A New TLM Model for the Analysis of Ferrite Media

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Abstract - In this paper, we develop a novel TLM model, using the symmetrical condensed node (SCN) and current sources, allowing a time domain study of electromagnetic (EM) waves propagation in ferrites media. The new formulation models the anisotropic and dispersive properties of ferrite media by adding current sources in supplementary stubs included in the standard SCN. The validity of this approach is proven by the study of the reflection and transmission of a plane wave normally incident on a magnetized ferrite wall.

I-Introduction

Ferrites are widely used in several microwave circuits. Their gyromagnetic effects are implemented in wide band power isolators. The propagation of electromagnetic waves (EM) in a ferrite-cylinder allows to obtain a circulator which is an important component for electronic control switching. Ferrites are also used in phase shifters and in microstrip patch antennas as substrates. The study of ferrite media is a difficult task owing to their gyromagnetic nature. The TLM method is a robust tool for the time domain simulation of complex objects and phenomena. This method analyzes efficiently EM waves interaction with linear materials with frequency dependent constitutive parameters [1]-[3]. In this paper, we present a TLM approach allowing the time domain simulation of EM waves propagation and scattering by anisotropic dispersive ferrite media. This approach is based on an improved NSC version and consists in adding current sources to this node to model the dispersive properties.

II. Formulation

Ferrites are characterized in the frequency domain by a permeability tensor $[\mu(\omega)]$. The inverse Fourier transform of this tensor gives the susceptibility functions $\chi(t)$ and $\kappa(t)$ which, in the time domain, describe the anisotropic and dispersive properties of ferrites media and couple the components of the EM wave propagating in this medium [4]. In a ferrite medium with a static biasing magnetic field parallel to the z-axis, the EM field components, supposed constant in the time interval Δt in the 3-D lattice ($i\Delta x$, $j\Delta y$, $k\Delta z$), are written at the instant $(n+1)\Delta t$ [4]:

$$\begin{pmatrix} H_x \\ H_y \\ H_z \end{pmatrix}_{n+1} = \begin{pmatrix} 1 & \kappa^0_{xy}/(1+\chi^0_{xx}) & 0 \\ -\kappa^0_{yx}/(1+\chi^0_{yy}) & 1 & 0 \\ 0 & 0 & 1 \end{pmatrix} \cdot \begin{pmatrix} {}_nH_x - \alpha_{mx}\cdot{}_nH_x + \beta_{mx}\cdot\left({}_n\Psi_{mx} - \frac{\Delta t}{\mu_0}\,{}_{n+1/2}(\nabla\times E)_x\right) \\ {}_nH_y - \alpha_{my}\cdot{}_nH_y + \beta_{my}\cdot\left({}_n\Psi_{my} - \frac{\Delta t}{\mu_0}\,{}_{n+1/2}(\nabla\times E)_y\right) \\ {}_nH_z - \alpha_{mz}\cdot{}_nH_z + \beta_{mz}\cdot\left({}_n\Psi_{mz} - \frac{\Delta t}{\mu_0}\,{}_{n+1/2}(\nabla\times E)_z\right) \end{pmatrix} \quad (1)$$

where

$$\begin{pmatrix} {}_n\Psi_{mx} \\ {}_n\Psi_{my} \\ {}_n\Psi_{mz} \end{pmatrix} = \begin{pmatrix} \sum_m^{n-1} \Delta\chi^m_{xx}\cdot{}_{n-m}H_x - \sum_m^{n-1} \Delta\kappa^m_{xy}\cdot{}_{n-m}H_y \\ \sum_m^{n-1} \Delta\chi^m_{yy}\cdot{}_{n-m}H_y + \sum_m^{n-1} \Delta\kappa^m_{yx}\cdot{}_{n-m}H_x \\ \sum_m^{n-1} \Delta\chi^m_{zz}\cdot{}_{n-m}H_z \end{pmatrix}, \quad (2)$$

are the discrete convolutions at the time $n\Delta t$ and are computed recursively. χ^m and κ^m are the generalized susceptibility [4]. The other parameters are defined by the following equations:

$$\begin{pmatrix} \alpha_{mx} \\ \alpha_{my} \\ \alpha_{mz} \end{pmatrix} = \begin{pmatrix} (\chi^{0\,2}_{xx} + \chi^0_{xx} + \kappa^{0\,2}_{xy})/((1+\chi^0_{xx})^2 + \kappa^{0\,2}_{xy}) \\ (\chi^{0\,2}_{yy} + \chi^0_{yy} + \kappa^{0\,2}_{yx})/((1+\chi^0_{yy})^2 + \kappa^{0\,2}_{yx}) \\ \chi^0_{zz}/(1+\chi^0_{zz}) \end{pmatrix}, \quad (3)$$

and

$$\begin{pmatrix} \beta_{mx} \\ \beta_{my} \\ \beta_{mz} \end{pmatrix} = \begin{pmatrix} (1+\chi^0_{xx})/((1+\chi^0_{xx})^2 + \kappa^{0\,2}_{xy}) \\ (1+\chi^0_{yy})/((1+\chi^0_{yy})^2 + \kappa^{0\,2}_{yx}) \\ 1/(1+\chi^0_{zz}) \end{pmatrix}. \quad (4)$$

In order to develop a time domain approach modelling ferrite media by the TLM method, we should make use of the equations defined above. This consists first in adding to the standard (18×18) SCN three other supplementary stubs (19, 20, 21) in which current sources (V_{six}, V_{siy}, V_{siz}) are introduced to model the gyromagnetic properties. Then, we impose the condition of magnetic flux conservation in the node, we use the equivalence between voltages and EM field components, and finally we couple equivalent currents in the xoy plane. Therefore, we find the expressions of the equivalent currents in the x, y, and z directions at the instant $(n+1)\Delta t$:

$$ {}_{n+1}\begin{pmatrix} I_x \\ I_y \\ I_z \end{pmatrix} = \begin{pmatrix} 1 & \kappa^0_{xy}/(1+\chi^0_{xx}) & 0 \\ -\kappa^0_{yx}/(1+\chi^0_{yy}) & 1 & 0 \\ 0 & 0 & 1 \end{pmatrix} \cdot \qquad (5)$$

$$\begin{pmatrix} {}_nI_x + \frac{1}{4+Z_{sx}}({}_{n+1}V_{six}+{}_nV_{six}) - \frac{4}{4+Z_{sx}}\frac{\Delta t}{\mu_0}\,{}_{n+1/2}(\nabla\times E)_x \\ {}_nI_y + \frac{1}{4+Z_{sy}}({}_{n+1}V_{siy}+{}_nV_{siy}) - \frac{4}{4+Z_{sy}}\frac{\Delta t}{\mu_0}\,{}_{n+1/2}(\nabla\times E)_y \\ {}_nI_z + \frac{1}{4+Z_{sz}}({}_{n+1}V_{siz}+{}_nV_{siz}) - \frac{4}{4+Z_{sz}}\frac{\Delta t}{\mu_0}\,{}_{n+1/2}(\nabla\times E)_z \end{pmatrix}$$

The comparison of equations (1) and (5) yields the expressions of the currents sources modelling gyromagnetic properties and the impedances of ferrite media:

$$\begin{pmatrix} {}_{n+1}V_{six} + {}_nV_{six} \\ {}_{n+1}V_{siy} + {}_nV_{siy} \\ {}_{n+1}V_{siz} + {}_nV_{siz} \end{pmatrix} = \begin{pmatrix} 4/\beta_{mx} \\ 4/\beta_{my} \\ 4/\beta_{mz} \end{pmatrix} \begin{pmatrix} -\alpha_{mx}\cdot {}_nI_x + \beta_{mx}\cdot {}_n\Psi_{mx} \\ -\alpha_{my}\cdot {}_nI_y + \beta_{my}\cdot {}_n\Psi_{my} \\ -\alpha_{mz}\cdot {}_nI_z + \beta_{mz}\cdot {}_n\Psi_{mz} \end{pmatrix} \qquad (6)$$

The diffraction in the SCN modelling ferrite media is obtained according to the following procedure: Equations of equivalent voltages and currents and those obtained from the continuity of the electric and magnetic fields allow to obtain diffraction in the main twelve 1-12 lines of the SCN [5], the scattered pulses in the six stubs 13-18 can be obtained directly from

$$\begin{pmatrix} V_{13} \\ V_{14} \\ V_{15} \end{pmatrix}^r = \begin{pmatrix} Vx \\ Vy \\ Vz \end{pmatrix} - \begin{pmatrix} V_{13} \\ V_{14} \\ V_{15} \end{pmatrix}^i \text{ and } \begin{pmatrix} I_{16} \\ I_{17} \\ I_{18} \end{pmatrix}^r = \begin{pmatrix} Ix \\ Iy \\ Iz \end{pmatrix} - \begin{pmatrix} I_{16} \\ I_{17} \\ I_{18} \end{pmatrix}. \qquad (7)$$

Finally, the additional three stubs 19, 20 and 21 contribute solely to the incident pulses associated with current sources characterizing the gyromagnetic media.

III- Numerical Results

In order to validate the proposed model, the reflection and transmission of a Gaussian plane wave normally incident on an air-ferrite interface are investigated. The spatial TLM lattice considered is $(1\times1\times800)\Delta l$, the ferrite layer spans $50\Delta l$, with Δl is the mesh width taken to be $\Delta l=75\mu m$. The propagation in the ferrite medium is described by Gilbert model or Bloch model [3]. For the first model, the physical parameters characterizing the ferrite are: the precessional frequency $\omega_0=2\pi\times20\times10^9$rad/s, the magnetization frequency $\omega_m=2\pi\times10\times10^9$rad/s and the damping constant $\alpha=0.1$ [4]. When it comes to the second model, the characterizing parameters are $\omega_0=2\pi\times19.8\times10^9$rad/s, $\omega_m=2\pi\times10\times10^9$rad/s and the transverse relaxation frequency $\nu_c=2\pi\times1.98\times10^9$rad/s. Figures 1 and 2 show the reflection and transmission coefficients for left and right circularly polarizations (LCP, RCP). The agreement between our results and those obtained analytically is very good.

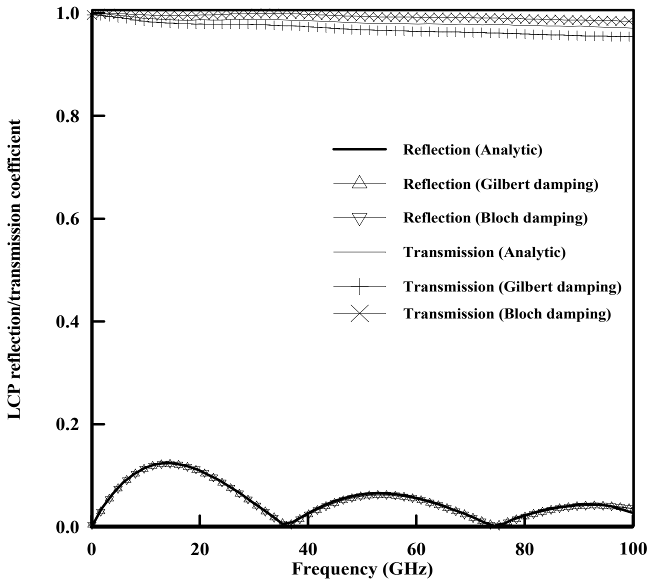

Fig. 1. LCP transmission and reflection coefficient magnitudes versus frequency.

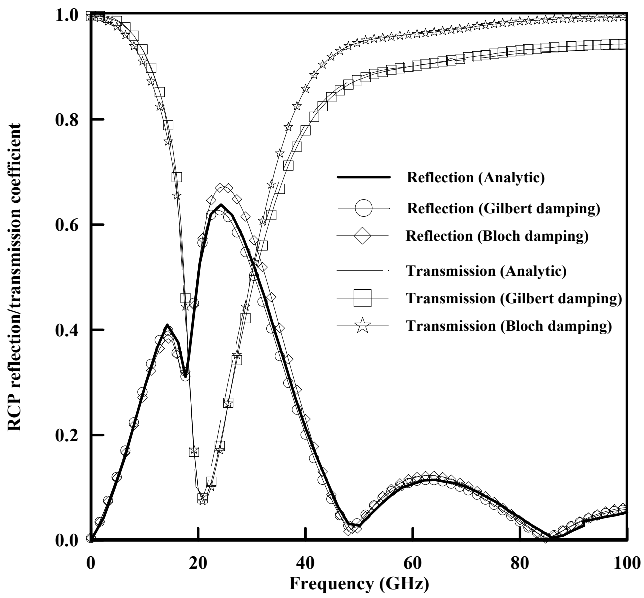

Fig.2. RCP transmission and reflection coefficient magnitudes versus frequency.

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IV. Conclusion

The modeling of ferrite media using the symmetrical condensed node (SCN) of transmission lines matrix (TLM) method and current sources is developed. The proposed approach allows to study the interaction between electromagnetic (EM) waves and gyromagnetic media. The obtained results are in good agreement with the analytical ones.

References

[1] I. Barba, A. C. L. Cabecera, M. Panizo, And J. Represa, "Modelling dispersive dielectrics in TLM method," *Int. J. Numer. Model*, 14:15-30, 2001.

[2] M. I. Yaich and Mohsine Khalladi, "The far-zone scattering calculation of frequency-dependent materials objects using the TLM method," *IEEE Trans. on Antennas and Propagation,* vol. 50, November 2002.

[3] J. Paul, C. Christopoulos and D. W. P. Thomas, "Generalized material models in TLM-Part-2: materials with anisotropic properties," *IEEE Trans. on Antennas and Propagation*, Vol. 47, pp. 1535-1542, October 1999.

[4] K. S. Kunz and R. J Luebbers, "The finite difference time domain method for electromagnetics," Boca Raton, FL: CRC, 1993.

[5] C. Christopoulos, "The transmission–line modeling method TLM," *IEEE Series on Electromagnetic Wave Theory*, New York, 1995.