Extension of the TLM method to the electromagnetic wide band analysis of anisotropic ferrite-based structures

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Abstract— The TLM (Transmission Line Matrix) method, in time domain, is extended to account for the presence of dispersive and anisotropic media in electromagnetic structures or devices. The model is thoroughly constructed by using Maxwell's equations that make it a unified general TLM formulation. The theoretical derivation was revisited, starting with Maxwell's equations, without invoking circuit analogy. The procedure is general and can be applied to derive the algorithm for new extended TLM nodes. The case of anisotropic ferrite-based structures is studied.

I. Introduction

The objective of the research is manifolds: First, to develop a rigorous model for electromagnetic field computation in anisotropic and dispersive media and second to insert an innovative model of non-saturated ferrite [1] into the TLM algorithm that can characterize a device over a wide frequency band in one run.

Indeed, presently there is no commercial simulator capable to account for the presence of magnetized magnetic materials biased by an external DC field whatever their magnetization state is. That constitutes a strong constraint for the design of such structures (circulators, isolators, tunable filters, antennas, etc) in which complex physical phenomena appear such as:

- Non-homogenous internal DC magnetic field,
- Non-saturated zones which implies the existence of magnetic domains
- Magnetostatic modes.

In order to predict the dynamic behaviour of polycrystalline ferrites for arbitrary magnetization state, it is proposed a theoretical approach which gives access to all elements of the permeability tensor as a function of the applied DC field strength, of the sample geometry and static characteristics. In addition, structural properties (magnetic domain shape and grain shapes) are accounted for by the model.

II. TLM Theoretical Model

In this paper, the first step of the research is to extend the TLM to dispersive and anisotropic media. The formulation is based directly on field Maxwell's equations [2] and gives a clear and systematic derivation that constitutes a general approach which can be applied to any type of media.

For the SCN (Symmetrical Condensed Node) TLM, the presence of materials affects the field values at the node center. These values are computed from the incident voltages travelling in the node arms by the following convolution process:

$$\begin{bmatrix} E_x \\ E_y \\ E_z \\ H_x \\ H_y \\ H_z \end{bmatrix}_c = [t]^{-1} \otimes \begin{bmatrix} E_x \\ E_y \\ E_z \\ H_x \\ H_y \\ H_z \end{bmatrix}_r \qquad (1)$$

where the tensor $[t]^{-1}$ describes the anisotropic and dispersive properties of the material in the frequency domain.

To validate this method, an X-band rectangular waveguide partially filled with a ferrite was investigated. When a DC magnetic field H_0 is applied along the small side, a field displacement along the *x*-axis breaks the reciprocity of the propagation structure: the transmission coefficient differs according to the wave propagation direction.

We compare the scattering parameters calculated by the mode-matching method [3], a frequency domain approach, with those computed by TLM for a non-saturated ferrite whose permeability tensor components are determined from the model proposed in [1].

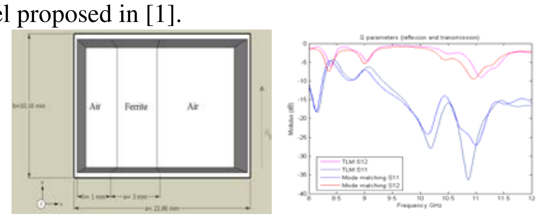

Fig. 1. Cross section of the waveguide partially filled with a non saturated ferrite slab M/Ms = 0.8 at X-band frequencies (8–12 GHz).

As one can observe in Fig. 1(b), comparison between both approaches yields some good matching.

III. Conclusion

A new permeability tensor model valid for different magnetization states of ferrites has been inserted in the TLM method thanks to a general approach. This theoretical tool will enable us to compute the electromagnetic fields in non reciprocal microwave devices (circulators, isolators) and more generally ferrite-based circuits (phase shifters, tunable filters, compact antennas, etc.).

IV. References

[1] P. Gelin, and P. Quéffélec, "Generalized Permeability Tensor Model: Application to Barium Hexaferrite in a Remanent State for Self-biased Circulators," IEEE Transactions on Magnetics, vol. 44, Jan. 2008.

[2] N. Peña and M. M. Ney, "A General Formulation of a three dimensional TLM Condensed Node with the Modeling of Electric and Magnetic Losses and Current Sources," 12th Annual Review of Progress in Applied Comp. Electromagnetics, CA, 1996.

[3] P. Quéffélec, M. Le Floc'h and Ph. Gelin "Nonreciprocal cell for the broad band measurement of tensorial permeability of magnetized ferrites: direct problem," IEEE Transactions on Microwave Theory and Techniques, Vol. 47, 1999.