

MODELLING TECHNIQUES FOR THE CALCULATION OF THE SHIELDING EFFECTIVENESS OF EQUIPMENT CABINETS

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Abstract: The paper describes recent advances in the modelling and simulation of materials and screens for the shielding and absorption of EM waves. Simple intermediate models are briefly outlined, followed by models for describing complex materials and screens in the time-domain.

Key words: Shielding effectiveness, absorbing materials, electromagnetic compatibility

1. Introduction

Advanced studies and design in electromagnetic compatibility (EMC) and signal integrity (SI) of high-speed circuits require sophisticated EM models of materials and also practical geometrical configurations. Modern IT and communication systems rely on strict signal specifications, noise and interference limits well up to microwave frequencies. Specifications are imposed over a very broad range of frequencies and under transient often non-linear conditions. Therefore characterization and modelling is best done in the time-domain. In recent years many different materials have emerged with electrical properties tailored to specific needs. These are incorporated in sheet (e.g. perforated screens, frequency selective surfaces) or block (e.g. RAM pyramids, ferrites) form as part of electromagnetically complex structures such as equipment cabinets. New materials with novel properties are also being tested such as chiral materials, nano-materials and negative refractive index materials.

In order to evaluate the performance of these materials in their actual working environment we need accurate, flexible and versatile models in the time-domain which can be readily integrated into generic EM modelling method such as FEM, FDTD and TLM. This presents two major difficulties.

First, we need general models for materials which exhibit frequency dependent, chiral, anisotropic, non-linear properties and where ϵ , μ when plotted against each other can have values in any quadrant. This is a complex task but significant progress has been made and is reviewed in this paper.

Second, irrespective of material properties engineering structures made out of them are formed

into complex patterns (e.g. with numerous perforations) and are part of a equally complex structure (e.g. a loaded equipment cabinet). The resulting systems cannot be modelled efficiently due to the widely different electrical scales of their constituent parts (e.g. very small diameter holes in a perforation pattern versus the large dimensions of a cabinet). This is a typical example of a multi-scale problem and requires special efficient models, otherwise modelling of such systems for design purposes is practically impossible.

It is precisely this aspect of material modelling and simulation that is addressed in this paper.

2. Shielding-Basic Concepts and Simplified Approaches

The most common practical parameter for evaluating shielding is the shielding effectiveness SE of an equipment cabinet. A typical example is shown in Fig. 1 where a radiator generating EMI is placed in the proximity of a cabinet with an aperture.

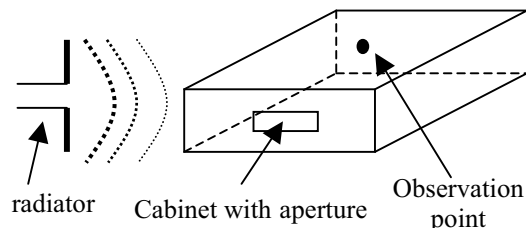


Fig. 1 Schematic of cabinet in the proximity of a radiator

The shielding effectiveness is defined as [1],

$$SE = 20 \log \left\{ \frac{E_0}{E_c} \right\}$$

where E_0 is the electric field at the observation point in the absence of the cabinet and E_c is the field at the same point with the cabinet present. The practical difficulty in simulations is the calculation of E_c .

One approach which is simple, effective and reasonably accurate for a range of simple apertures,

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including multiple apertures, is based on an intermediate level technique [2]. This intuitive model is based on sound science as it represents the cabinet as a short-circuited waveguide and the aperture as two segments of a short-circuited coplanar stripline as shown in Fig. 2.

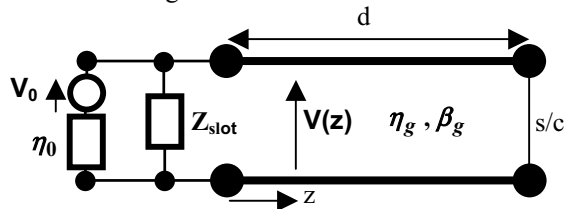


Fig. 2 Equivalent circuit of a cabinet with an aperture.

Starting from the left-hand side the equivalent circuit consists of the Thevenin equivalent of the radiator, the impedance representing the aperture and the short-circuited waveguide with parameters corresponding to the waveguide propagation constant and impedance. The electric field at a point a distance z from the aperture is represented by the voltage $V(z)$. The SE is obtained in closed form and the accuracy is good as long as there are not too many box resonances in the frequency range of interest and the apertures are distributed in a regular way at the front panel. The effects of loading may also be studied [3]. This model represents a simple and effective tool for conceptual design studies but it cannot cope with the more general situations described in the introduction.

2. Modelling of General Material Properties in the Time-domain

As already indicated, current and future applications in the shielding and absorption of EM waves make increasing use of materials with tailor-made properties of an increasingly complex electrical behaviour. Powerful modelling capabilities are now available to describe such materials. The basic principle behind these techniques is the development of digital interface algorithms (DFI) which mimic the frequency dependent properties of the materials and also interface readily to the time-domain field simulation algorithms. In Fig. 3(a) the general DFI is shown embedded into the TLM field solver [4]. Given the incident voltages V^i and excitations V_f , the reflected voltages V^r are obtained. All the transformations in this diagram except $t(z)$ depend on geometrical factors related to physical laws and the structure of the TLM node.

Matrix $t(z)$ contains information specific to the properties of the material in each node. For the case of a bi-anisotropic material, $t(z)$ is shown in Fig. 3(b).

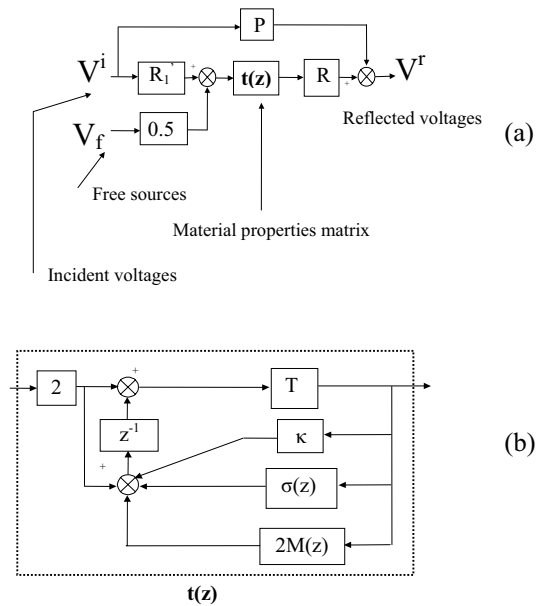


Fig. 3 General scheme for modelling materials in TLM (a), example of the material matrix $t(z)$ for bi-anisotropic material (b).

The detailed theory, examples and comparisons for validation purposes may be found in a series of papers which cover various aspects including frequency dependent materials [5,6], non-linear materials [7], ferromagnetic materials [8] and negative refractive index materials [9].

3. Modelling of Thin Perforated Screens

An important modelling requirement in EMC and microwaves is the description of thin panels with a pattern of perforations. Applications which fall into this category are cooling grids, frequency selective surfaces, ferrite grid tiles, etc. In all these cases, in addition to modelling the material properties of the screen the complex pattern of perforations and the thinness of the screen need also to be described. This presents a major dilemma to the modeller. If the mesh resolution is made finer to accommodate the fine features (thickness of the panel, size of perforations) this will result to a prohibitively large computation. If this is not done the accuracy of the simulation deteriorates alarmingly. This type of problem, known as a multi-scale problem, is well known but difficult to address. However, the techniques described in section 2 in connection with materials modelling may also be adapted to deal with this problem. We illustrate the approach again in connection with the TLM field solution technique.

The modelling of a thin material screen, with or without perforations, placed between two computational nodes may be understood with reference to the connection process between two adjacent TLM nodes shown in Fig. 4.

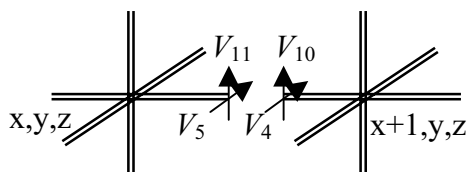


Fig. 4 Connection between two TLM nodes at x and x+1.

In the absence of any screen, connection is simply the exchange between V_5 and V_4 , and, V_{11} and V_{10} . If a perfectly conducting screen is placed between the two nodes then the incident voltage pulses from either side are reflected with a reflection coefficient equal to -1 . If however, a perforated screen or a finite conductivity screen with arbitrary material properties is introduced a more complex reflection and transmission pattern takes place. Connection is yet another scattering event dependent on screen properties,

$$S(f) = \begin{bmatrix} R(f) & T(f) \\ T(f) & R(f) \end{bmatrix}$$

where for each port R and T are the reflection and transmission coefficients which are in general frequency dependent. The scattering coefficients for a complex screen, as a function of frequency, may be obtained by experimental, analytical or numerical means as a pre-processing task. The general procedure is then for each coefficient to extract the poles (s-domain) followed by the application of the bi-linear z-transform to obtain an expression in the z-domain relating incident and reflected voltages,

$$S_{ij}(z) = \frac{k_{+1} V^i(x+1)}{k V^r(x)} = B_0 + \frac{\sum_{i=1}^{NP} B_i' z^{-i}}{1 + \sum_{i=1}^{NP} A_i z^{-i}}$$

where NP is the number of poles used to approximate the scattering coefficient. The algorithm employed to implement the scattering is in the form shown in Fig. 5. Theoretical details and applications of this approach for a number of practical problems may be found in [10,11].

Another area of considerable importance for modeling complex shapes is the ability to place accurately particular features such as thin panels in the numerical mesh. Here the difficulty is in ensuring that the regular mesh, invariably used in time-domain simulations, is capable of mapping exactly the detailed dimensions of the problems. Thus 'true placement' is rarely possible except if the mesh is extremely fine. This latter option results in very large computations and it is thus rarely a practical proposition.

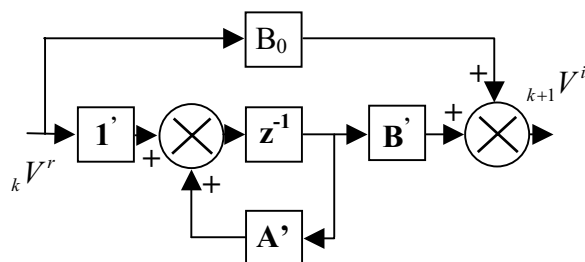


Fig. 5 Schematic of the DFI for reflection through a screen with frequency selective properties.

In such cases, special techniques are required for fractional placement of screens and panes in the mesh. We describe here the general structure of the DFI for the case where a 'stretch' is required in the boundary between nodes when placing a lossy dielectric layer. The configuration is shown in Fig. 6.

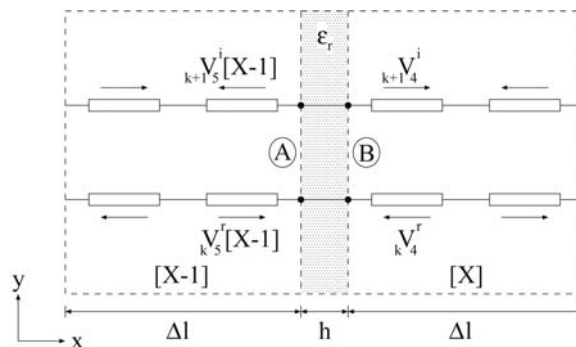


Fig. 6 Schematic of the placement of a dielectric layer between two nodes.

The presence of the layer of thickness h (from A to B) is represented by the DFI algorithm shown in Fig. 7.

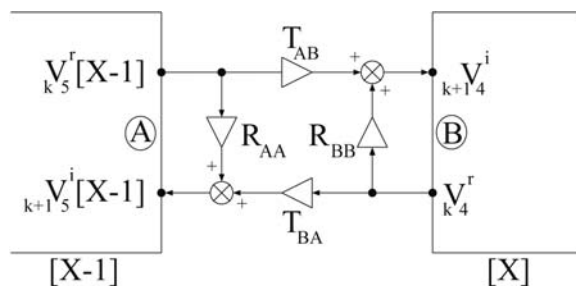


Fig. 7 General form of the DFI algorithm.

This general scattering process may be simplified depending on the problem. As an illustration for an external boundary stretch only R is required and is given by,

$$R(s) = \frac{s - c/d}{s + c/d}$$

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where, d is the required stretch of the node boundary and c is the speed of light. This expression is transformed into the discrete time domain by the application of the bi-linear z-transform. For the more general case of a boundary stretch with a lossy dielectric layer both R and T are employed as shown in Fig. 8 and have the form

$$R \text{ or } T = \frac{b_1 s + b_0}{a_1 s + a_0}$$

where the a and b coefficients are obtained analytically from the layer properties and dimensions. We illustrate this technique by showing the fields inside a cabinet loaded with a dielectric slab as shown in Fig. 8. The vertical component of the electric field is plotted at the measurement point M as a function of frequency in Figs. 9(a) and 9(b). The desired box size to be modelled is $293 \times 120 \times 432 \text{ mm}^3$, but a TLM mesh having a space step of 10 mm can only accurately model a box of size $290 \times 120 \times 430 \text{ mm}^3$. Modes 1 (analytical) and Sim 1 (TLM simulation) refer to the case where there is no dielectric slab and no stretching is used thus modelling the incorrect size box. Modes 2 and Sim 2 are for no dielectric slab but with stretching to model the correct size box. Sim 3 is the general case with dielectric and with stretching used to position the slab correctly and to represent the box. The stretching algorithm correctly predicts the small shifts in frequency. We also note that the (310) mode is suppressed by the slab.

4. Conclusions

We have shown how modelling and simulation techniques can be used to predict shielding and damping in EMC problems. Sophisticated material models and efficient algorithms are available to model very general material properties and geometrical configurations.

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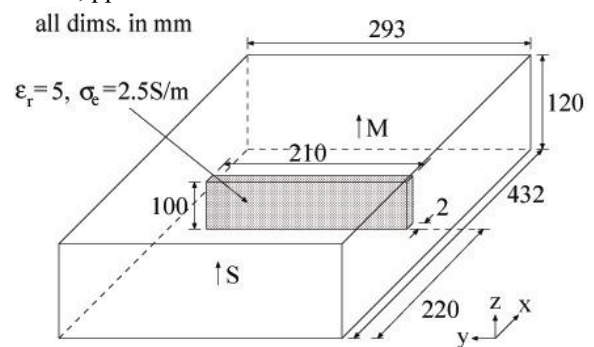


Fig. 8 Metallic box loaded with lossy dielectric layer.

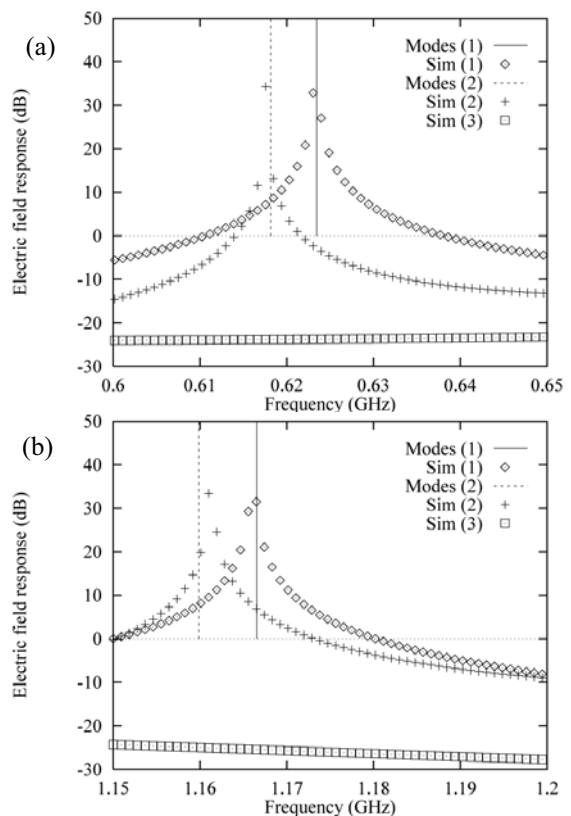


Fig. 9 Electric field at (a) (110) and (b) (310) resonances.