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IMPROVED MAGNETIC LOSS FOR TLM

Indexing terms

Transmission line matrix, TLM, Modelling, Electromagnetic waves

Abstract

A method of modelling magnetic losses which closely approximates the behaviour of real ferrite materials is described and compared with earlier formulations. The scattering matrix for the symmetrical condensed node is given and numerical results are presented which show the accuracy possible with this method.

Introduction

The transmission line matrix (TLM) method of numerical electromagnetic analysis with the symmetrical condensed node is well known [1]. The representation of conductivity by means of a shunt conductance has been described in [2]. The concept of a series resistive element to represent magnetic loss was first proposed in [3] however the method used emulates a material with a constant real part of its permeability and an imaginary part which varies inversely with frequency. Most real materials (e.g. ferrites) exhibit a change in both real and imaginary parts of the permeability. The variation of permeability of ferrite materials can approximated by the function:

$$\mu_r = 1 + \frac{\left(\mu'_{r0} - 1\right)}{1 + \frac{\omega}{\omega_r}} \qquad (1)$$

where μ_r is the complex permeability, μ'_{r0} is the real part of the low frequency permeability of the material, ω is the angular frequency and ω_r is the angular frequency at which the real and imaginary parts of the permeability are equal in magnitude.

Conceptual model

The the voltages and currents in the transmission lines in the TLM model are analogous to the electric and magnetic fields in the medium being modelled. The inductance and capacitance per unit length in the transmission line are analogous to the real parts of the material permeability μ'_r and permittivity ε'_r. For "free-space" let the line inductance and capacitance per unit length be L_0 and C_0 respectively then for a medium of relative permeability and permittivity additional stubs are added so that the inductance and capacitance per unit length become $\mu'_r L_0$ and $\varepsilon'_r C_0$ respectively.

A shunt conductance (G) in the line represents accurately material conductance but the series resistance used in the old magnetic loss formulation (see Fig. 1a and [3]) indicates an energy loss associated with a direct current (analogous to a constant magnetic field) which does not occur in real materials.

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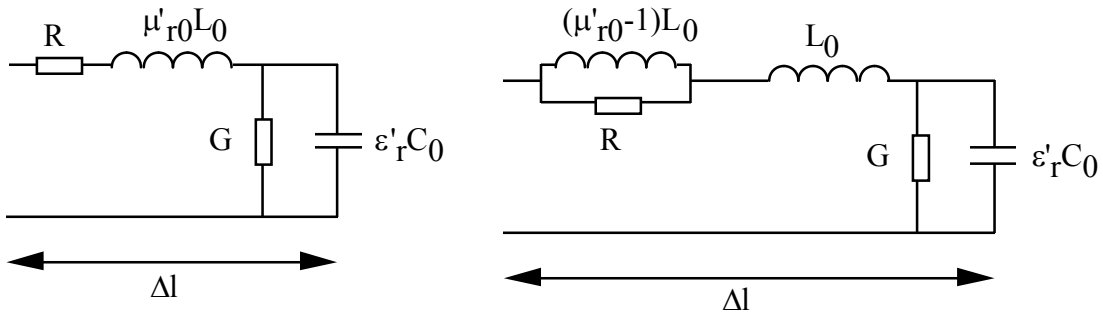
If the magnetic loss resistance is placed in parallel with the part of the line inductance representing the effect of the magnetic susceptibility of the material (see Fig. 1b) then a frequency dependent magnetic loss, which has the characteristic of equation (1), can be represented.



a Original **b New**

Fig. 1 Transmission line models showing the magnetic loss resistance R

The complex permeability represented by the transmission line model of Fig. 1a is:

$$\mu_r = \mu'_{r0} + \frac{R}{j\omega L_0} \tag{2}$$

whereas the model of Fig. 1b gives a permeability of:

$$\mu_r = 1 + \frac{(\mu'_{r0} - 1)}{1 + \frac{j\omega L_0}{R}} \tag{3}$$

which corresponds with equation (1) if:

$$R = \omega_r(\mu'_{r0} - 1)\, L_0 \quad \text{Ohm} \tag{4}$$

Formulation

The conceptual model fits well with the TLM symmetrical condensed node because the line inductances representing the material permeability are already split into two parts in the correct proportions - the stubs associated with the interconnecting ports of the matrix and the additional short-circuit 'permeability' stubs used to increase the inductance of the transmission line to represent magnetic materials. Resistances can therefore be connected in parallel with the permeability stubs to provide magnetic loss with an equivalent circuit similar to that of Fig. 1b.

In the symmetrical condensed node 4 stubs of inductance $L_0\Delta l/2$ are connected in series with the short circuit stub, for each axis (see [4]), which must be of inductance:

$$L_m = 4(\mu'_{r0} - 1)L_0\frac{\Delta l}{2} \quad \text{Henry} \tag{5}$$

to produce the correct increase in overall inductance for an initial permeability of μ'_{r0}. In order to retain the same frequency dependence the shunt resistance, normalised to the impedance (Z_0) of the interconnection stubs, must be:

$$R_m = \frac{2\omega_r(\mu'_{r0} - 1)L_0\Delta l}{Z_0} \tag{6}$$

Not to be included in final text

(read between eqns (6) and (7))

$$Z_0 = \sqrt{\frac{L_0}{C_0}}$$

and since the wave progresses Δl from the input stub to the output stubs in one time-step Δt , but a plane-wave in the mesh progresses $\Delta l/2$ in one time-step then the apparent propagation velocity in the transmission lines is 2c therefore:

$$2c = \sqrt{\frac{1}{L_0 C_0}}$$

so:

$$\frac{L_0}{Z_0} = \frac{1}{2c}$$

hence:

In line with earlier work this should be expressed only in terms of the mesh size rather than the line inductances and impedances and becomes:

$$R_m = \frac{\omega_r(\mu'_{r0} - 1)\Delta l}{c} \tag{7}$$

where c is the velocity of electromagnetic waves in free space.

The elements of the new scattering matrix **S'** can be developed from the elements of the old scattering matrix **S** (as in [1]) by considering the effect of the parallel resistance R_m on waves incident upon the junction of the "permeability" stub, the resistance, and the remainder of the node.

The elements which were previously dependant upon Z_m (the normalised impedance of the permeability stub) now depend on both Z_m and R_m.

Let Z'_m be the parallel combination of Z_m and R_m:

$$Z'_m = \frac{Z_m R_m}{Z_m + R_m} \tag{8}$$

Using the notation of [1] for the elements of **S**: a', c', d', and f' of **S'** can be determined by simply replacing Z_m by Z'_m in a, c, d, and f of **S**. All scattering related to these elements will see the apparent impedance of the "permeability" stub altered from Z_m to Z'_m by the addition of the new loss stub. Elements b, e, and h are unaffected since Z_m and hence Z'_m do not appear in the expressions for these parameters. Elements i' and j' can be determined by considering the loss resistance in parallel with the remainder of the node as the termination for waves returning after reflection at the short circuit end of the "permeability" stub.

The elements of the new scattering matrix **S'** are therefore:

$$a' = \frac{-Y_e}{2(Y_e + 4)} + \frac{Z'_m}{2(Z'_m + 4)} \tag{9}$$

$$c' = \frac{-Y_e}{2(Y_e + 4)} + \frac{-Z'_m}{2(Z'_m + 4)} \tag{10}$$

$$d' = \frac{4}{2(Z'_m + 4)} \tag{11}$$

$$f' = Z'_m d' \tag{12}$$

$$i' = \frac{\frac{4R_m}{4+R_m}}{2\left[\frac{4R_m}{4+R_m} + Z_m\right]} \tag{13}$$

$$j' = \frac{\frac{4R_m}{4+R_m} - Z_m}{\frac{4R_m}{4+R_m} + Z_m} \tag{14}$$

where Y_e is the normalised admittance of the 'permittivity stubs'. The scattering matrix can easily be extended to include conductivity and the magnetic loss proposed in [3].

Results

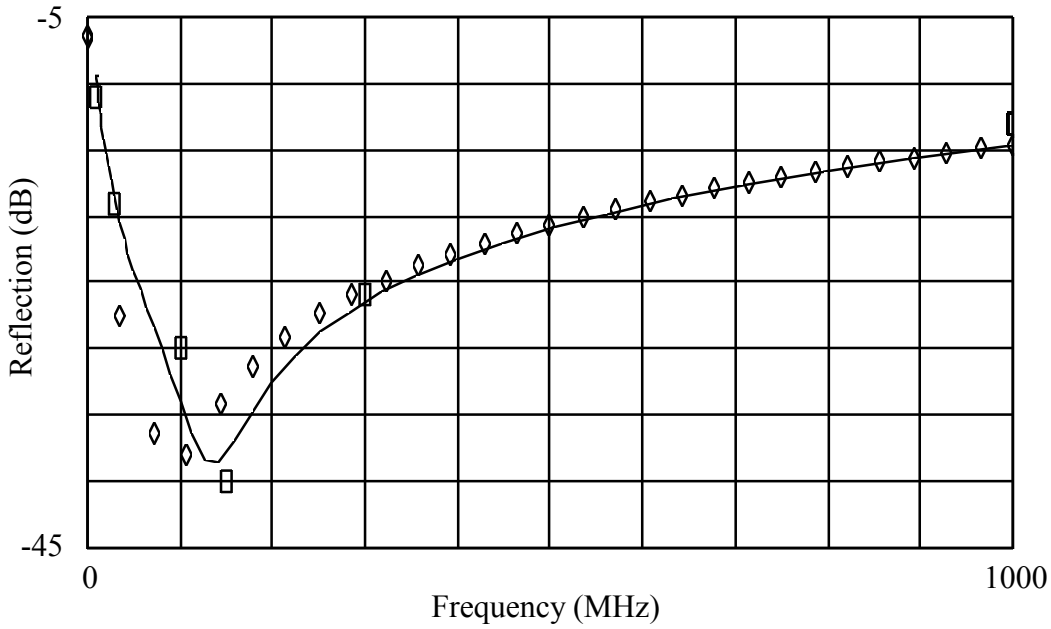


Fig. 2 Reflectivitivy of 6.3 mm Ferrite tile (μ_{r0} = 1051, f_r = 7.02 MHz, εr = 12)

- ▯ Manufacturers data
- ◊ TLM
- — Analytic solution

In order to verify the the above formulation the reflectivity of a number of ferrite tiles was determined by the TLM method using values of μ_{r0} and ω_r estimated from the manufacturers data.

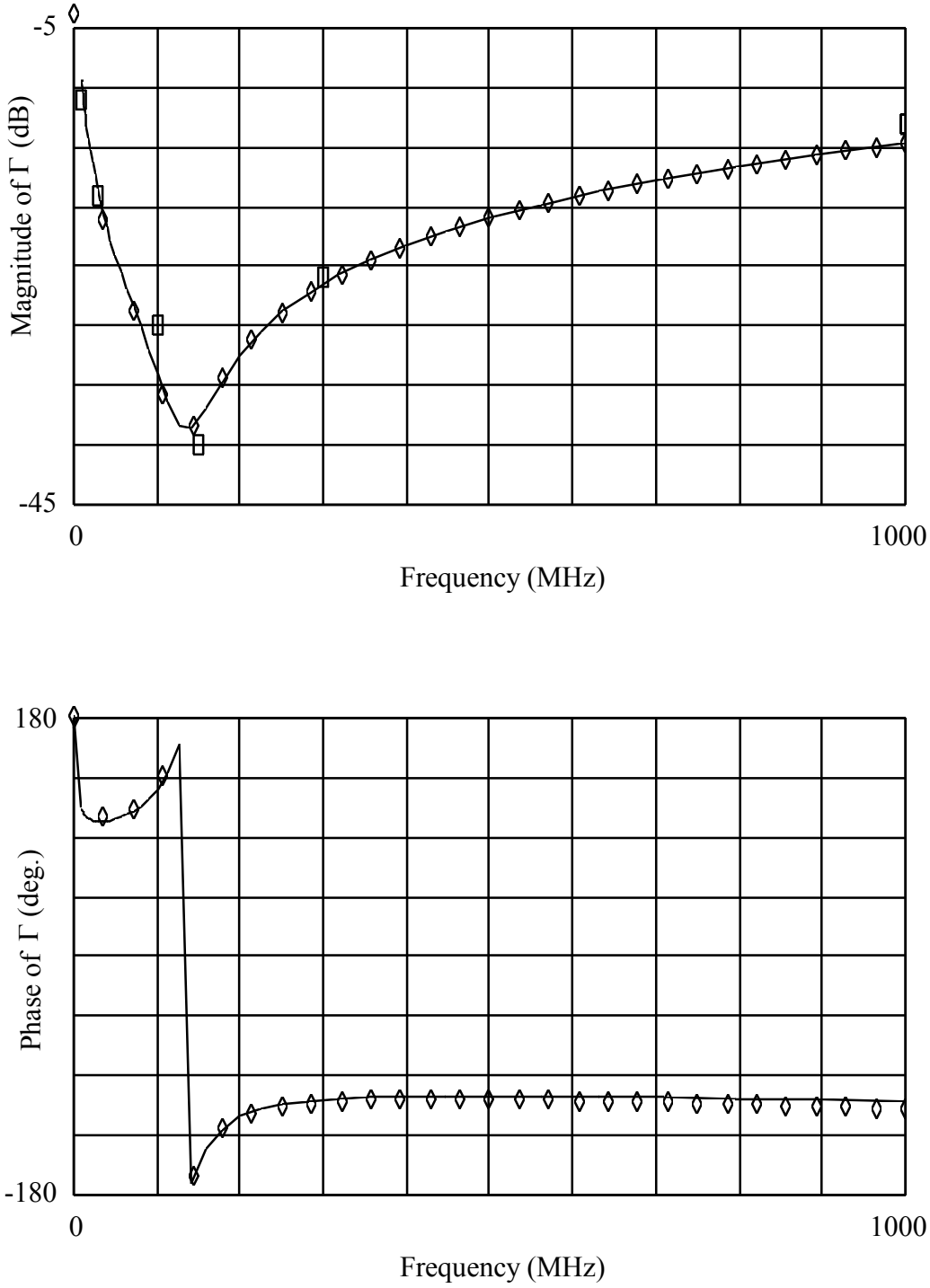


Fig. 3 Reflectivitivy of 6.3 mm Ferrite tile (μ_{r0} = 1051, f_r = 7.02 MHz, ε_r = 12) with TLM μ_{r0} reduced to 680

▯ Manufacturers data

◊ TLM

— Analytic solution

The results for one tile are presented and compared with both the manufacturers reflectivity figures and that calculated using an analytical solution including the approximation for the permittivity given in equation (1). It can be seen (Fig. 2) that the TLM results match the manufactures and computed values reasonably well. The greatest error occurs at low frequencies near the reflection minimum. The values of reflectivity (particularly near the minimum) are highly dependent on the material parameters and tile thickness. It should be noted that the values of μ_{r0} and f_r ($\omega_r = 2\pi f_r$) were chosen to provide a good fit to the manufacturers permeability curves over the frequency range of interest; this resulted in the value of μ_{r0} being different from the manufacturer's stated initial permeability.

It was observed that if the value of permeability entered in the TLM model was reduced to 680, with f_r increased in proportion (R_m stays constant) then the TLM results correspond almost exactly with the analytical data (Fig. 3). The phase of the reflection coefficient also follows the analytical value closely.

Modelling the broadband characteristics of ferrite absorbing tiles using the earlier formulation of [3] is not possible as the frequency dependence of permeability is entirely different. Single frequency computations are possible but this is very wasteful in a time domain method.

Conclusions

A method has been presented which allows the simulation of the performance of lossy magnetic materials with greater accuracy than was previously possible using the TLM method. Currently the technique is being applied to determine the performance of partially lined screened enclosures and in predicting the effect of ferrite absorber within equipment enclosures on radiated emissions.

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