Ultra WideBand Matching of the Rectangular Microstrip Patch Antennas (RMPA) Using Microstrip Non Uniform Transmission Lines (MNUTL)

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Abstract

Simulation and modeling configurations of Rectangular Microstrip Patch Antennas (RMPA) are dealt with in this paper. Microstrip Non Uniform Transmission Lines (MNUTL) are used to feed the RMPA leading to ultra-wideband impedance matching. Microstrip linear and sinus tapered characteristic impedance lines and Microstrip uniform lines are both taken to feed the same antenna patch and finally to compare their performances. The analysis is based upon the Finite Difference Time Domain method FDTD combined with the Absorbing Boundary Conditions Perfectly Matched Layers (ABC PML). An RMPA whose resonance frequency is 7.5 GHz is analyzed over a frequency band from 5GHz to 16GHz by calculating the return loss and the input impedance from the time-domain simulated data.

Keywords: *Microstrip Antennas, MNUTL, FDTD-PML technique, Ultra Wideband impedance matching.*

1. Introduction

Microstrip Antennas are widely used thanks to their several advantages that make them suitable for many applications, such as: Telecommunications, Telemetry, Military, and Medicine [1, 10]. The main purpose is to make them compact on a large band of frequencies and to improve the bandwidth. Many techniques can be used, such as: mechanism of parasitic coupling, gap-coupled, directly coupled, etc. As mentioned above, MNUTLs will be investigated in order to achieve this goal [7].

Several numerical methods are available to analyze electromagnetic problems. The FDTD, a full wave method, has been used to solve electromagnetic problems since 1966 [3,6]. As presented first by Berenger [4], the PML technique is suitable to model the unbounded conditions. Hence, the FDTD-PML algorithm can be used to analyze structures under unbounded conditions, including antennas of any shapes, Radar, Bio-electromagnetic problems, etc.

In this paper, the FDTD-PML technique is adopted to analyze several RMPAs. The use of the Fast Fourier Transform FFT is required to treat time-domain simulated data and finally to set the system frequency dependence.

2. FDTD Method

As well known, the FDTD method is adopted to solve Maxwell curl equations by means of discretization of time and space. Easy to implement, the algorithm is that the six vector electromagnetic components located in each cell (Fig. 1) must be updated at each time step [13]. However, as the number of the cells increases, the number of time steps increases also. These equations are:

$$\mathrm{rot}\,\vec{E} = -\mu \frac{\partial}{\partial t}\vec{H} - \sigma_m \vec{H} \qquad (1)$$

$$\mathrm{rot}\,\vec{H} = \varepsilon \frac{\partial}{\partial t}\vec{E} + \sigma_e \vec{E} \qquad (2)$$

where σ_e and σ_m are electromagnetic losses and ε and μ are permitivity and permeability of a dielectric medium. Maxwell equations can be developed according to cartesian coordinates, as follow:

$$\frac{\partial}{\partial y}E_z - \frac{\partial}{\partial z}E_y = -\mu \frac{\partial}{\partial t}H_x - \sigma_m H_x \qquad (3)$$

$$\frac{\partial}{\partial z}E_x - \frac{\partial}{\partial x}E_z = -\mu \frac{\partial}{\partial t}H_y - \sigma_m H_y \qquad (4)$$

$$\frac{\partial}{\partial x}E_y - \frac{\partial}{\partial y}E_x = -\mu \frac{\partial}{\partial t}H_z - \sigma_m H_z \qquad (5)$$

$$\frac{\partial}{\partial y}H_z - \frac{\partial}{\partial z}H_y = \varepsilon \frac{\partial}{\partial t}E_x + \sigma_e E_x \qquad (6)$$

$$\frac{\partial}{\partial z}\mathrm{H_x} - \frac{\partial}{\partial x}\mathrm{H_z} = \varepsilon\frac{\partial}{\partial t}\mathrm{E_y} + \sigma_e \mathrm{E_y} \qquad (7)$$

$$\frac{\partial}{\partial x}\mathrm{H_y} - \frac{\partial}{\partial y}\mathrm{H_x} = \varepsilon\frac{\partial}{\partial t}\mathrm{E_z} + \sigma_e \mathrm{E_z} \qquad (8)$$

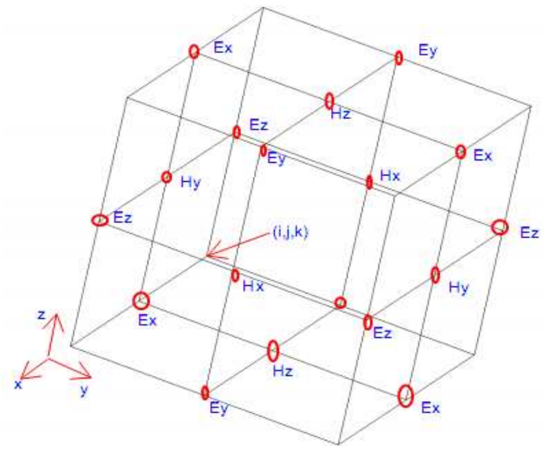

Fig. 1 Cell Yee (proposed in 1966)

The system or the volume under test is seen as a fine number of cells and it must be backed with a PEC (Perfect Electric Conductor) or a PMC (Perfect Magnetic Conductor). The stability and the precision of the FDTD algorithm are given by Courant-Friedrichs-Levy (CFL) stability condition:

$$\Delta t \leq \frac{1}{V\sqrt{\frac{1}{\Delta x^2}+\frac{1}{\Delta y^2}+\frac{1}{\nabla z^2}}} \qquad (9)$$

where Δx, Δy and Δz are the mesh grid and V the wave velocity in the dielectric substrate**.**

3. PML Technique

The system under study is extended in an infinite medium and any machine cannot simulate such a system. So, the solution is to surround the system of interest by ABC. The ABC PML is adopted from others because it is easy to implement and the outgoing waves are attenuated properly.

In the PML technique, the system is divided into three areas: The main area which contains the device under test, the PML area to mitigate the outgoing waves and the PEC or PMC area to back the system (Fig. 2). Regardless to the system dimensions, in the PML area, each component field is split into two sub-components [4].

The variation of the conductivities which is the main parameter of the PML is a function of PML thickness and geometry profile (polynomial and geometric profiles).

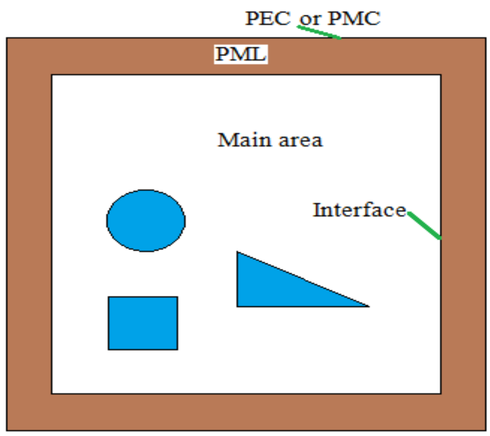

Fig. 2 PML area with clusters in the main area.

For the polynomial profile, the current conductivity variation in the x direction (Eq. 10) and the amount of the waves reflected (Eq. 11) by the external boundaries conditions are given by [16]:

$$\sigma_x = \frac{(\mathrm{pos_x})^m}{\mathrm{dpml}}\sigma_{max} \qquad (10)$$

$$R_0 = \exp\left[-\frac{1}{m+1}\frac{\mathrm{dpml}*\sigma_{max}}{c\varepsilon}\right] \qquad (11)$$

where the parameters m, dpml, $\mathrm{pos_x}$, c, ε and σ_{max} represent the polynomial degree, PML area thickness, current layer thickness , the wave velocity in the vacuum medium, the electromagnetic permittivity and electric conductivity maximum, respectively.

The technique adopted in order to generate the incident wave and to determine the total consists in defining two planes (Source and reference Planes) separated by a minimum distance d (Fig. 7) in line length direction. As given in recent articles [17], the Source Plane is always in the main area between the ground and the conductor strip.

4. Microstrip Non Uniform Transmission Line (MNUTL)

As mentioned above, the main purpose is to feed the RMPA leading to the ultra-wideband impedance matching. To reach this goal, one can use cascaded microstrip uniform lines (Fig. 3) or the MNUTL (Fig.4). By using first technique, many drawbacks rise, such as: bulky system, coupling phenomenon, mismatching between two Microstrip lines, etc. However, the use of the MNUTL appears as the main solutions to overcome some of the drawbacks.

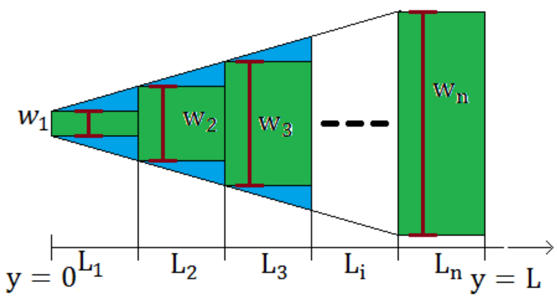

Fig. 3 Example of Cascaded Microstrip Uniform Lines

where L_i and w_i (i=1,2,…,n) are the length and width of the current line.

The MNUTL' properties depend on the tapered function. In the MNUTL [8], the characteristic impedance depends on the tapered functions: sinus, Gaussian, Blackman, Kaiser, Welch, Hanning, Hamming, Cones, Bartlett, etc [15]. Each microstrip tapered line is seen as infinity of uniform line sections cascaded (Fig. 4) and it is easy to calculate the scattering parameters of each section.

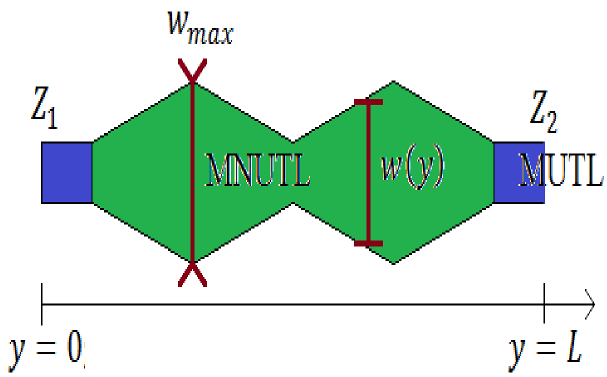

Fig. 4 Microstrip linear tapered Line

where $Z_1$and $Z_2$are the input and output impedance of the microstrip line, respectively.

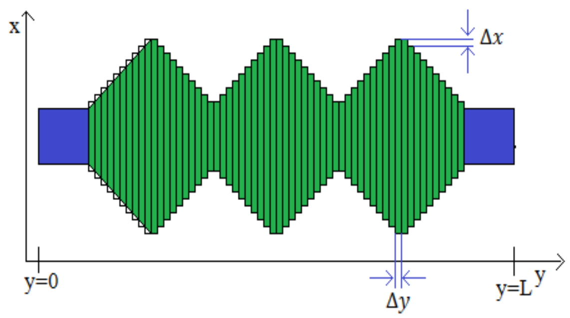

Fig. 5 Microstrip linear tapered line is divided into Microstrip uniform line of length Δy.

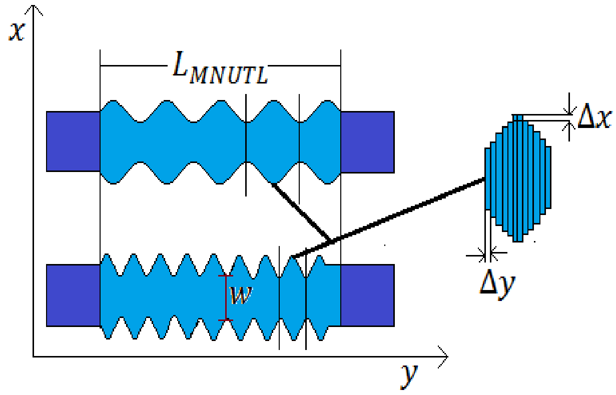

Fig. 6 Microstrip sinus tapered line is divided into microstrip uniform line of length Δy.

Among many methods, the Finite Difference, the Taylor' Series Expansion and the Fourier's Series Expansions are most used to analyze these structures.

In this paper, the FDTD method should been used and the microstrip sinus and linear tapered lines will be analyzed and the results will be compared to those of the uniform line. However, the analysis of the MNUTL by the FDTD-PML technique requires a very small space grid. For example, in the microstrip sinus taper configuration, the bandwidth depends on the induce-modulation and the magnitude value.

5. Configuration of the Rectangular Microstrip Patch Antenna (RMPA)

5.1. RMSA Dimensions

An RMPA consists of a radiating patch on one side of a dielectric substrate and the ground plane on other side. As explained in [14], feeding techniques, such as: coaxial probe, microstrip line, electromagnetic coupling, aperture coupling and coplanar waveguide can be used. In this paper, only the MNUTL and MUTL are used to feed the same patch.

Knowing the resonant frequency f_r, the relative permitivity ε_r of the substrate and the substrate thickness h, we obtain the dimensions of the antenna [18].

$$W = \frac{c}{2f_r\sqrt{\frac{\varepsilon_r+1}{2}}} \tag{12}$$

$$L_{eff} = \frac{c}{2f_r\sqrt{\varepsilon_{eff}}} \tag{13}$$

$$\Delta L = 0.412h \frac{(\varepsilon_{eff}+0.3)}{(\varepsilon_{eff}-0.258)} \frac{\left(\frac{W}{h}+0.264\right)}{\left(\frac{W}{h}+0.8\right)} \quad (14)$$

$$L = L_{eff} - 2\Delta L \quad (15)$$

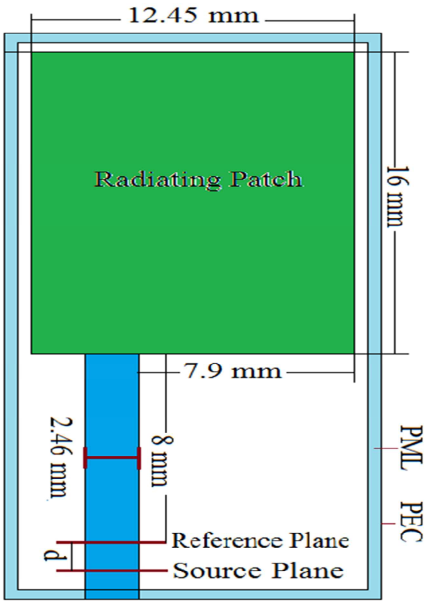

Fig. 7 RMPA Feeded by microstrip uniform line

Instead of microstrip line, we connect a MNUTL between the reference plane and edge. The idea is to modify some of their parameters (such as: MNUTL's length, width's amplitude) in order to achieve the Ultra Wideband Matching.

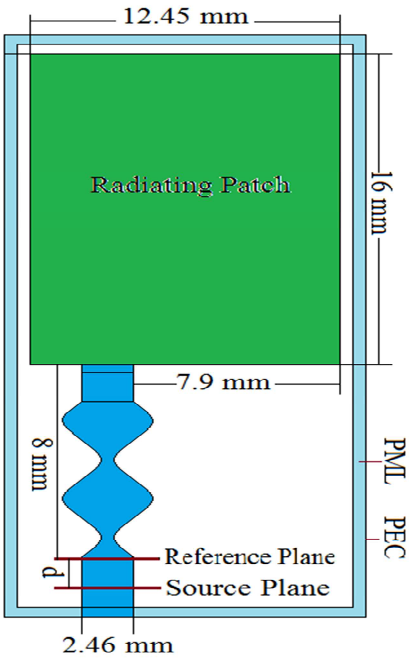

Fig.8 RMPA feeded by Microstrip sinus tapered line

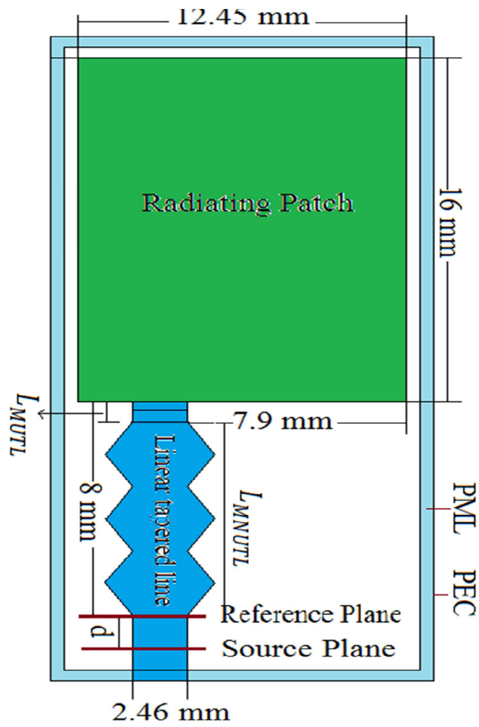

Fig. 9 RMPA feeded by Microstrip linear tapered line

As shown in the figures 4 and 5, the feeding microstrip line is located at the non radiation edge where the input impedance is 50 Ω. In this situation, the impedance matching between the line and the antenna is verified. The reflexion coefficient is low at the resonant frequency.

5.2. Parameters of the antenna

The time-domain simulated data must be handled by means of FFT to have parameters such as: the input impedance of the antenna, the return loss and the directivity of the antenna. Our purpose is to determine the frequency dependence of the reflection coefficient from voltages, currents or electromagnetic field to the reference plane. All calculations rely on the electrical components of the plane wave.

A. Return loss

The microstrip antenna is seen as a simple device with a single port and it can be characterized by its reflection coefficient, which is the ratio between the reflected and the incident waves. The frequency domain expression is obtained only from the FFT of time-domain simulated data:

$$s_{11}(t) = \frac{E_{ztot} - E_{zinc}}{E_{zinc}} \quad (16)$$

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$$S_{11}(f) = \frac{FFT(E_{ztot} - E_{zinc})}{FFT(E_{zinc})} \quad (17)$$

Where E_{ztot} and E_{zinc} represent the total and incident electric fields, respectively.

B. Input impedance

The input impedance is defined as the input impedance of the line down to the input of the antenna given by the famous equation impedance transformer (Eq.18).

$$Z_{ina} = Z_{car} \frac{1 + S_{11} \exp(2j\beta La)}{1 - S_{11} \exp(2j\beta La)} \quad (18)$$

where β, La and Z_{car} represent the wave number, the length of the line (from the reference plane to the antenna) and the characteristic impedance of the Microstrip line (50 Ohms).

The wave number β, as a function of the frequency, is given by:

$$\beta(f) = \frac{2\pi f \sqrt{\varepsilon_{eff}(f)}}{C} \quad \text{(rad/m)} \quad (19)$$

where $\varepsilon_{eff}(f)$ and C represent the actual relative permittivity and the propagation speed in a vacuum respectively.

6. Results and Discussions

The antenna (Fig. 4) has a resonant frequency at 7.5GHz. The incident and total waves are calculated at the reference plane whereas the reflected wave is obtained from the difference between total and incident waves. The excitation plane is located at the area of 3 cells PML and the reference plane is defined to a minimum of 10 cells from the source plane. Other parameters are summarized in the tables below (Table 1&2).

Table 1: space and time steps

Δx	Δy	Δz	Δt
0.4mm	0.4mm	0.265mm	0.44167ps

Table 2: cells and time steps number and the parameters R and m

Time steps	Nx	Ny	Nz	R	m
2500	52	86	14	10^{-4}	3

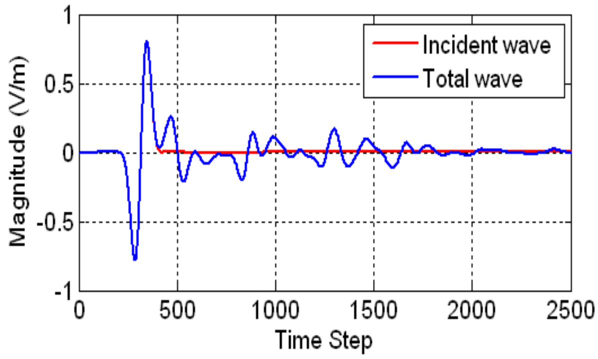


Fig. 10 Time-domain simulated data of the RMPA feeded by microstrip uniform line (E_{zinc} (blue) and E_{ztot} (red))

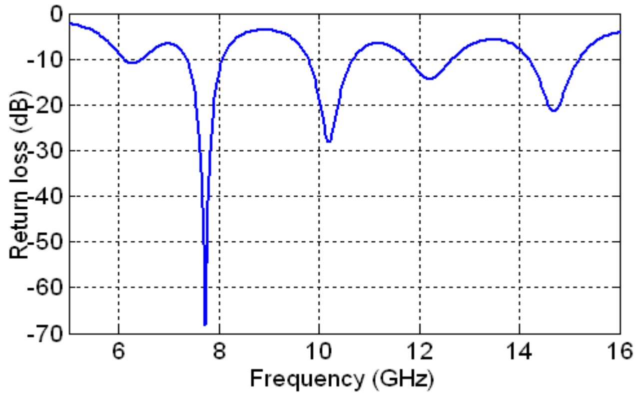
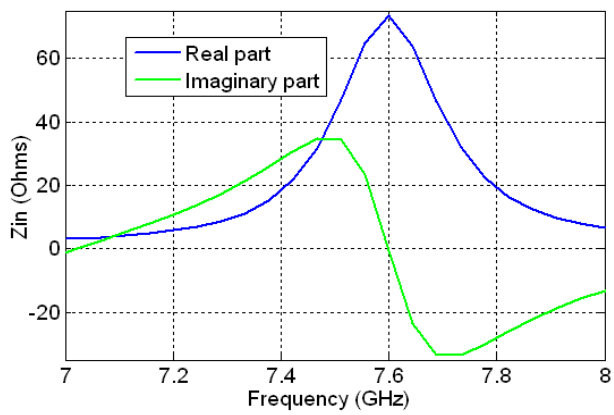


Fig. 11 Return loss vs. frequency of the RMPA feeded by microstrip uniform line

From 5GHz to 16GHz (Fig. 11), we notice more than 4 resonances but some are very matched with narrow bandwidth. As mentioned, the main purpose is both to match the input impedance and to enlarge the bandwidth of the system by means of Non Uniform Transmission Lines.



Frequency (GHz)

Fig. 12 Input impedance of the RMPA feeded by microstrip uniform line

From fig.12, the imaginary value of the input impedance is around zero and the real part in maximum at 7.59GHz frequency resonant.

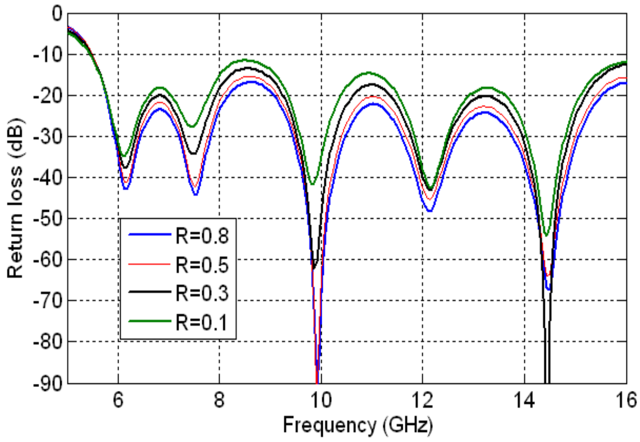


Fig. 13 Return loss vs. frequency of the RMPA feeded by the microstrip linear tapered line

By using the linear tapered line instead of microstrip uniform transmission line (MUTL), the antenna is adapted ranging 5GHz to 16GHz with a good level. For the linear tapered line, the bandwidth and the matching level depend on the ration R (Eq. 20) between the MNUTL's length and MUTL's length.

$$R = \frac{L_{MNUTL}}{L_{MUTL}} \tag{20}$$

So, as the R decreases, the results tend to those of the microstrip uniform line.

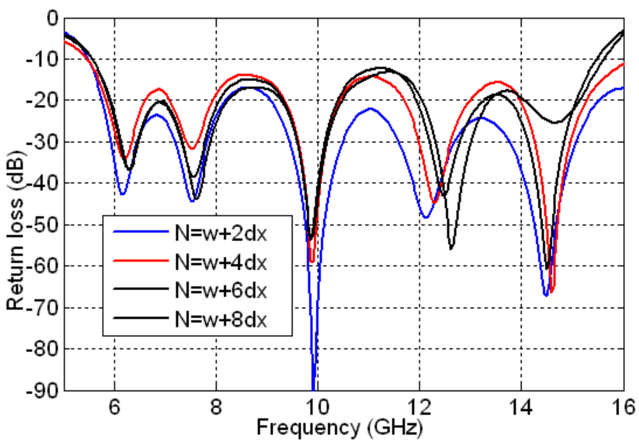


Fig. 14 Return loss vs. frequency of the RMPA feeded by the microstrip sinus tapered line

For the sinus tapered line, the bandwidth depends on the magnitude value N of the ripples (Fig. 14). Here, we notice an ultra-wideband matching ranging from 5.5 GHz to 16 GHz for N=w+8dx (w=2.46 mm).

By comparing the results (fig. 14, 13 and 11), the MNUTL show good results compared to the MUTL. First, the MNUTL offer level of impedance matching less than 16 dB for the Microstrip linear and sinus tapered lines. Secondly, they provide an ultra-wideband bandwidth unlike the microstrip line for which there is a low bandwidth around each resonance frequency.

7. Conclusion

Despite the CFL condition stability, the FDTD-PML technique remains a good tool for analyzing the microstrip patch antennas. Through the results, we can say that the Microstrip non uniform transmission lines are essential in the design of transformers impedances leading to the ultra-wideband matching of the Microstrip rectangular patch antennas. The matching level was found good comparatively to the microstrip uniform line. In this paper, we have dealt with two types: linear and sinus tapered lines. Those structures should be employed to design other microwaves devices, such as: filters, couplers, connectors, etc.

References

[1] Girish Kumar, K. P. Ray, "Broadband Microstrip Antennas", Artech House, Boston . London

[2] Pavel HAZDRA, Miloš MAZÁNEK, Jiří ČERMÁK, "Wideband Rectangular Microstrip Patch Antenna Using L-Probe Feeding System", RADIO-ENGINEERING, VOL. 16, NO. 3, SEPTEMBER 2007

[3] A. Taflove, "Computational Electrodynamics: THE FINITE -DIFFERENCE TIME DOMAIN ", Artech House, Boston. London.

[4] J. P. Bérenger, "A Perfectly Matched Layer for the Absorbing of Electromagnetic Wave", JOURNAL OF COMPUTATIONAL PHYSICS 114, 185-200 (1994).

[5] G. Çakir, L. Sevgi, "Modeling and Simulation of Microstrip Patch Antennas via the FDTD Technique", Kocaeli University, Dogus University, Turkey.

[6] Srikumar Sandeep, "Broadband analysis of microstrip patch antenna using 3D FDTD – UPML", ECEN 5134-Term paper, University of Colorado at Boulder

[7] HAMADE Ali, "SYN'IXÈSE DES CIRCUITS D'ADAPTATTON ET DE FILTRAGE MICRO-ONDES A LIGNES DE TRANSMISSION NON-UNIFORMES", Université de Montréal, Ecole Polytechnique de Montréal.

[8] Mazlina Esa, Nik Noordini Nik Abd Malik, Nadiyatulakmar Abdul Latif, and Jayaseelan Marimuthu, “Performance Investigation of Microstrip Exponential Tapered Line Impedance Transformer Using MathCAD”, Progress In Electromagnetics Research Symposium Proceedings, Moscow, Russia, August 18-21, 2009 1209.

[9] Shao Ying Huang, Yee Hui Lee, “Tapered Dual-Plane Compact Electromagnetic Bandgap Microstrip Filter Structures”, IEEE TRANSACTIONS ON MICROWAVE THEORY AND TECHNIQUES, VOL. 53, NO. 9, SEPTEMBER 2005.

[10] Constantine A. Balanis, “Modern Antenna Handbook”, A JOHN WILEY & SONS, INC., PUBLICATION

[11] Adil Hameed Ahmad and Basim Khalaf Jar’alla, “Design and Simulation of Broadband Rectangular Microstrip Antenna”, Eng.Tech. V0l.26, No1, 2008

[12] Enric Miralles, H´ ector Esteban, Carmen Bachiller, Angel Belenguer and Vicente E. Boria, “Improvement for the Design Equations for Tapered Microstrip-to-Substrate Integrated Waveguide Transitions”, Universidad Polit´ ecnica de Valencia.Camino de Vera, s/n-46022 Valencia (Spain), Universidad de Castilla-La Mancha. Campus Universitario. 16071 Cuenca (Spain).

[13] DENNIS M. SILLIVAN, “Electromagnetic Simulation Using the FDTD Method”, IEEE Press, 445 Hoes Lane, P.O. Box 1331, Piscataway, NJ 08855-1331.

[14] J R James & P S Hall, “Handbook of Microstrip Antennas”, IEEE ELECTROMAGNETIC WAVES SERIES 28

[15] Mohamed Boussalem, “Etude Et Modélisation De Structures De Transmission Non Uniformes Applications A L'adaptation D'impédance Et Au Filtrage”, Institut National Polytechnique De Toulouse, Ecole Supérieure De Communication De Tunis

[16] A. M. Shreim and M. F. Hadi, “INTEGRAL PML ABSORBING BOUNDARY CONDITIONS FOR THE HIGH-ORDER M24 FDTD ALGORITHM”, Progress In Electromagnetics Research, PIER 76, 141–152, 2007.

[17] Antoine BOUQUET, “Caractérisation des Structures Rayonnantes par une méthode de type Galerkin Discontinu associée à une technique de domaines fictifs’’, Université de Nice-Sofia Antipolis.

[18] C.R.BYRAREDDY, N.C.EASWAR REDDY, C.S.SRIDHAR, “COMPACT TRIPLE BAND RECTANGULAR MICROSTRIP ANTENNA FOR WLAN/WIMAX APPLICATIONS”, Bangalore -560004, Tirupathi-517501.

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