Numerical Simulation using FDTD Method to Estimate Return Loss for Ultra-Wideband Antennas Built with High Loss FR-4 Substrate

S. T. M. Gonçalves[1], L. R. Milagre[1], L. M. Tomaz[1], M. M. Afonso[1], U. C. Resende[1]

[1]Post-Graduate Program in Electrical Engineering, CEFET-MG, Minas Gerais, 30510-100, Brazil
sandro@div.cefetmg.br, ludymilagre@hotmail.com, marciomatias@des.cefetmg.br, resendeursula@des.cefetmg.br

This work presents an accurate simulation using FDTD-UPML of two microstrip antennas built with FR-4 substrate, being one for validation and the other an ultra-wideband antenna. The FR-4 is inhomogeneous, anistropic and has high tangent loss, which become the project and estimation of radiation characteristics a challenger task. However, the FR-4 is easy to manipulate and is cheaper than others substrates commonly used to manufacture microstrip antennas. To enhance the FDTD code, substrate loss and plane wave excitation were implemented. Besides, Dey-Mittra algorithm was also implemented since it reduces simulation errors in small structures and corners as well as bents and curves. To compare the results simulated, the return loss was used. The microstrip antennas was also simulated in CST Microwave Studio, with Transient Solver, and built. The measurements were performed in a Network Analyzer. The set of numerical improvements made the results to be satisfactory and slightly better than those found in literature.

***Index Terms*— FDTD, FR-4, Microstrip Antennas, UWB.**

I. Introduction

MICROSTRIP patch antennas (MPA's) are widely used for wireless communication systems and have many applications especially in the field of medical, military, mobile and satellite communication [1]-[2].

The Finite Difference Time Domain (FDTD) method provides a useful way to solve the Maxwell's curl equations [3] and can be used to simulate several applications as the radiating antenna system [4]. The time-domain analysis is useful to evaluate antennas in wideband frequencies since it requires just one simulation for a specific geometry. To simulate an infinite computational domain, the Uniaxial Perfectly Matched Layer (UPML) can be used since it has low reflection coefficients [3].

Despite the FDTD efficiency, degraded results may be obtained in the antenna simulation. One of the most prominent factors that degrade the results is the presence of reflections from the feed line/air interface. Besides, a truly plane wave can not be modelled at the feed line but a spherical wave is inserted in the computational space. This can originate several propagation modes that can degrade the expected results in the simulation. Another issue is the diagonal to the mesh air/antenna interface or curves, which generate a staircase error in the modelling of the FDTD object. Finally, the dieletric losses are critical in high frequency and are often neglected. This work uses several computational procedures in FDTD to step in the previous issues to improve the return loss calculation.

II. Withdraw Reflections from Feed Line/Air Interface

The return loss can be calculated from the ratio between the reflected electric field and incident electric field as shown in (1):

$$S_{11} = \frac{E_{tot}(f) - E_{inc}(f)}{E_{inc}(f)}. \tag{1}$$

To obtain the incident electric field, the feed line was emulated as it has infinite length. To do that, the feed line is forced to inside the UPML until it touches the perfect conductor at the outer boundary of the UPML so the fields impinging upon it are absorbed without any reflection. Figure 1 shows the geometry of a microstrip antenna used for validation defined in the FDTD computational space. Figure 1 (a) shows how total field is calculated and Fig. 1 (b) shows how incident field is calculated. The incident and total field was separated because the excitation is defined in the computational domain setting the fields at a plane between the feed line and the ground plane. This plane of excitation generates a spherical wave instead a plane wave. Separating the calculation of incident and total field remove some of these non-ideal effects. The reflected field is then calculated by subtracting the incident field from the total field as shown in (1).

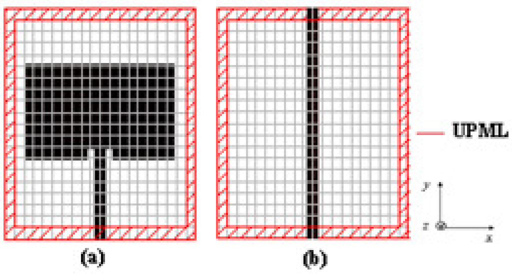

Fig 1. (a) Total field calculation. (b) Incident field calculation.

III. Dey-Mittra Implementation

The FDTD method efficiently simulates antennas with rectangular geometries. However, when a curve or a bent is introduced in the computational space, some modifications in the FDTD equations are mandatory; otherwise to obtain accurate results, a very time-consuming simulation would be required to reduce the staircase error. The Dey-Mittra method modifies the magnetic field at a Yee cell surface to account the length and area of air and metal of the cell surface at the interface air/antenna [5]. This reduces the staircase error since it soften the discontinuity caused by the rectangular grid. The update equations from the Dey-Mittra algorithm for a magnetic flux density B_z is presented in (2):

$$B_{z(i+1/2,j+1/2,k)}^{n+1/2} = B_{z(i+1/2,j+1/2,k)}^{n-1/2} + \frac{\Delta t}{A_{xy(i+1/2,j+1/2,k)}}, \quad (2)$$
$$(E_{x(i+1/2,j,k)}^{n} \cdot l_{x(i+1/2,j,k)} - E_{x(i+1/2,j+1,k)}^{n} \cdot l_{x(i+1/2,j+1,k)} + E_{y(i+1,j+1/2,k)}^{n} \cdot l_{y(i+1,j+1/2,k)} - E_{y(i,j+1/2,k)}^{n} \cdot l_{y(i,j+1/2,k)}),$$

where l_x e l_y are the lengths of the cells borders where the electric fields components E_x e E_y are located and A_{xy} is the external surface area of the cell centered in B_z. The index n represents the discrete time of the simulation, x, y and z are the orthogonal components of the electric field E and magnetic flux density B respectively.

IV. DIELETRIC LOSS IN FR-4

The inclusion of losses in FDTD simulations is, in fact, important to predict the performance of resonant structure in lossy dielectric substrates [6]-[7]. The FR-4, widely used in Printed Circuit Boards (PCI), was used to build antennas since it is cheap and easy to manipulate. However, it presents significant losses at high frequencies with tangent loss as high as $\tan\delta = 0.018$ for permittivity of $\varepsilon_r = 4.3$. There are others dieletrics fiberglass plates like GETEK™ and RT Duroid 5880 that presents respectively $\tan\delta = 0.006$ for $\varepsilon_r = 3.4$ and $\tan\delta = 0.004$ for $\varepsilon_r = 2.2$. It can be noted the FR-4, when just its constitutive parameters are considered, is not the best choice to be used at high frequencies and wideband.

Since the conductivity of FR-4 vary with frequency, the mean conductivity of the analyzed band was used. It can be calculated from its tangent loss as show in (3).

$$\sigma_{m,diel} = 2\pi \cdot f_m \cdot \tan\delta \cdot \varepsilon_r \cdot \varepsilon_0, \quad (3)$$

where f_m is the mean frequency of the band and ε_0 is the vacuum permittivity. It does not accurately predict the FR-4 losses. However, the results are better than if no losses are used in the simulations.

V. RESULTS AND DISCUSSION

Figure 2 presents the return loss comparing the results with CST Microwave Studio®, with Transient Solver, and measurements for antenna presented in Fig. 1. It can be seen that the resonances were well predicted in an ultra wideband.

Figure 3 (left) shows the return loss for an antenna with diagonal borders shown in Fig. 3 (right) which requires Dey-Mittra algorithm for better results. It can be seen the ultra-wideband radiation for this geometry.

These results are considered good since FR-4 is difficult to predict, especially at high frequencies for ultra wideband simulations.

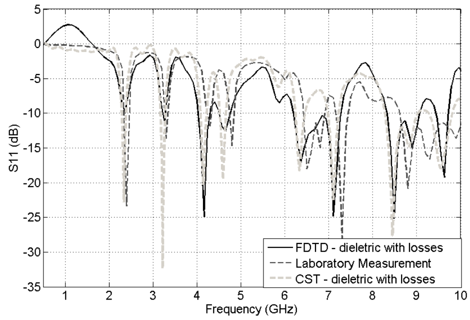

Fig 2. Return loss for antenna presented in Fig.1.

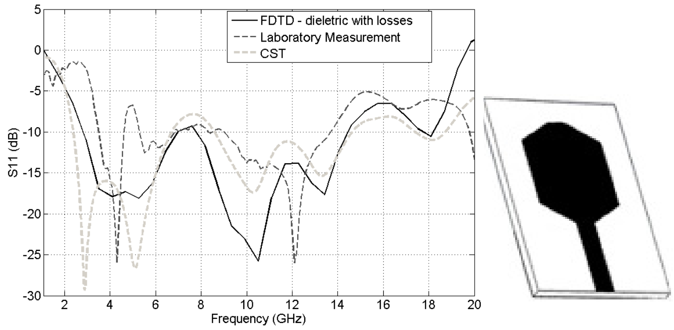

Fig 3. Return Loss (left) and UWB antenna simulated and built (right).

There are others characteristics that can be included as the FR-4 anisotropic and inhomogeneous permittivity and conductive dependency with frequency but this information are not fully available from experimental research or manufactures. This explain the difference between simulations and measurements.

ACKNOWLEDGEMENT

This work was partially supported by CEFET-MG, CNPq, CAPES and FAPEMIG.

REFERENCES

[1] H. Baheti, D. K. Pathak and U. K. Kommuri, “Broadband and High Gain Low Profile (thin) Capacitive-coupled microstrip antennas for wireless applications,” *Annual IEEE India Conference (INDICON).* Mumbai, pp. 1-5, Dec. 2013.

[2] A. A. Qureshi, M. U. Afzal, T. Taqueer and M. A. Tarar, “Performance Analysis of FR-4 Substrate for High Frequency Microstrip Antennas,” *Microwave Conference Proceedings (CJMW).* Hangzhou, pp. 1-4, Apr. 2011.

[3] G. Ngendakumana and N. El Ouazzani, “Laguerre-FDTD (LFDTD) Analysis of the Sinus Microstrip fed-Patch Antenna for Broadband Matching,” *Multimedia Computing and Systems (ICMCS).* Marrakech, pp. 1279-1284, Apr. 2014.

[4] S. Jiang, Z. Lin, Y. Zhang and B. Wei, “Simulation of a Microstrip Array using Parallel FDTD on a Supercomputer with 100K CPU Cores,” *3rd Asia-Pacific Conference on Antennas and Propagation(APCAP).* Harbin, pp. 1024-1026, Jul. 2014.

[5] Dey, S.; Mittra, R., "A locally conformal finite-difference time-domain (FDTD) algorithm for modeling three-dimensional perfectly conducting objects," *Microwave and Guided Wave Letters, IEEE*, vol.7, no.9, pp.273,275, Sep 1997

[6] K. P. Prokopidis, T. D. Tsiboukis, “The Effect of Substrate Dispersion on the Operation of Square Microstrip Antennas,” *IEEE Transactions on Magnetics*. Vol. 42, pp. 603-606, issue 4, Apr. 2006.

[7] D. C. Wittwer and Richard W. Ziolkowski, “The Effect of Dielectric Loss in FDTD Simulations of Microstrip Structures,” *IEEE Transactions on Microwave Theory and Techniques.* Vol. 49, pp. 250-262, Feb. 2001.