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MODELLING THE DAMPING OF SCREENED ROOM RESONANCES BY FERRITE TILES USING FREQUENCY DEPENDENT BOUNDARIES IN TLM

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ABSTRACT

A new technique which allows the simulation of thin ferrite absorbing tiles in a coarse TLM mesh is described. Results are presented which show a good fit to manufacturers' reflectivity curves. Experimental and simulation results for a screened room partially lined with ferrite are presented to demonstrate the accuracy of the method.

INTRODUCTION

The Transmission Line Matrix (TLM) method of numerical electromagnetic analysis with the symmetrical condensed node is well known [1]. The representation of lossy materials is described in references [2], [3], and [4]. To represent the operation of a lossy dielectric or magnetic material using these methods the material blocks must be about 6 mesh units deep. This is often feasible for lossy dielectric radio absorbent materials, such as those used to line anechoic chambers, as the material depth is relatively large compared to the mesh size. Ferrite absorbing tiles are only a few millimetres in depth and cannot easily be represented as material blocks when the mesh size required to model a typical anechoic chamber may be a significant fraction of a metre. In order to overcome this problem an efficient means of approximating the reflectivity of ferrite absorbers with frequency dependent boundaries is presented. It allows the simulation of ferrite tile absorber by the use of frequency dependent boundaries. Thus allowing the use of a much larger mesh size than would be possible if the absorber were represented as material blocks. This means that it is realistic to simulate the effect of fully, or partially ferrite-lined screened enclosures with the TLM method.

The method requires the storage of only 4 values for each mesh-unit sized boundary patch. This is very efficient compared with the alternative possibility of using multi-grid or graded mesh TLM which would require a large ratio of mesh sizes, and a large number of mesh elements to adequately represent the tiles.

FERRITE ABSORBING TILES

Material Parameters

The variation of permeability of ferrite materials can approximated by the function:

$$\mu_{rm} = 1 + \frac{(\mu'_{r0} - 1)}{1 + \frac{j\omega}{\omega_r}} \quad (1)$$

where μ_{rm} 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.

Flat tiles

If the material parameters and thickness (d) of a flat tile are known its reflectivity (Γ) for a plane wave at normal incidence can be easily calculated.

$$\Gamma = \frac{\Gamma_f + \Gamma_b \exp(-2\gamma_m d)}{1 + \Gamma_f \Gamma_b \exp(-2\gamma_m d)} \quad (2)$$

Where Γ_f is the reflection coefficient at the front face of the tile, Γ_b is the reflection coefficient at the back face, and γ_m is the propagation constant of the tile.

$$\Gamma_f = \frac{Z_m - Z_0}{Z_m + Z_0} \quad (3)$$

where Z_m is the characteristic impedance of the material and Z_0 is the characteristic impedance of free space (assuming the front face of the tile is in air). If the rear face is metal backed then:

$$\Gamma_b = -1 \quad (4)$$

The material impedance Z_m varies with frequency and is given by:

$$Z_m = Z_0 \sqrt{\frac{\mu_{rm}}{\varepsilon_{rm}}} \quad (5)$$

The material propagation constant γ_m is given by:

$$\gamma_m = \gamma_0 \sqrt{\mu_{rm} \varepsilon_{rm}} \quad (6)$$

where γ_0 is the propagation constant for free space.

Grid tiles

Ferrite tiles consisting of a grid of ferrite have a lower reflectivity than the flat tiles. However calculation of the reflectivity of grid structured tiles is more complex and will not be considered here. However the overall shape of the reflectivity curve is similar.

TLM REPRESENTATION

Formulation

The formulation is based on the observation that the frequency dependence of ferrite absorbing tiles behaves in a similar manner to the second order function:

$$F(s) = -\left[\frac{s^2 + 2\zeta\omega_n s + \omega_n^2}{k(s+d)(s+e)}\right] \qquad (7)$$

where s is the Laplace variable. It has a minimum magnitude ρ_{min} when $s = j\omega_n$. This formulation includes the pole at s=-e to give a limit to the value of the reflection coefficient at high frequencies. This was not considered not considered in [5] and is significant for small mesh sizes where the formulation given in [5] may result in reflection coefficients with a magnitude of greater than one at high frequencies.

For large s:

$$F(s) \approx -\left[\frac{1}{k}\right] \qquad (8)$$

and as s tends to zero:

$$F(s) \approx -\left[\frac{\omega_n^2}{k\,d\,e}\right] \qquad (9)$$

We know that the reflection coefficient for the tile tends to -1 at low frequencies so we can match the functions by taking key points on the reflectivity curve of the ferrite tile. Therefore:

$$\omega_n = 2\pi f_{min} \qquad (10)$$

where f_{min} is the frequency of the reflection minimum ρ_{min}. The factor k is given by:

$$k = \frac{1}{\rho_h} \qquad (11)$$

where ρ_h is the magnitude of the reflection coefficient at the highest frequency part of the curve (where the reflection coefficient levels out). The pole e is then determined by:

$$e = \frac{2\pi f_u}{k\,\rho_u} \qquad (12)$$

where f_u is the frequency of a point well above the reflection minimum, before the reflection coefficient levels out, and ρ_u is the magnitude of the reflection coefficient at that point. The damping factor ζ can be expressed as a function of earlier factors and the minimum value of the reflectivity ρ_{min}:

$$\zeta = \frac{k\,e\rho_{min}}{2\,\omega_n} \qquad (13)$$

The pole position, d, is fixed by the fact that the reflectivity (and hence F(s)) must become -1 as s tends to zero so that re-arranging (9) we get:

$$d = \frac{\omega_n^2}{k\,e} \qquad (14)$$

The continuous function F(s) can be approximated by the discrete time function:

$$H(Z) = \frac{b_0 + Z^{-1}b_1 + Z^{-2}b_2}{1 - a_1Z^{-1} - a_2Z^{-2}} \qquad (15)$$

where Z^{-1} represents a unit delay. The a and b coefficients can be determined using the impulse invariant transform from F(s) so that:

$$a_1 = e^{-dT} + e^{-eT} \qquad (16)$$

$$a_2 = -e^{-dT}\ e^{-eT} \qquad (17)$$

$$b_1 = -b_0\ \Re(z_{z1} + z_{z2}) \qquad (18)$$

$$b_2 = b_0\ e^{-(2\zeta\omega_n T)} \qquad (19)$$

where $\Re(x)$ indicates the real part of x . The value of b_0 is chosen such that H(1) = -1. T is the sample period for the filter which is made equal to the TLM time-step and the zeros, z_{z1} and z_{z2}, of H(Z) are given by:

$$z_{z1} = e^{\left(-\zeta\omega_n T + j\omega_n T\sqrt{1-\zeta^2}\right)} \qquad (20a)$$

$$z_{z2} = e^{\left(-\zeta\omega_n T - j\omega_n T\sqrt{1-\zeta^2}\right)} \qquad (20b)$$

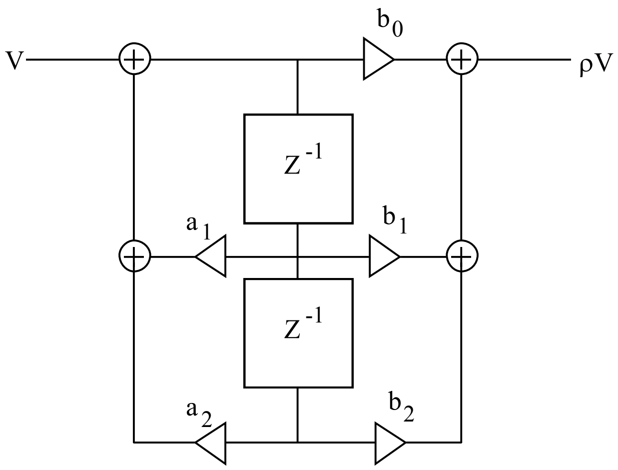

Fig. 1 Second order digital filter section

The filter can be implemented as shown in Fig. 1 where V is the incident voltage and ρV is the reflected voltage. Two such filters are required to implement the reflection coefficient at each mesh element boundary - one for each wave polarisation.

Results

Here results are presented which compare the manufacturers data with analytical solution for Γ and the discrete time filter for the conventional flat-plate tiles (Fig. 2). Then the response of the discrete time filter is compared with manufacturers data for the new grid-structure ferrite tiles (Fig. 3). To compute these results with the material blocks of [3] and [4] would require a mesh size of approximately 1 mm - in many cases the use of such a fine grid would be impractical.

Considering Figures 2 and 3 it can be seen that the discrete time filter response results corresponds closely to the manufacturers' data above the reflection minimum but an error of several dB occurs at low frequencies. The fit is best in the case of the flat tile. It can also be seen that there is some discrepancy between the analytical value for the reflection coefficient and the manufacturers data. This may be due to the fact that the permeability is only approximately given by Equation (1).

When used in the TLM mesh a further error may occur in the reflectivity response of the tiles due to the low pass response of the TLM mesh itself. This is not normally a problem for mesh sizes smaller than 1/10th of a wavelength.

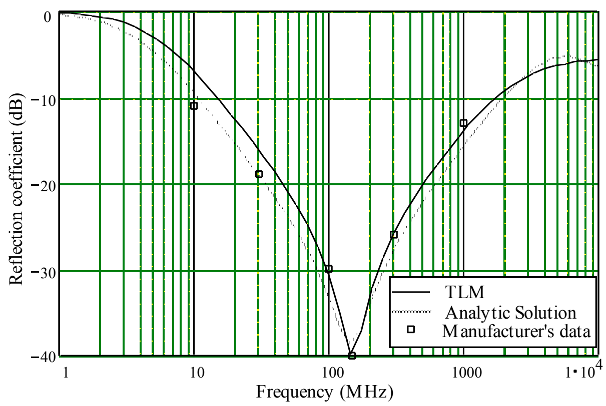

Fig. 2 Flat Ferrite tile

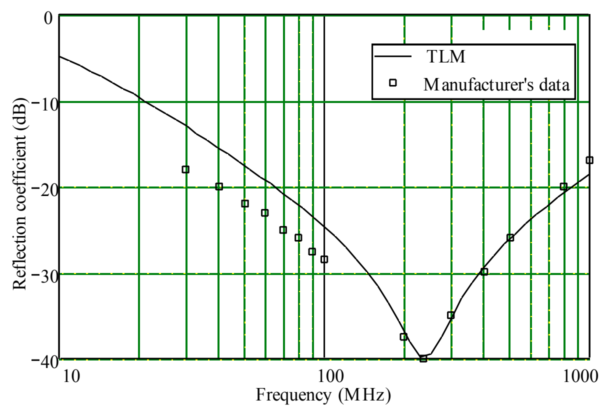

Fig. 3 Grid -structure ferrite tile

MEASUREMENTS

For electromagnetic measurements in a screened room a full lining of absorber on the walls and ceiling is near ideal giving the semi-anechoic conditions of an pen area test site. It is impractical to make a small room semi-anechoic at low frequencies due too the depth of absorbing material required on the walls. Partially lined screened rooms are of interest because of their lower cost than fully lined anechoic chambers. It has been shown in reference [6] that the use of ferrite absorbing tiles at the magnetic field maxima can significantly damp the resonances of the enclosure which improves the quality of measurements that can be made in it. Here we compare measured and simulated results which show the damping achieved for a screened room partially lined with grid-structured ferrite tiles placed as in [6] (Fig. 6).

An electrically small source and antenna were used in the measurement programme because of the difficulty of adequately representing typical antennas (e.g. bi-conical or log periodic) used in screened room measurements within the TLM method. The source was an optically coupled spherical dipole and the receive antenna was a short, active monopole with top loading. The receive antenna was positioned with its cable running along the floor of the enclosure.

Figs. 4 and 5 show the measured and simulated screened room response for a room lined with tiles placed at the H-field maxima as explained in reference [6]. The absolute levels in the figures are not significant, as the antenna system used was not calibrated, but the degree of damping achieved when the tiles are present is. It can be seen that the reduction in amplitude of the resonant peaks predicted by the simulation corresponds with the reduction measured.

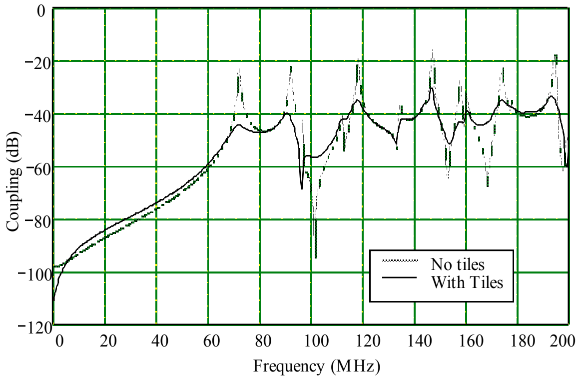

Fig. 4 Simulation of screened room with/without ferrite tiles

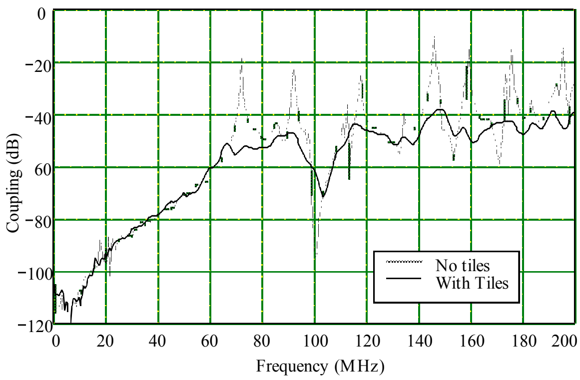

Fig. 5 Measurement of Screened room with/without ferrite tiles

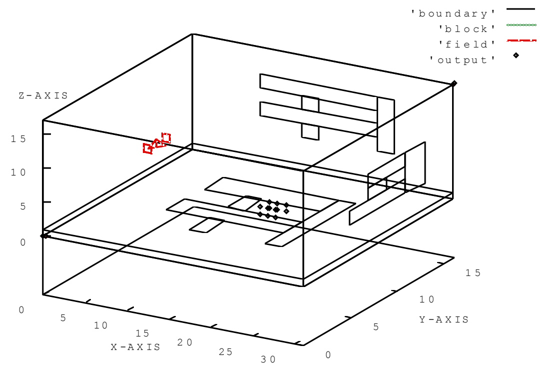

Fig. 6 Screened room layout showing tile location

FURTHER WORK

Additional work is currently being carried out to verify the frequency dependent boundary representation for ferrite tiles. This includes:

measurement of angular dependence of the simulated tile reflection coefficient;

comparison of damped screened room results for flat tiles;

simulation of the determination of tile parameters by the perturbation method - the change in frequency and Q-factor of a small resonant cavity in the presence of a material sample is measured;

simulation of the effects of ferrite tiles on radiation through apertures in enclosures is being carried out.

CONCLUSIONS

A method of efficiently representing ferrite absorbing tiles in the TLM method has been presented. The method has been shown to give good results with grid-structured ferrite tiles although the accuracy of the results are limited by the fact that the method does not follow the frequency response of grid structured tiles as well as for flat tiles. Further work is required to determine the accuracy which can be achieved.

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