. INTRODUCTION

The search for relations between the far electromagnetic (EM) field patterns and near field (NF) measurements has motivated interesting research studies and methods. The far-field (FF) radiated emissions from EM devices such as antennas, PCB, or other sources can be characterized through measurements on a conventional distance and frequency range. Sometimes this setup is not viable, but FF can also be characterized by means of NF scanning or simulation followed by NF to FF transformations.

A lot has been published on this topic, and it is not our intention to rediscuss this. As an alternative, we recommend the reading of a comprehensive chronological review of what the authors believe to be the most important NF to FF transformation methods since 1950 [1]-[2].

In more recent studies, researchers have tried to improve these approximations by using novel techniques [3]-[5]. In this paper, a methodology with no NF-FF transformation is presented. We simulate the EM field emitted by a chosen EM source, and then characterize the outward radiation using an approximation delivered with the help of a neural network. The method is tested with simplified radiations of a Hertzian dipole and a small circular loop, and the objective is to be able to characterize the radiation from more complex antennas, or other EM sources, such as a PCB for instance.

II. MODELING CONFIGURATION AND PROCEDURE

The main purpose of the modeling is to achieve effective representation of a real problem, which clearly can be done by various numerical methods, such as FEM, TLM, and FDTD.

A. The TLM Model

The TLM has been applied to modeling EM fields for numerous application areas since the first time it was presented as the current known TLM method [6]. The propagation media are modeled by nodes that represent a network of interconnected transmission-lines, and the properties of each material are represented by the equivalent lumped circuit components. The scattering process is based on Huygens principle [7], and the environment must conform to the following statements:

- Conservation of electric charge
- Conservation of magnetic flux
- Electric field continuity
- Magnetic field continuity

The boundaries are modeled using matched conditions. The appropriate development of Maxwell's equations for waves in rectangular coordinates, and the analogy between Kirchhoff circuit laws define the relations shown in Table I.

TABLE I
Relations between fields and voltages

Fields variables		Circuit variables
$E(y,t)$	≡	$v(x,t)$
$H(z,t)$	≡	$i(x,t)$
ε	≡	C_d
μ	≡	L_d
σ_e	≡	G_d

With those relations at hand, it is possible to characterize the E and H fields at any point of the domain with (1) and (2):

$$E_i = -V_i / \Delta i \quad (1)$$

$$H_i = I_i / \Delta I \quad (2)$$

where all units are in the SI, the index i is the Cartesian direction x, y and z, and consequently the Δi is the size of the element in direction x, y and z. The SSCN was chosen in order to adapt the modeled geometries as wires and planes.

The Δi was 1 *mm* for most of the materials, except in the dipole and dielectric cross sections, where it was reduced to 0.25 *mm*. The materials simulated are on Table II.

TABLE II
Electrical properties of the materials simulated

	μ_r	ε_r	σ *[S/m]*
air/vacuum	1.0	1.0	0.0
dipole	1.0	1.0	5.96×10^7
dielectric	1.0	4.3	0.0

The source amplitude was normalized, applied equally to the antennas (electric dipole and small loop) and to the parallel lines over the PCB. We applied 1 A peak of both 1GHz sinusoidal and Gaussian impulse current to the dipoles, but only 1 A peak of 1GHz sinusoidal to the PCB parallel lines with and without the ground plane. More information on the modeling and simulation will be provided in the full paper.

B. The Neural Network Model

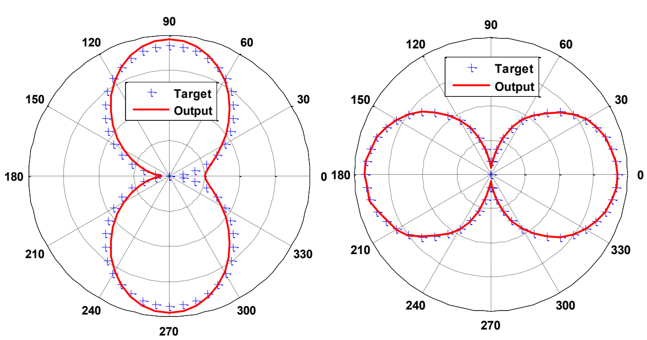
Artificial Neural Networks is a multidisciplinary topic related to Artificial Intelligence that comprises areas of neuroscience, physics, mathematics and computing to engineering. Their ability to learn through examples, with or without supervision, and to generalize this learning, allows multiple applications in areas such as modeling and function approximation, time series analysis, multicriteria optimization problems, pattern recognition, signal processing, control, among other growing areas of interest.

The key reasons for choosing ANN to deal with this problem were the inexistence of a simple mathematical definition for the FF radiation, the knowledge of a pattern, even though it is unknown, and the existence of simulated data to train and test the network.

The most common networks used for approximation are Backpropagation (BP) and Radial Basis Functions (RBF). As typically recommended, the data set was blindly separated into three subsets as follows, 70% for training, 15% for validation and 15% for testing the network. We used the early stopping technique to avoid overfitting, assuring better generalization performance. The networks were trained and validated, adding neurons to the hidden layer and reducing the mean squared normalized error (MSE). The training was stopped when the MSE augmented after the addition of a neuron. The goal was to have the smallest number of neurons in the hidden layer, thus to minimize overfitting and yet to be able to generalize.

III. Numerical Results

A half-wave electric dipole and a small loop antenna were chosen as proof of concept. The results presented on Fig. 1 (a) and (b) are the dipole case only, the loop results were omitted due to the space limitation. The curve called *Target* is the theoretical computed FF patterns for E_θ and E_ϕ according to [8]. The curve called *Output* is the RBF network estimate for the same pattern, considering the TLM NF simulation parameters, results and distance, as inputs to the network.

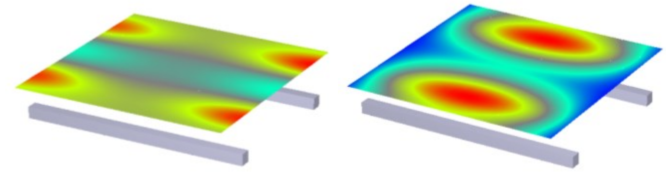


(a) E_θ (Elevation slice)　　(b) E_ϕ (Azimuth slice)

Fig. 1. Dipole FF patterns: Target (Theoretical) and RBF result.

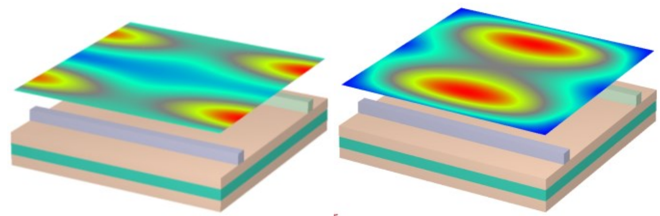
The RBF network was not able to generalize in the case of the PCB emitted fields, where the BP network presented better results. This was due to the RBF limited number of inputs.

The following figures (Fig. 2 and Fig. 3) represent the E and H field patterns estimated with the BP network 6λ away from the sources (the two parallel lines of the PCB).



(a) *E*　　(b) *H*

Fig. 2. E and H field pattern for two parallel lines on a PCB with no ground plane.



(a) *E*　　(b) *H*

Fig. 3. E and H field pattern for two parallel lines on a PCB with ground plane.

These patterns can be confronted with commercial software for validation purposes. More information on the BP network modeling will also be provided in the full paper.

IV. Conclusion

In this paper we have presented an option for PCB emissions estimation with use of TLM NF simulation and ANN. We used RBF and BP to estimate the FF, where the first showed excellent approximation for simpler cases, such as single dipoles and others with fewer variables, and the second showed reasonable results for more complex cases, as the PCB cases tested. For the digest, we chose to present compact results, which will be detailed in the full paper.

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