ELECTROMAGNETIC PROPAGATION INTO REINFORCED-CONCRETE WALLS

E. Richalot, M. Bonilla, M.F. Wong, *Member, IEEE*, V. Fouad-Hanna*, *Fellow, IEEE*, H. Baudrand**, *Senior Member, IEEE*, J. Wiart

France Telecom CNET, DMR/RMC, France
* Universite Pierre et Marie Curie (Paris 6), France
** Laboratoire d'Electronique - Groupe de recherches en electromagnetisme, ENSEEIHT, France

Abstract : *A 3D finite element method with a decomposition on Floquet's modes is presented to study the transmission parameters of building walls. The influences of gratings in concrete walls, of wall dimensions, and of the electromagnetic excitation with single field of a plane wave or with diffuse field, on wall transmission properties are then studied by this method.*

I- Introduction

The urban and indoor wave propagation simulation can be considerably simplified if the electromagnetic propagation through buildings materials is thoroughly estimated and consequently represented by simplified equivalent formulae. In modern buildings, two types of walls are commonly employed namely concrete walls and reinforced concrete ones, which is typically made up of a steel grid embedded in a slab of concrete. Our goal in this paper is to determine the transmission and reflection properties of these two types of walls.

Two trends are generally adopted when studying metallic grids. The first one is based on the use of approximate formulas and is only available for concrete mesh dimensions small compared to the wavelength [1]. The geometries and the frequencies chosen in our study won't permit us to use them. The second one is based on the use of rigorous numerical methods. The method of moment was successively employed in the study of grids of any geometry [2]. But this last method fails to study complex grids inserted into lossy multi-layers. So, we have chosen to use the finite element method (FEM) because this rigorous method presents the advantage of being able to take into account any geometry and losses. Two frequencies of operation, 900MHz and 1800MHz, are chosen due to the importance of the results for indoor and outdoor wireless communications.

II- Method of analysis

The studied structure is a reinforced-concrete wall illuminated by a plane wave of wave vector $\vec{k}_0$ as shown in figure 1. The wall is composed of a square grid immersed in a dielectric. The dimensions of the wall are large enough compared to the wavelength, so it is possible to treat the wall as an infinite array.

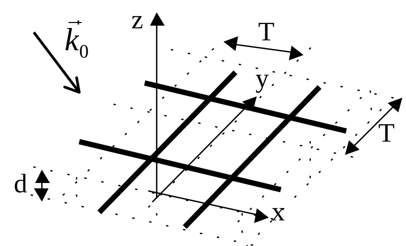

Fig 1: Infinite reinforced concrete wall

According to Floquet's theorem, periodic boundary conditions involve the periodicity of the fields. This allows us to reduce the studied domain to an elementary cell (fig. 2). The boundary conditions on the lateral sides of the cell describe the biperiodicity with the following expressions [3] :

$$f(x+T,y,z) = f(x,y,z)e^{-jk_xT} \text{ and}$$
$$f(x,y+T,z) = f(x,y,z)e^{-jk_yT} \quad (1)$$

for a $e^{j\omega t}$ time dependency, where T is the period.

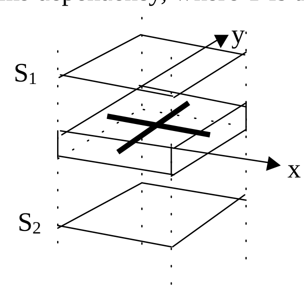

Fig. 2 : Elementary cell

Moreover the resolution of Helmholtz equation having periodic boundary conditions in the z=0 plane leads to a solution which can be written as the sum of an infinite discrete expansion of plane waves which are

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called Floquet modes ; a set of orthogonal functions are formed, whose expressions are functions of the incident wave [3] :

$$\vec{E} = \sum_{m=-\infty}^{+\infty} \sum_{m=-\infty}^{+\infty} \left(\vec{A}_{mn} \Psi_{mn} e^{jk_{zmn}z} + \vec{B}_{mn} \Psi_{mn} e^{-jk_{zmn}z} \right) \text{ for } z>0$$

$$\vec{E} = \sum_{m=-\infty}^{+\infty} \sum_{m=-\infty}^{+\infty} \vec{B}'_{mn} \Psi_{mn} e^{-jk_{zmn}z} \text{ for } z<-d \qquad (2)$$

where $\Psi_{mn} = e^{-j(k_{xmn}x + k_{ymn}y)}$,

$$k_{xmn} = k_x + \frac{2\pi m}{T_u},$$

$$k_{ymn} = k_y + \frac{2\pi n}{T_v},$$

$$k_{zmn}^2 = k_0^2 - k_{xmn}^2 - k_{ymn}^2 \qquad (3)$$

Then the FEM is used to study an elementary cell like that shown in fig. 2 where S1 and S2 are two references plane surfaces parallel to two periodic planes. We use the conventional FEM described in [4] where the fields are decomposed using edge elements, while fields exterior to this elementary cell are known by the coefficients of their expansion on Floquet's harmonics as expressed in eq. (2).

III- Results

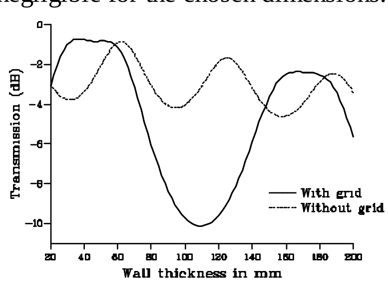
III-1- Influence of grid dimensions

We have studied the influence of some critical parameters of the grid on the transmission characteristics of the wall, and compared the results to those obtained for walls without grid.

III-1-A- Square grid side length

The transmission coefficients are calculated for a mesh having a square side lenght varying between 5cm and 25cm, and for wall thicknesses varying between 20mm and 200mm. This study is made at 900MHz and 1.8GHz, for a normal incidence, and a relative permittivity $\varepsilon_r = 7 - j0.3$. The steel diameter is 1.5mm.

Results are given in the figures 3 and 4. One can see that the influence of the presence of the grid can never be negligible for the chosen dimensions.



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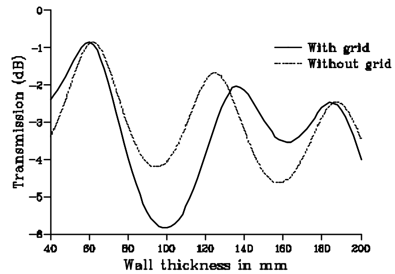

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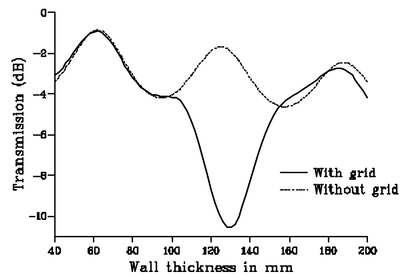

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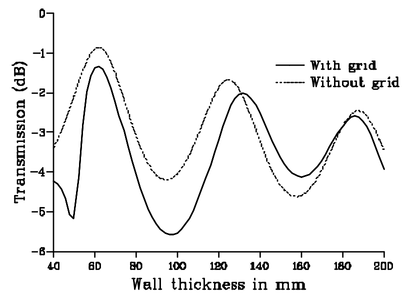

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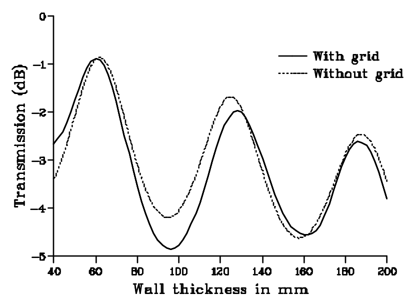

(e)

Fig. 3 : Transmission at 900MHz for a normal incidence, for a grid having a square side length of : (a) 5cm, (b) 10cm, (c) 15cm, (d) 20cm, (e) 25cm.

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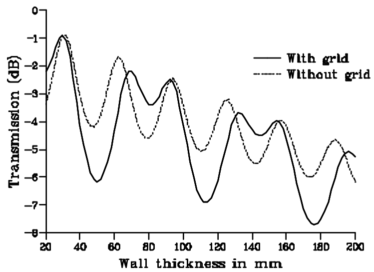

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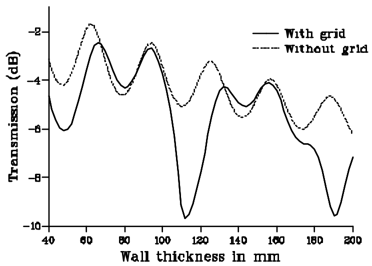

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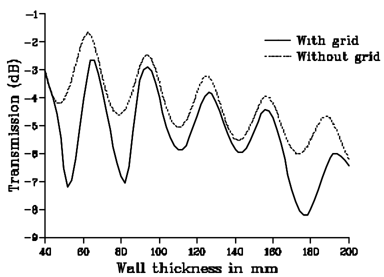

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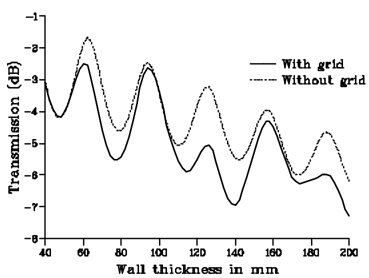

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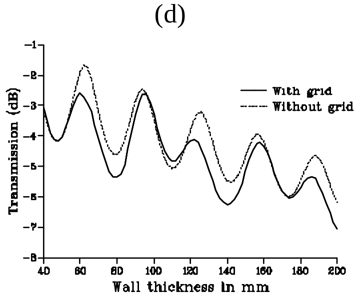

(e)

Fig. 4 : Transmission at 1.8GHz for a normal incidence, with a grid having square side length of : (a) 5cm, (b) 10cm, (c) 15cm, (d) 20cm, (e) 25cm.

III-1-B- Steel diameter

For a relative permittivity $\varepsilon_r = 7 - j0.3$ and a square grid of side length of 12cm, steel diameters of 2mm, 3mm and 4mm are considered. The results obtained for diameters of 2mm and 4mm at 900MHz and 1.8GHz are shown in figures 5 and 6. We can see that the steel diameter has negligible affect at 900MHz, while at 1.8GHz the attenuation is more important when the diameter is bigger.

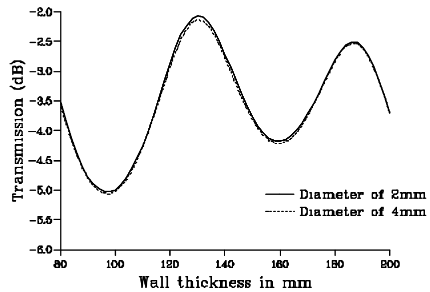

Fig. 5 : At 900MHz

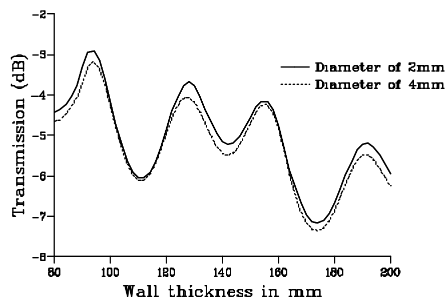

Fig. 6 : At 1.8GHz

III-2- Diffuse fields

Due to the multi-reflections phenomena involved in urban and indoor propagation, the electromagnetic fields have to be considered as the resultant of the incidence of a number of plane waves having different propagation directions and polarizations. Taking an infinite number of plane waves, this phenomena is well described by the concept of diffuse fields, for which each direction of propagation is equiprobable. This concept is more commonly known in mode stirred chamber and it can provide a good figure of merit on reflection or transmission characteristics when the incident field is not clearly known. The power transmission coefficients in diffuse fields are given by [5] :

$$T_{diffused} = \frac{2}{\pi} \int_0^{\pi/4} \int_0^{\pi/2} \left(T_{TE\,(\theta,\varphi)} + T_{TM\,(\theta,\varphi)} \right) \sin(2\theta) d\theta d\varphi$$

where T_{TE} and T_{TM} are the power coefficients for TE and TM polarized incident plane waves

θ and φ angles define the incidence direction as defined in figure 8.

To calculate it we discretize the angle variation in $\pi / 36$ and simulate the problem for each associated incidence.

The precision of our method has been verified for a steel grid of diameter 0.7mm and mesh size 4.7mm in the air at 10GHz. Our simulation has given a transmission of -11.7dB while -11.1dB were found experimentally [5].

We have then studied a wall, whose square size length is of 200mm, steel diameter of 8mm, and relative permittivity $\varepsilon_r = 7 - j0.2$ at 900MHz.

The influence of the direction of incidence of plane waves has firstly been studied in the plane $\varphi = 0$. Figure 7 shows that the transmission decreases when the incidence direction becomes oblique.

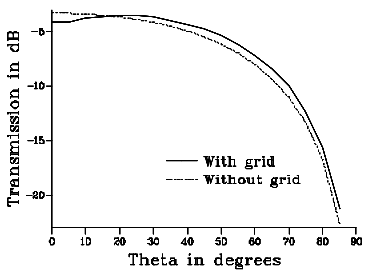

Fig 7 : $\varphi = 0$

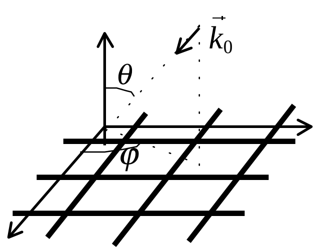

Fig. 8 : Problem geometry

The transmission properties considering only normal incidence has been studied for this test case and results are given in fig.9.

Furthermore, this structure has then be studied using diffuse field concept and results are shown in fig. 10. It can be seen from theses two figures that results are nearly identical for the case without grids, while, for the case of a wall with grids, the diffuse field concept gives different results. This is due to the presence of more reflections on the grids. Also, the results given in figures 7, 9 and 10 show that the presence of grids modifies the transmission properties of the walls.

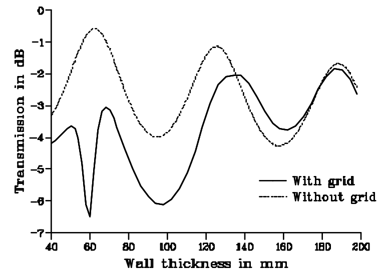

Fig. 9 : Normal incidence

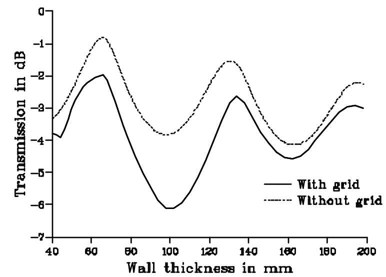

Fig. 10 : Diffuse field

IV- Conclusion

A rigorous method based an the FEM and a decomposition of the fields on Floquet's harmonics has proven to be efficient to analyze precisely the electromagnetic characteristics of buildings walls. We have seen firstly that the influence of the grid can't be neglected, and secondly that walls dimensions can have an influence on the transmission, and we have demonstrated the importance of the diffuse field concept when studying the transmission properties of walls with grids.

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