FDTD MODELLING OF FINITE SIZE EBG STRUCTURES

Marta Martínez Vázquez Rens Baggen
Department of Antennas & EM Modelling
IMST GmbH, Carl-Friedrich-Gauss-Str. 2, D-47475 Kamp-Lintfort, Germany
e-mail : martinez@imst.de e-mail : baggen@imst.de

***Abstract-* To characterise the reflection properties of printed surfaces like FSS (Frequency Selective Surfaces) and EBG (Electromagnetic Band-Gap), it is standard to use a plane wave excitation, and then compare the phase of the incident and the reflected waves. Thus, the phase difference over the frequency can be obtained. Nevertheless, in most cases, only infinite size structures are considered. In this paper a procedure is proposed for the modelling of finite size substrates containing printed EBG elements, using a plane wave excitation in combination with the FDTD (Finite Difference Time Domain) method.**

I. INTRODUCTION

FSS or EBG printed surfaces techniques are usually characterised through the evolution of the so-called reflection phase over the frequency. In order to assess this behaviour, the structure is exposed to a plane wave, and the phase of the incident and the reflected waves are compared. Normally, in simulations, infinite size structures are considered. In these cases, a single unit (EBG or FSS) cell is simulated, while the use of Periodic Boundary Conditions (PBCs) allows extending the analysis to the infinite structure.

This kind of analysis yields good results for the study of the theoretical behaviour of the surface, but does not assess the real situation, in which the structure is always finite in size. For example, if an EBG substrate is used to improve the radiation characteristics of a circular polarised antenna, such as those used for GPS applications, it is important to determine how the truncation of the infinite EBG cell distribution will affect the overall performance of the antenna.

In this paper, a novel simulation model, which allows an accurate and flexible modelling of finite size substrates is presented. This model was developed for its use with the field solver EmpireTM [1], based on FDTD. First, the simulation method adapted to the finite structure problem will be presented, along with the problems that may arise. Two different configurations for the analysis will be compared.

To investigate the accuracy of both FDTD models, an error analysis will be carried out. Finally, a typical finite size EBG structure will be studied using this methodology, and the obtained results will be discussed.

II. DESCRIPTION OF THE PROBLEM

The basic idea of this method for characterising the reflection phase of a certain Structure Under Test (SUT) is similar to the traditional one used for finite structures. A plane wave will fall on the structure, with an arbitrary angle, and the reflected plane wave will have to be determined, as shown in Figure 1. A nearfield-to-farfield transformation will be applied to the nearfield components, to extract the desired components of the diffracted farfield in the direction of the reflected wave.

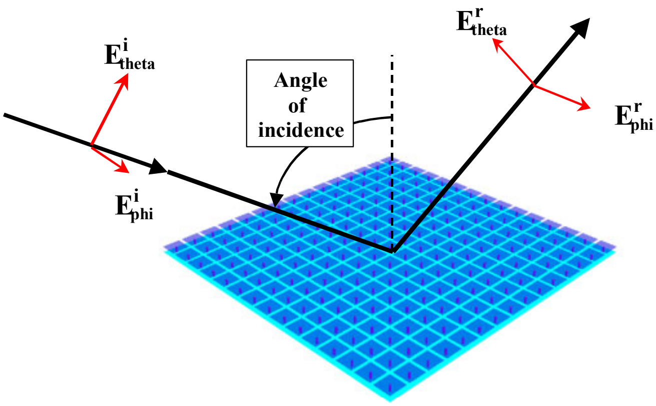

Figure 1: SUT under plane wave excitation: incident and reflected waves.

As the nearfield-to-farfield transformation introduces an unknown phase offset, it is not possible to directly establish the absolute phase difference between the phase of the incident wave and that of the reflected wave. So, only a relative phase difference can be determined.

In order to obtain the absolute phase difference, a second simulation is necessary, in which the SUT is replaced by an ideal conducting plate of identical size. Again, the relative phase difference between the incident and the reflected waves is calculated. Thus, the absolute phase difference for the SUT can be determined, by normalising the relative phase difference to that obtained for the metal plate. In this way, it is possible to plot the typical reflection phase diagram as presented in [2], [3] as function of the frequency of the incident wave.

III. FDTD MODELLING

To carry out the simulations as described in the previous section, two features must be included in the FDTD model, namely: a plane wave excitation and a nearfield-to-farfield transformation. In EmpireTM, both are defined as boxes within the FDTD simulation space.

The nearfield-to-farfield (NF-FF) box will register the nearfield components on its faces, and transform them into farfield components using Huygens' principle.

The plane wave (PW) box is defined in such a way that the plane wave, which will be used as excitation, only exists inside the box, whereas outside only scattered fields are present. This can be obtained by defining a certain field distribution on the surfaces of the PW box. This field distribution will generate a plane wave that will propagate inside the box with a certain direction. In order to avoid this plane wave from exiting the PW box, equal opposite fields are defined on the opposite faces of the box, to cancel the outbound wave.

This technique has a good accuracy if the scattering objects contained within the PW box do not disturb significantly the propagation of the plane wave. In practise, these objects should then be small compared to the size of the PW box.

In the case of the problem considered here, this condition cannot be respected. Indeed, the study of FSS or EBG structures requires a very fine meshing of the SUT. To keep simulation time and memory requirements within reasonable limits, it is therefore necessary to reduce to the minimum the simulation space that has to be discretised. This implies that the PW bow will not be much larger than the SUT, which will influence the accuracy of the plane wave model defined within the PW box. Indeed, in this case the SUT will intercept most of the incident wave. This is not taken into account by the PW box model, and can result into excitation fields (error fields) leaking out the PW box. This, in turn, will induce errors on the values of the nearfield detected on the faces of the NF-FF box, and lead to inaccuracies in the results of the simulations.

In order to overcome this problem, two different configurations are investigated, as displayed in Figure 2:

- PWFF model: The PW-box is contained within the NF-FF box. This configuration is based on the hypothesis that, for waves coming from the top of the PW box, most of the 'error' fields will exit the PW box through the bottom surface, which is almost completely shadowed by the SUT. To compensate the error when calculating the farfield, the nearfield components on the bottom surface of the NF-FF box will then be set to 0. This can be assumed to be true for angles of incidence up to approximately 60°, if 0° represents a plane wave with a direction of propagation perpendicular to the surface of the SUT.

- FFPW model: In this configuration, the NF-FF box is contained within the PW-box. The excited plane wave goes through the NF-FF box, and is cancelled when calculating the farfield. The error fields that leak out of the PW box will not be registered by the NF-FF box, and will therefore have no influence upon the farfield results.

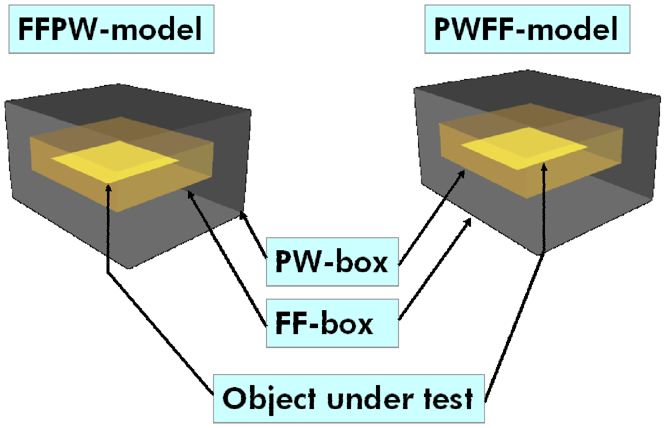

Figure 2: FDTD models for investigating finite size substrates.

IV. ERROR ANALYSIS

In order to assess the accuracy of the models described above, a simple test was implemented: a metal plate was placed within the simulation space, and the farfield was calculated. For each of the simulation setups, two simulations were carried out, with the metal plate at two different heights, as shown in Figure 3. This is a suitable benchmark problem, as the phase difference of the reflected waves for the two positions of the metal plate can be easily determined analytically.

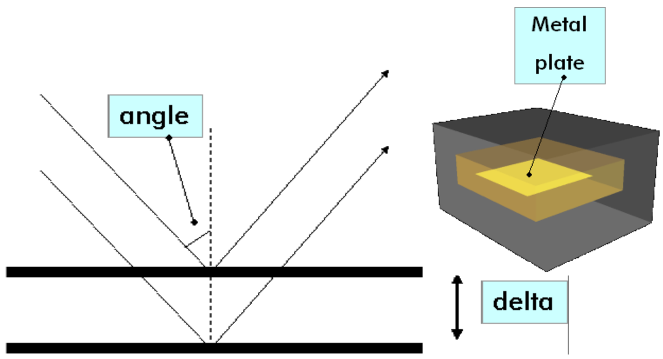

Figure 3: Test setup for error analysis.

The relative reflection phase obtained by using the proposed models is shown in Figure 4, along with the analytical results. An angle of incidence of 60° was considered. The difference between the two positions of the metal plate was delta=3mm.

The PWFF configuration leads to quite approximate results, but the error is still noticeable both for the lower and the higher frequencies. For the FFPW configuration, the difference between the simulated results and the analytical solution is negligible, and only for the lower frequencies, for which the edge effects are more important, a small discrepancy can be found. Similar results were obtained for other angles of incidence.

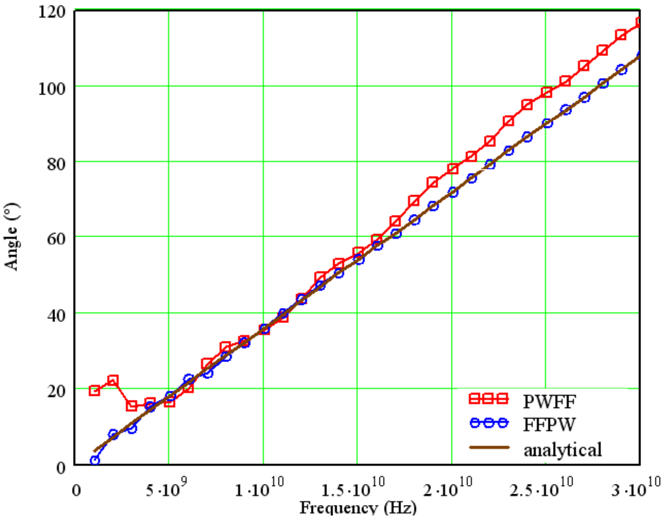

Figure 4: Phase difference vs. frequency, simulated and analytical results for delta = 3 mm.

The FFPW model seems then particularly suited for the problem that was proposed, namely, the characterisation of the reflection phase of structures of finite size.

V. EXAMPLES OF APPLICATION

The FFPW model was used to investigate the properties of a mushroom-like square EBG substrate as presented in Figure 5. The basic EBG cell consists of a 30x30 mm square patch, with a 2.5 mm in diameter shorting pin. The gap between the patches is 5 mm. The height of the patches over the ground plane is 10 mm, with air as substrate.

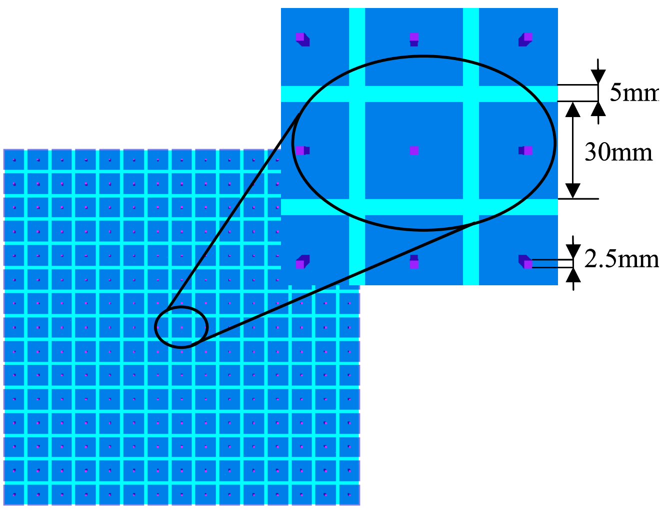

Figure 5: Mushroom-like EBG structure.

A. *Effect of the size of the EBG surface.*

To illustrate the effect of the finite size of the substrate, different simulations were performed, with substrates of different sizes, and, conversely, different number of EBG cells. The obtained results are displayed in Figure 6.

It can be observed how, when the number of cells is insufficient, undesired resonance effects appear in the reflection phase diagram. In this case, this happens for the structures composed of 5x5 cells and 9x9 cells. These resonances tend to disappear when the number of EBG cells is increased, as shown in the plots for the 11x11 cells and 15x15cells structures.

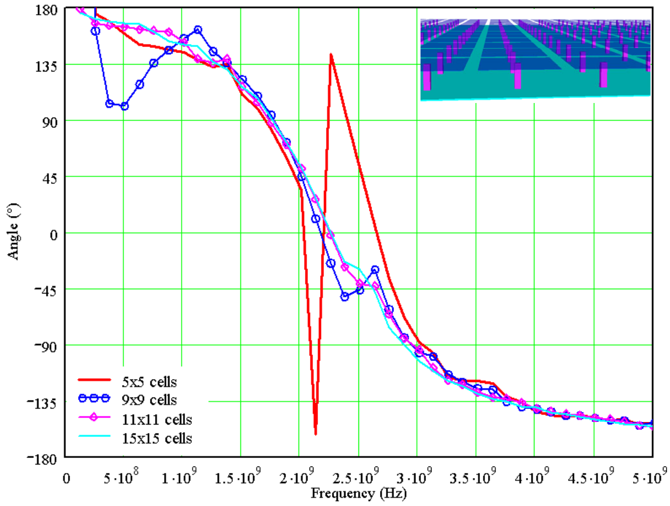

Figure 6: Simulation of the reflection phase for different sizes of the EBG.

The simulation results obtained for the 15x15 cells configuration agree with the typical results that can be found in the literature [3]. Only for the lower frequencies a certain ripple can be detected, which is due to the diffraction of the plane wave at the edges of the structure. This effect had already been observed in the error analysis discussed previously. For higher frequencies the ripple is smoothed.

As long as a sufficient number of elements is considered, the FFPW model suffices to simulate EBG surfaces,. Unfortunately, enlarging the structure also means enlarging the number of discretisation cells, which implies longer simulation times and higher memory requirements. A compromise has to be found between accuracy and a realistic modelling of the problem.

B. *Effect of the angle of incidence.*

Another important point is that an EBG structure can behave in a different way depending on the polarisation of the incident wave, and its angle if incidence. This is especially critical if the EBG substrate is used to improve the properties of circularly polarised antennas used for positioning systems. Should an EBG surface not exhibit the same properties the two orthogonal linear components, the ellipticity of the signal will increase. Moreover, the direction of arrival of the signal is not constant, and therefore the properties of the system must be constant over a large beamwidth.

In Figure 7, the evolution of the reflection phase over the frequency, for the E_{theta} component of a circularly polarised wave is shown for different angles of incidence.

In this case, the EBG surface was composed of 15x15 cells. It is clearly visible that the bandgap centre frequency is modified: from about 2.25 GHz in the case of an angle of incidence of Theta=0° to 1.65 GHz for Theta=60°. This shift can thus amount to about 600 MHz, and should be taken into account in practical application.

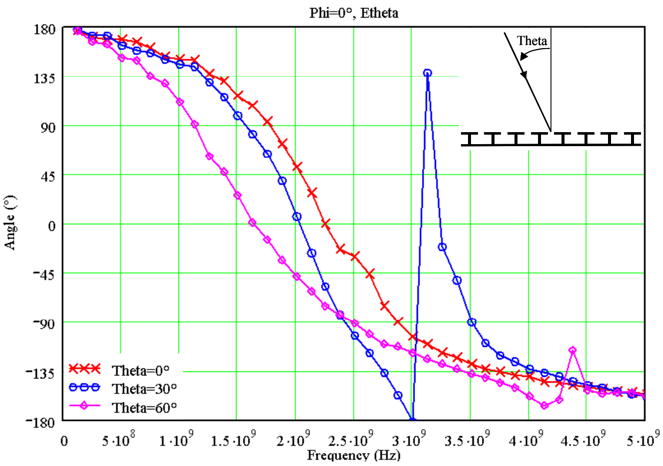

Figure 7: Simulation of the reflection phase for different sizes of the 15x15 cells EBG.

The second effect that can be observed is a change in the slope of the curves. This, in turn, translates into significant changes in the width of the bandgap.

These effects are typical for EBGs, and the employed simulation method has successfully characterised them. Therefore, in a further step, the FFPW model will be applied to characterise substrates with different shapes of EBG cells, in order to find designs with characteristics that are more stable with respect to variations in the polarisation and angle of incidence.

VI. CONCLUSIONS

The FDTD method was used to characterise the reflection phase of structures with finite size. Two different configurations have been proposed, from which ones yield very accurate results, and seems to be good suited to solve this kind of problems. The method was applied to investigate a typical EBG structure. Further work will include the analysis of more sophisticated EBG cells, and the combination of antennas and EBG surfaces. The results will be validated through measurements.

LITERATURE

[1] EMPIRE User and Reference Manual, IMST GmbH, 2003.

[2] F. Yang and Y. Rahmat-Samii, ‘Reflection Phase Characterisation of the EBG Ground Plane for Low Profile Wire Antenna Applications’, IEEE Trans. on A&P, Vol. 51, NO. 10, PP. 2691-2703, October 2003

[3] J.M. Baracco, P. de Maagt, ‘Radiating Element on a photonic bandgap structure for phased array applications’, JINA, Nice, 12-14 November, 2002.