Detection, 2022, 9, 29-36
https://www.scirp.org/journal/detection
ISSN Online: 2331-2084
ISSN Print: 2331-2076

Modeling of Radiating Aperture Using the Iterative Method

Rafika Mejri, Taoufik Aguili

Communication System Laboratory Sys'Com, National Engineering School of Tunis, University Tunis El Manar, Tunis, Tunisia
Email: mejrirafika@yahoo.fr, Taoufik.Aguili@gmail.com

How to cite this paper: Mejri, R. and Aguili, T. (2022) Modeling of Radiating Aperture Using the Iterative Method. *Detection*, **9**, 29-36.
https://doi.org/10.4236/detection.2022.93003

Received: January 26, 2022
Accepted: July 26, 2022
Published: July 29, 2022

Abstract

We are interested in this work to electromagnetic leakage, for example the door of the microwave oven (or shielding of electronic functions working in the microwave band containing holes for ventilation circuit) which must be transparent (chain link) but the level of electromagnetic leakage issued by this device must not exceed certain standards. This work started with this article in which we are interested in a simple structure consisting of a multilayer structure incorporating a radiating aperture. We show in this paper mainly the interests of this study and the limitations of using these structures. Modeling of this device is provided by the wave concept iterative procedure (WCIP) which is simple to implement and is characterized by the fast execution method. The validation of our work is carried out by comparing our results with those calculated by the Ansoft HFSS software which shows a good agreement.

Keywords

Electromagnetic Leakage, Radiating Aperture, Microwave, Iterative Method, Planar Structure, Multilayer, Electromagnetic Shielding

1. Introduction

Microwave ovens use high-frequency electromagnetic radiation (microwave). This radiation is absorbed by food and transformed into heat. Microwaved foods do not contain microwaves and do not radiate but the metal housing of the microwave oven and the metal grid of the oven door retain most of the radiation inside the oven. Some of this radiation escapes from the furnace in the form of leakage radiation. These constraints require researchers to continually innovate electromagnetic simulation tools to analyze and predict an accurate electromagnetic leakage produced by these circuits. These requirements lead us in this article to be interested in the modeling of these radiating apertures to reduce at the maximum or even cancel these electromagnetic leakages [1]. The method used is an iterative method (WCIP), [2] [3] [4] [5] characterized by its simplicity of implementation due to the absence of test functions and its timeliness mainly due to the systematic use of FMT "Fast Modal Transform". The results found in this study are validated by the Ansoft HFSS software. They show good agreement.

2. Theory

2.1. Study Structure

The study structure is a planar structure, consisting of three layers of different thicknesses. Between these layers are planes of discontinuity Ω_1 and Ω_2. The excitation circuit " Plane Ω_1" constituted by an excitation source of dimensions "$c_1 \times d_1$" strictly less than the wavelength and a metal strip of dimensions "$c_1 \times l_1$", negligible thickness and "open line". The "Plane Ω_2" contains a metal surface incorporating a radiating aperture dimensions "$a_1 \times b_1$". Between the metal surface and the top cover we include/layer water. The assembly is placed in a metal case. The lower cover of the housing forms the ground plane. This structure is depicted in Figure 1.

2.2. Formulation of the Method

The theoretical formulation of the structures for the iterative method is based on determining the relationship between the incident and reflected waves [4] in the spectral domains and spatial domains shown in Figure 2.

The evolution of iterations through the spectral domain to the space domain is done using the Fourier transform modal "FMT" which considerably reduces the calculation time. Modal Fourier transform [5] requires the fragmentation of

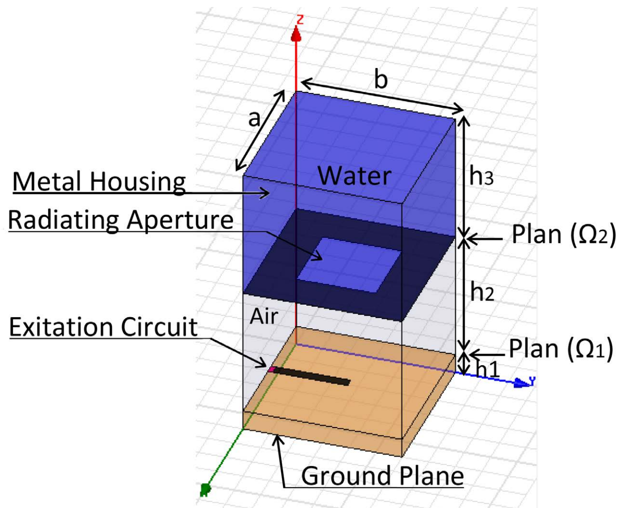


Figure 1. Study structure. Parameters of the study structure: $a = b =$ 12 mm, $c_1 = 0.75$ mm, $d_1 = 0.375$ mm, $h_1 = 1.5$ mm, $h_2 = 10$ mm, $h_3 =$ 10 mm, $a_1 = b_1 = 6$ mm, $l_1 = 5.625$ mm, $\varepsilon_{r1} = 4.32$, $\varepsilon_{r2} = 1$, $\varepsilon_{r3} = 80$, Meshing of plans Ω_1 et Ω_2: 128 × 128 pixels.

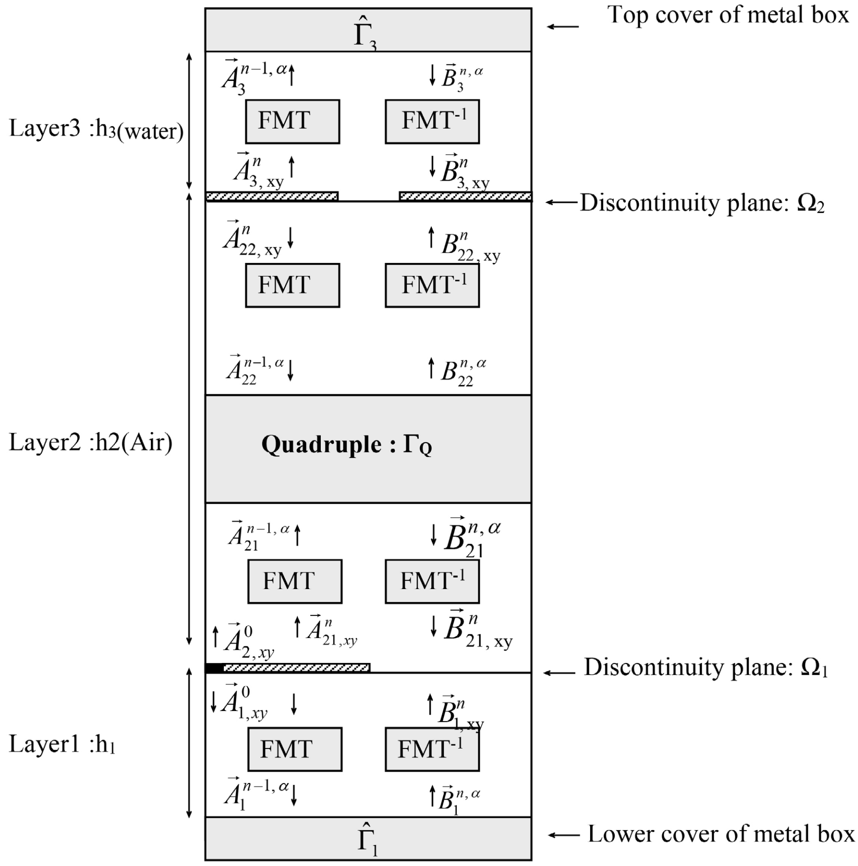


Figure 2. Synoptic diagram summarizing the iterative method for planar structures with three layers.

discontinuity planes (Ω_1 and Ω_2) in pixels and this so that the electromagnetic behavior of the overall circuit will be summarized by writing the boundary conditions and continuity of the tangential fields on each pixel. The iterative process stops when it reaches the convergence of results.

The evolution of iterations through the spectral domain to the space domain is done using the Fourier modal transform "FMT" [2] [5] [6] which considerably reduces the calculation time. Fourier modal transform requires the fragmentation of discontinuity planes (Ω_1 and Ω_2) in pixels and this so that the electromagnetic behavior of the overall circuit will be summarized by writing the boundary conditions and continuity of the tangential fields on each pixel. The iterative process stops when it reaches the convergence of results.

The terms below link the incident waves "$\vec{A}_1$, $\vec{A}_{21}$, $\vec{A}_{22}$ and $\vec{A}_3$" to the reflected waves "$\vec{B}_1$, $\vec{B}_{21}$, $\vec{B}_{22}$ and $\vec{B}_3$" when they pass the space domain to the spectral domain:

$$\begin{pmatrix} A_1 \\ A_{21} \end{pmatrix} = \hat{\Gamma}_{\Omega 1} \begin{pmatrix} B_1 \\ B_{21} \end{pmatrix} + \begin{pmatrix} A_1^0 \\ A_2^0 \end{pmatrix}$$

$$\begin{pmatrix} B_{21} \\ B_{22} \end{pmatrix} = \hat{\Gamma}_{Q} \begin{pmatrix} A_{21} \\ A_{22} \end{pmatrix}$$

$$\begin{pmatrix} A_{22} \\ A_3 \end{pmatrix} = \hat{\Gamma}_{\Omega 2} \begin{pmatrix} B_{22} \\ B_3 \end{pmatrix}$$

$$\begin{pmatrix} \vec{J}_{21} \\ \vec{J}_{22} \end{pmatrix} = \begin{pmatrix} \hat{Y}_{11} & \hat{Y}_{12} \\ \hat{Y}_{21} & \hat{Y}_{22} \end{pmatrix} \begin{pmatrix} \vec{E}_{21} \\ \vec{E}_{22} \end{pmatrix} \tag{1}$$

$\hat{\Gamma}_k$: Reflection Operator ensuring the link between the incident waves and the reflected waves. It is defined in the spectral domain. It contains information on the housing walls and the relative permittivity of the different mediums of the structure, $k \in$ {medium 1, medium 3}.

$\hat{\Gamma}_Q$: Diffraction Operator at each interface (Ω_1 and Ω_2).

The operators of diffraction $\hat{\Gamma}_{\Omega 1}$ and $\hat{\Gamma}_{\Omega 2}$ contain the images of the circuits that are in the Ω_1 and Ω_2 planes, defines these two planes of discontinuities.

The evolution of the iterative method for a planar structure with three layers of different mediums is very detailed in our articles [7] [8].

According to the diagram in **Figure 3** we can write:

$$\begin{pmatrix} B_{21} \\ B_{22} \end{pmatrix} = \hat{\Gamma}_Q \begin{pmatrix} A_{21} \\ A_{22} \end{pmatrix} \tag{2}$$

- **Parameters $\hat{Y}_{ij}$ du quadruple Q:**

$$\begin{cases} J_{21} = Y_{11}E_{21} + Y_{12}E_{22} \\ J_{22} = Y_{21}E_{21} + Y_{22}E_{22} \end{cases} \tag{3}$$

$$\begin{cases} \vec{J}_0 = \vec{J}_1 + \vec{J}_{21} \\ \vec{J}_2 = \vec{J}_{22} + \vec{J}_3 \\ \vec{J}_1 = \hat{Y}_1 \cdot \vec{E}_1 \\ \vec{J}_3 = \hat{Y}_3 \cdot \vec{E}_3 \\ \vec{E}_1 = \vec{E}_{21} \\ \vec{E}_{22} = \vec{E}_3 \end{cases}$$

The symmetry of the structure allows us to write:

$$\begin{cases} \hat{Y}_{11} = \hat{Y}_{22} \\ \hat{Y}_{12} = \hat{Y}_{21} \end{cases} \tag{4}$$

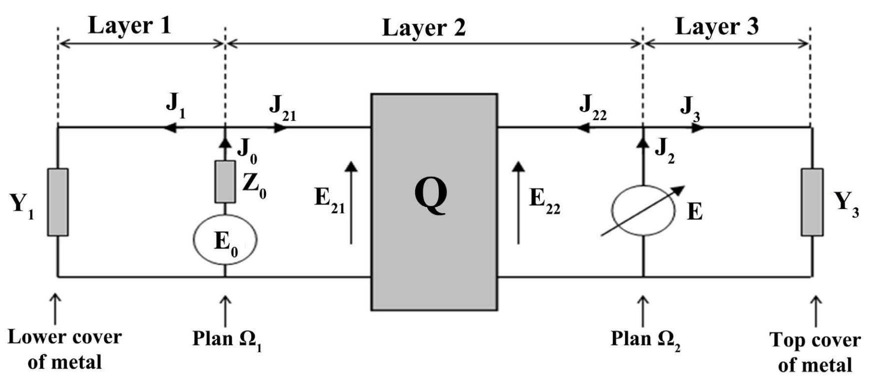


Figure 3. Equivalent electrical circuit of the planar structure including three layers of different mediums.

After some mathematical manipulation, it is possible to determine the matrix:

$$\hat{\Gamma}_Q = \frac{1}{C}\begin{bmatrix} 1-(Y_{11}Z_{02})^2+(Y_{12}Z_{02})^2 & -2Y_{12}Z_{02} \\ -2Y_{12}Z_{02} & 1-(Y_{11}Z_{02})^2+(Y_{12}Z_{02})^2 \end{bmatrix} \tag{5}$$

with: $C = (1+Y_{11}Z_{02})^2 - (Y_{12}Z_{02})^2$

$$\Gamma_Q = \sum_{m,n,\alpha}\begin{bmatrix} \left| f_{mn}^{\alpha} \right\rangle \dfrac{1-(Y_{11}Z_{02})^2+(Y_{12}Z_{02})^2}{(1+Y_{11}Z_{02})^2-(Y_{12}Z_{02})^2} \left\langle f_{mn}^{\alpha} \right| & \left| f_{mn}^{\alpha} \right\rangle \dfrac{-2Y_{12}Z_{02}}{(1+Y_{11}Z_{02})^2-(Y_{12}Z_{02})^2} \left\langle f_{mn}^{\alpha} \right| \\ \left| f_{mn}^{\alpha} \right\rangle \dfrac{-2Y_{12}Z_{02}}{(1+Y_{11}Z_{02})^2-(Y_{12}Z_{02})^2} \left\langle f_{mn}^{\alpha} \right| & \left| f_{mn}^{\alpha} \right\rangle \dfrac{1-(Y_{11}Z_{02})^2+(Y_{12}Z_{02})^2}{(1+Y_{11}Z_{02})^2-(Y_{12}Z_{02})^2} \left\langle f_{mn}^{\alpha} \right| \end{bmatrix} \tag{6}$$

f_{mn}^{α} : Bases function of the box modes.

$$\begin{cases} B_{21}^{\alpha} = \sum_{m,n,\alpha} \left| f_{mn}^{\alpha} \right\rangle \left(\dfrac{1-(Y_{11}Z_{02})^2+(Y_{12}Z_{02})^2}{(1+Y_{11}Z_{02})^2-(Y_{12}Z_{02})^2} \right)^{\alpha} \left\langle f_{mn}^{\alpha} \middle| A_{21}^{\alpha} \right. + \sum_{m,n,\alpha} \left| f_{mn}^{\alpha} \right\rangle \left(\dfrac{-2Y_{12}Z_{02}}{(1+Y_{11}Z_{02})^2-(Y_{12}Z_{02})^2} \right)^{\alpha} \left\langle f_{mn}^{\alpha} \middle| A_{22}^{\alpha} \right. \\ B_{22}^{\alpha} = \sum_{m,n,\alpha} \left| f_{mn}^{\alpha} \right\rangle \left(\dfrac{-2Y_{12}Z_{02}}{(1+Y_{11}Z_{02})^2-(Y_{12}Z_{02})^2} \right)^{\alpha} \left\langle f_{mn}^{\alpha} \middle| A_{21}^{\alpha} \right. + \sum_{m,n,\alpha} \left| f_{mn}^{\alpha} \right\rangle \left(\dfrac{1-(Y_{11}Z_{02})^2+(Y_{12}Z_{02})^2}{(1+Y_{11}Z_{02})^2-(Y_{12}Z_{02})^2} \right)^{\alpha} \left\langle f_{mn}^{\alpha} \middle| A_{21}^{\alpha} \right. \end{cases} \tag{7}$$

with $\alpha \in \{\mathrm{TE}, \mathrm{TM}\}$

3. Convergence of the Method

Convergence of the Input Impedance

- Structure without the top cover:

This analysis requires a study of the convergence of the input impedance of the circuit Figure 4 based on iterations to optimize the calculation time and to improve the accuracy of the results. The figure shows that the real part of the impedance converges from 500 iterations and the imaginary part converges from 100 iterations for a frequency of 14 GHz.

Figure 4. Convergence of the input impedance of the study structure as a function of iterations. (Number of iterations: 2000).

4. Validation of the Method

To validate our results we have compared it with those cited in our article [7] and those computed by the HFSS software of Ansoft. Figures show that there is good agreement between the two simulations' results.

Figure 5 shows that at the frequency *f* = 17.2 GHZ the reflection is minimal, this means that the radiation of structure 1 is maximum; knowing that the dielectrics and metal conductors constituting our structure are considered lossless.

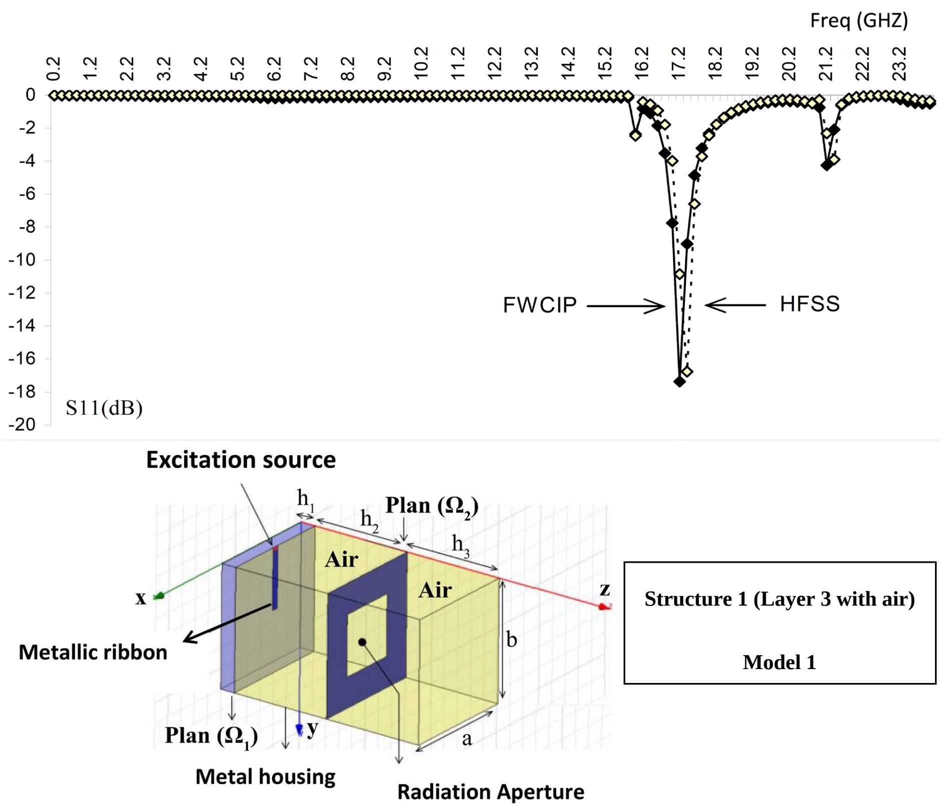
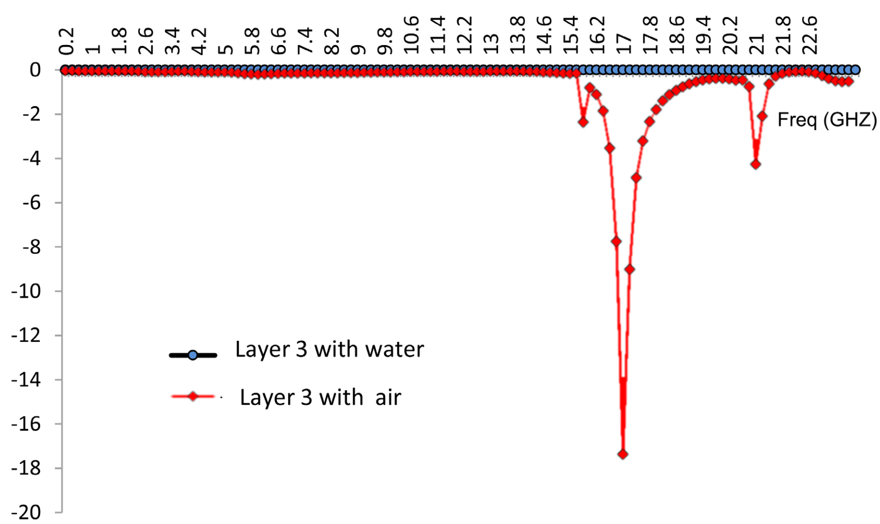


Figure 5. Variation of the reflexion coefficient S11 according to layer 3 of structure 1.



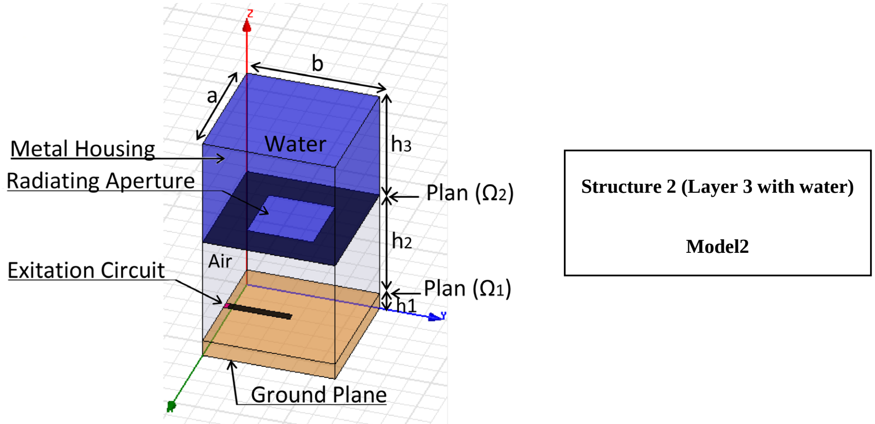


Figure 6. Comparison of the variation of the reflexion coefficient S11 according to the layer 3 of structure 2.

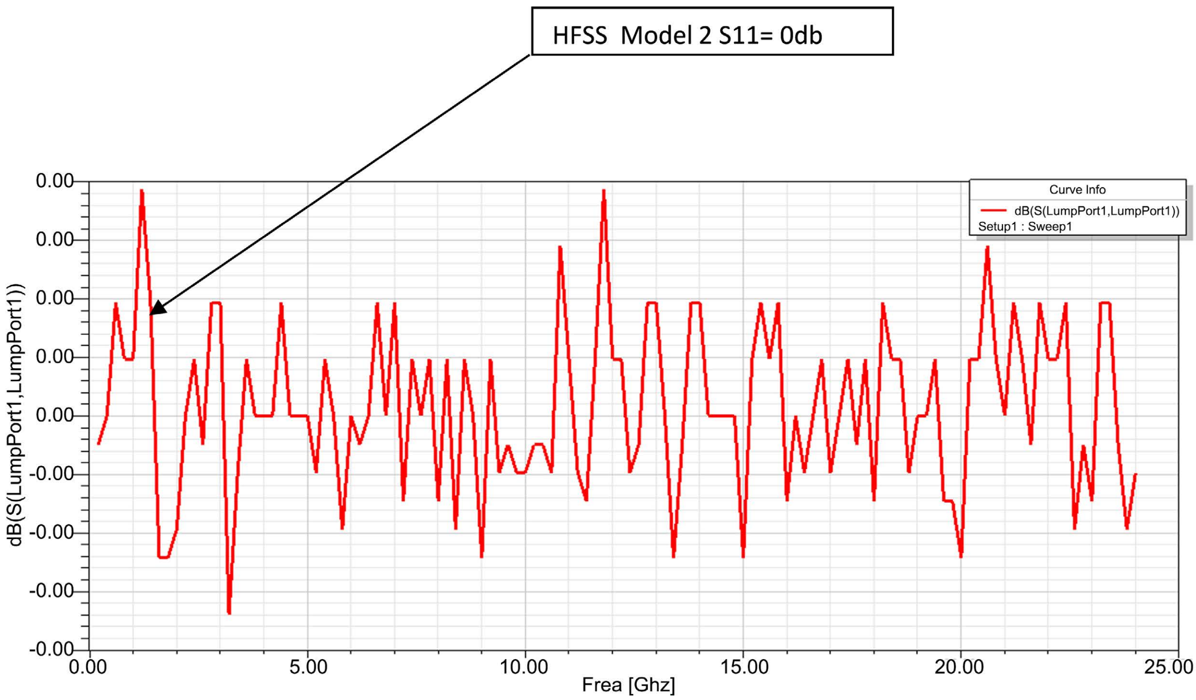


Figure 7. Variation of the reflection coefficient S11 of the structure according to layer 3 of structure 2 (HFSS).

Figure 6 shows that if we choose the dielectric permittivity of the third layer $\varepsilon_3 = 80$ (water layer) the reflection becomes total (S11 = 0 dB) which implies no radiation. On the other hand, if we choose $\varepsilon_3 = 1$ the reflection becomes negligible (S11 = −17 dB) which corresponds to a considerable radiation of the study structure. This is checked for a frequency margin to 25 Ghz.

The validation of our work is carried out by comparing our results with those calculated by the Ansoft HFSS software **Figure 7** which shows a good agreement.

5. Conclusion

We focus in our research on the effectiveness of the electromagnetic shielding of a metal enclosure integrating an aperture of ventilation. The level of electromagnetic leakage must not exceed certain standards; this work was started by modeling a very simple structure incorporating an opening for ventilation. Preliminary results show good agreement with those calculated by Ansoft HFSS software, and we can confirm that the level of electromagnetic leakage can be reduced by properly choosing the dimensions of the structure and the integration of the water layer.

Acknowledgements

This work has been supported by The SYSCOM laboratory, National Engineering School of Tunis Tunis El Manar University.

References

[1] Mejri, R. and Aguili, T. (2017) Contribution to the Study of the Shielding Effectiveness by an Iterative Method (FWCIP). *IINTE'*2017, Gafsa, 20-22 October 2017. https://doi.org/10.1109/IINTEC.2017.8325933

[2] Serres, A., Serres, G.K.F., Fontgalland, G., Freire, R.C.S. and Henri, B. (2014) Analysis of Multilayer Amplifier Structure by an Efficient Iterative Technique. *IEEE Transactions on Magnetics*, **50**. https://doi.org/10.1109/TMAG.2013.2285601

[3] Akatimagool, S., Bajon, D. and Baudrand, H. (2001) Analysis of Multi-Layer Integrated Inductors with Wave Concept Iterative Procedure (WCIP). 2001 *IEEE MTT-S International Microwave Sympsoium Digest*, Phoenix, 20-24 May 2001.

[4] Bajon, D., Wane, S., Baudrand, H. and Gamand, P. (2002) Full Wave Analysis of Isolated Pockets to Improve Isolation Performances in Silicon Based Technology. 2002 *IEEE MTT-S International Microwave Symposium Digest*, Seattle, 2-7 June 2002.

[5] Henri, B., Sidina, W. and Damienne, B. (2002) The Concept of Waves: Theory and Application in Electronic Problems. *International Conference on Mathematical Methods in Electromagnetic Theory*, Kiev, 10-13 September 2002.

[6] Baudrand, H. and N'gongo, R.S. (1999) Applications of Wave Concept Iterative Procedure. *Microwave Theory & Tech*, **I**, 187-197.

[7] Mejri, R. and Aguili, T. (2016) A New Approach Based on Iterative Method for the Characterization of a Micro-Strip Line with Thick Copper Conductor. *Journal of Electromagnetic Analysis and Applications*, **8**, 95-108. https://doi.org/10.4236/jemaa.2016.85010

[8] Mejri, R. and Aguili, T. (2016) New Formulation of the Multilayer Iterative Method: Application to a Coplanaire Lines with Thick Conductor. *Journal of Electromagnetic Analysis and Applications*, **8**.