FDTD Modeling of Absorbing Materials for EMI Applications  
Jianfeng Xu, Marina Y. Kole dintseva, Soumya De, Andriy Radchenko, Richard E. DuBroff, James L. Drewniak, Yongxue He, and Richard Johnson  
Center for EMC, Missouri University of Science and Technology, Rolla, MO, USA  
\{jianfeng@mst.edu; marinak@mst.edu; adwt2@mst.edu; ar8r3@mst.edu; red@mst.edu; drewniak@mst.edu; yongxue.he@lairdtech.com; rick.johnson@lairdtech.com\}

Abstract—A few scenarios of applying different magneto-dielectric absorbing sheet materials to mitigate electromagnetic interference (EMI) are analyzed in this paper using a full-wave 3D finite-difference time-domain (FDTD) technique. Frequency characteristics of both permittivity and permeability of these magneto-dielectric materials are approximated by the series of the Debye terms suitable for time-domain simulations. This approximation is accomplished using a new curve fitting technique based on the Legendre polynomials and the regression analysis optimization. The results of the numerical simulations are verified by the corresponding experiments, and the good agreement is obtained.

I. INTRODUCTION

Electromagnetic interference (EMI) issues can arise anywhere in electronic equipment with unpredictable and troublesome effects. Therefore, it becomes essential to limit and shield electronic equipment against sources of undesirable electromagnetic coupling and/or radiation. Design of electromagnetic absorbers (EMA) has become essential for effective elimination of EMI in the given range of frequencies. The EMA can be used as coatings whose electrical and/or magnetic properties can be engineered in such a way that they would allow for effective absorbing of electromagnetic energy either at discrete frequencies, or over broadband ranges. Typically, EMA are composite materials with dielectric, conducting, and/or magnetic particles embedded in a polymer matrix [1]-[6]. The goal of an absorber design is to balance electrical performance, thickness, weight, mechanical properties, and cost. The EMA containing ferrite (non-conducting) or ferromagnetic (conducting) inclusions typically exhibit good noise attenuation performance in the frequency range from a few hundred MHz to several GHz [5], [6]. These materials due to their unique electromagnetic and physical characteristics have already been effectively used in a variety of applications, including EMC/EMI [1], [2], [5]-[7]. The objective of this paper is to analyze a few scenarios of applying different magneto-dielectric absorbing sheet materials using full-wave numerical finite-difference time-domain (FDTD) technique, and verify modeling results by experiments. To effectively model these magneto-dielectric materials in time domain, it is important to represent frequency characteristics of both complex permittivity and permeability of these materials as analytical rational-fractional functions that would satisfy Kramers-Kronig causality relations [8]. In the microwave frequency range, both permittivity and permeability of the most absorbing materials of interest can be expanded into series of the Debye terms with the poles of the first order, suitable for time-domain simulations [9]. If there are pronounced narrowband resonances, then Lorentzian terms with poles of the second order would be needed [9]. However, the present study is limited to Debye terms only. The materials whose both permittivity and permeability frequency functions can be represented through Debye terms are called double-Debye materials (DDM) [6], [10].

II. EXTRACTION OF MATERIAL FREQUENCY DEPENDENCES

The EZ-FDTD code that allows for effective modeling of DDM has been developed in the Center for EMC of Missouri University of Science and Technology (MS&T) [6], [7], [10]. EZ-FDTD uses auxiliary differential equations for incorporating frequency-dispersive materials. Currently, EZ-FDTD allows for taking into account up to five Debye terms in the frequency response. The EZ-FDTD code allows for taking into account up to five Debye terms both in permittivity and in permeability frequency responses.

II. EXTRACTION OF MATERIAL FREQUENCY DEPENDENCES

The representation of frequency dependencies of dielectric and magnetic properties as sums of Debye-like terms is convenient for using them in the FDTD simulations. Previously, a curve-fitting technique based on genetic algorithm (GA) optimization was used for extracting parameters of the Debye terms from experimentally available [10] or analytically obtained (from effective media theories and mixing rules for composites) frequency characteristics of
materials [9]. Though GA yields a global optimum, it is a very tedious task to obtain proper results using the GA method considering the numerous initial values that needs to be provided by the user at the start. Obtaining a good plot would require the best possible initial values that would allow the GA to converge. Currently, a less complicated technique with more accurate plots based on the Legendre polynomials [11] and regression analysis using the least-squares method is being developed and has been applied for this study. This technique allows for modeling permittivity and permeability as multi-term Debye curves for up-to five terms each as compared to two terms using GA.

In the current approach, a two-step method is used to approximate the frequency dependent parameters. First, Legendre polynomials are used as the basis functions to model the measured data. Second, a non-linear least squares regression analysis is performed on the modeled data by using the Debye model approximation [9]. As is shown by Kirkpatrick and Heckman [12], and as is implemented in [13], Legendre polynomials have several favorable properties for curve-fitting. These properties are the following:

- the functions are orthogonal;
- there is flexibility to fit sparse data;
- higher orders are estimable for high levels of curve complexity;
- computations converge fast.

Figs. 1 and 2 show measured and curve-fitted data for permittivity and permeability of a DDM.

Thus, it becomes easier to interpolate the data in cases where we have less or noisy measured data. However, in a few cases it becomes evident that even though the curve-fit is excellent, the physical values obtained for the frequency dependent parameters are not in accordance with the realizable physical values. Thus in such cases it becomes necessary to make sure that the values are proper before going ahead with the FDTD modeling step. This could be achieved by using a manual approximation scheme that had been developed in previous research.

III. NUMERICAL RESULTS AND MEASUREMENTS

The effect of various absorbing sheet materials on frequency characteristics of a specially designed microstrip line shown in Fig. 3 has been studied. The length of the board is 14.7 cm with a 3.5 mm wide trace. The height of the dielectric is 1 mm and the relative permittivity is 3.53 with a tangent loss 0.001 to make the characteristic impedance of the board to be 50 $\Omega$. The microstrip line was operating in two regimes, short- and open-circuited. The measurements were carried out using an Agilent vector network analyzer E-5071C in the frequency range from 0.9 GHz to 6 GHz.

The same structure was modeled using the MS&T FDTD codes with DDM in bulk discretization cells. The modeling
setup is shown in Fig. 4. In the simulations, the length of the line was tuned to take into account the effect of two connectors. The cell size along $z$ direction is 0.1 mm, while the sizes along $x$ and $y$ directions are 0.5 mm.

Fig. 3 Microstrip line geometry

Fig. 4 FDTD model setup

Fig. 5 shows the simulation results of the bare board together with the measured data for the short-circuit termination. As is seen from this figure, the agreement between the simulated and measured results in the short-circuit case is excellent for both real and imaginary parts of the input impedance through the whole frequency range of interest. The difference of the resonance magnitudes may be explained by the perfect electric conductor assumption for ground plane and trace in the simulation.

![Graph](image_url_1)

(a) Simulated

(b) Measured

Fig. 5 FDTD modeled and measured input impedance of the bare board in the short-circuit case: (a) real part, and (b) imaginary part.

Fig. 6 shows the simulation results and the corresponding measured data for the microstrip board covered with an absorbing magneto-dielectric material, in the case of the short-circuit termination. The absorbing sheet sample is put directly upon the trace. The size of the sheet is 10 cm x 10 cm, and its thickness is 1 mm. As is seen from this figure, in the loaded case, resonances damp and shift to the lower frequencies, which is correct from physics point of view. The agreement between the simulation and measured results in the short-circuit case matched very well for both real part and imaginary part of the input impedance through the whole frequency domain. The dots in the figures are those values of the bare board at the sampling frequency. The well-matched curves verify the correctness of the simulation method, and also mean that the curve-fitting the parameters of the absorbing material were found and used in the numerical simulations correctly.
IV. CONCLUSIONS

The EZ-FDTD code, developed in MS&T, can model various complex geometries containing frequency dispersive magneto-dielectric materials in bulk cells. Good agreement between the EZ-FDTD simulations and corresponding measurements carried out on a microstrip test fixture with and without absorbing material sheets upon the signal trace has been obtained. This means that by running numerical experiments with different geometries and absorbing material characteristics, it is possible to efficiently evaluate whether a material could be a successful candidate for mitigating an EMI noise. Practical cases and geometries may include enclosures, spurious radiations from chips and other active circuit components, and so on. The further optimization to choose the proper dielectric and magnetic properties as well as geometries (thickness of layers and their configurations) for particular practical problems can be proceeded based on the results of this work. The novel curve-fitting algorithm based on Legendre polynomials and regression analysis has been implemented for incorporating double-Debye materials in EZ-FDTD codes. These curve-fitted frequency characteristics of materials will be used in the subcell thin-layer algorithm in FDTD codes. These curve-fitted frequency characteristics of materials will be used in the subcell thin-layer algorithm in EZ-FDTD codes. These curve-fitted frequency characteristics of materials will be used in the subcell thin-layer algorithm in EZ-FDTD codes.

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