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Synthesis of Reconfigurable Conical Antenna for Mobile Communication System

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Abstract: Remarkable equipment development in the field of communication and the growing end user requirement has lifted the need for multi-functional wireless communication devices. Since antenna is the basic part of each wireless communication scheme and multi-functional antennas are looked-for to meet up the requirements of present progress, those be able to sustain compound functions in a particular antenna constituent by sustaining other than one operational frequency . For this reason reconfigurable multiband antennas can be used basically to lessen the amount of antennas needed for projected system application.

The purpose this thesis is to Synthesis of Reconfigurable Multiband Conical Antenna equipped with the competence of fine-tuning to Synthesis a antenna that could work with mobile equipments also. Varactor diodes are used, and the capacitance range from 1 pF to 10 pF are engaged to get Reconfigurability and Matlab software tool is used to carry out the antenna Synthesising.

Keywords: Reconfigurable Conical Antenna, Balun, Matlab.

I. INTRODUCTION

The need of ultrawideband (UWB) antennas with omni-directional coverage is increasing for both military and commercial applications (Wiesbecket. al., 2009; Minin, 2010). The UWB radio technology promises high resolution radar applications, sensor networks with a large number of sensors for industrial or home surveillance as well as high data-rate communication over short range for personal area networks. With a need for antennas with the characteristics of broad bandwidth and small electrical size, conical antenna structures have been a focus of research because of its broad bandwidth and omni-directional radiation pattern (Maloney & Smith, 1993; Sandler & King, 1994; Yu & Li, 2008; Palud et. al., 2008). The bi-conical antenna exhibits a very stable omni-directional radiation pattern in the plane normal to the dipole axis together with an excellent transient response. However, the feeding with a usual coaxial cable requires a balun, which transforms the asymmetric mode of the feed line into a symmetric mode at the feed point. For the coaxial balun the ultra wide bandwidth demands very high precision in the manufacturing process in order to get a good and stable matching especially for the high frequencies. The mono-cone antenna as asymmetric structure does not need any balun for an asymmetric feed line but it needs an infinite ground plane, which in reality can only be approximated. The theory of wide-angle conical antennas has been developed sufficiently to permit calculation of the transfer functions relating source voltage to radiated field and incident field to load voltage over the range of frequencies required in the study of transients. Such calculations were demonstrated in (Harrison & Williams, 1965). Due to their three-dimensional configurations, conical antennas are bulky and difficult to fabricate, integrate, and reconfigure. Moreover, since conventional conical antennas comprise of free-standing metal, they are typically heavy in order to achieve sufficient mechanical stability. Several configurations have been proposed to improve conical antennas' mechanical performance (Ma et. al., 2009; Zhou et. al., 2009, Kliroset. al., 2010a). Resistive loading for conical antennas, which is investigated in (Maloney 1993), does not constitute the optimal solution as it reduces the antennas' efficiency. Recently, investigations have been carried out on configurations that employ a dielectric or magnetic material to cover the conical antenna (Gentili et. al., 2004, Lu, 2007). Dielectric and magnetic coating of the radiating cone, enables making the antenna electrically smaller and more rugged while maintaining a wide band input impedance. In this chapter, we present a Finite Difference Time Domain (FDTD) code in spherical coordinates implemented in MATLAB in order to simulate the performance of dielectric covered conical antennas. MATLAB provides an interactive environment for algorithm development, data post-processing and visualization. The spherical FDTD equations can be found using a modified Yee cell in spherical coordinates (Fusco, 1990). Spherical Beranger's perfectly matched layer (PML) is applied as absorbing boundary condition where a parabolic conductivity profile in the spherical PML-region is used (Beranger, 1996). A unique feature of the PML is that electromagnetic waves of arbitrary incidence, polarization and frequency are matched at the boundary in reflection less manner. Results concerning time evolution of the radiated electromagnetic field, the return loss, input impedance, maximum gain as well as far-field radiation patterns across an extended bandwidth, are presented. A time domain study has also been performed to characterize the antenna's behavior in case an UWB pulse is used. For evaluating waveform distortions caused by the antenna, we examine the degree of similarity between source pulse and received pulse waveforms in several propagation directions. The effect of the dielectric spherical cover on the antenna's performance is investigated. The author mostly worked in MATLAB version 7.4 and the related sample codes are provided in the Appendix.

II. CONICAL ANTENNA SYNTHESIS

In this section, we present the Synthesis of a conical antenna covered by a dielectric material with hemispherical shape and describe the FDTD algorithm in spherical coordinates for the analysis of the radiation as well as the time-domain characteristics of the antenna. Dielectric coating of the metallic radiating cone enables making the antenna electrically smaller and more rugged while maintaining a wide band input impedance. Moreover, dielectric coating enables the Synthesis of a quasi-planar structure with approximately omni-directional radiation pattern. Therefore, this antenna can beeasily integrated with planar circuits.

III. CONICAL ANTENNA GEOMETRY

The dielectric covered conical antenna is illustrated in Fig. 8 and can be described by two parameters: the half-cone angle (flare angle) θ^0 and (the length of the cone's arm antenna length) ι . The spherical dielectric cover is made of homogeneous material with permittivity $\varepsilon_r\varepsilon_0$ and permeability $\mu_r*\mu_o$, where ε_o and μ_o are the permittivity and permeability of free space, respectively. The addition of the dielectric cover provides mechanical support to conical radiator and enables physical size reduction of the antenna. The bottom side of the dielectric is coated by metal and behaves as the ground plane. The metallic cone and the ground plane jointly form a mono-cone radiator. The antenna is fed by a coaxial connector, with its outer and inner conductors connected to the ground plane and the cone tip respectively. The radiation mechanism of this dielectric covered antenna is similar to the conventional mono-conical antenna. Since the feed is located at the center of a revolutionarily symmetric structure, spherical transverse electromagnetic (TEM) wave is launched in the dielectric material. When the TEM wave hits the end of the cone, it is reflected and scattered. The reflection and scattering attenuate as frequency increases and therefore, the antenna approaches a semi-infinitely long transmission line for high frequencies. Compared to conventional mono-conical antennas, the addition of the dielectric cover introduces some complications (Lu et. al., 2007):

a. The wavelength within the dielectric material is shorter than that in the air and as a result, the electrical length of the antenna increases. This affects the UWB performance of the antenna.
b. The dielectric-air interface results in more reflection and scattering of the outgoing TEM wave, making the antenna less matched to free space.
c. The dielectric material forms a cavity that stores energy, hence would reduce the antenna's bandwidth.
d. The conductivity of the dielectric cover would reduce the antenna's efficiency and low dielectric loss should be another criterion for the antenna's cover. Consequently, it is not easy to predict the effect of the dielectric cover on the performance of the conical antenna for UWB applications.

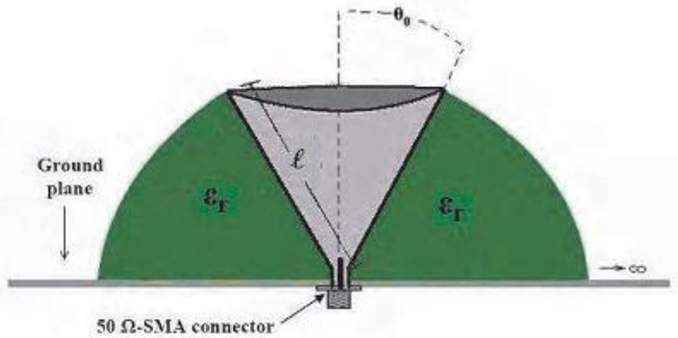

Figure 1: Geometry of the dielectric covered conical antenna.

3.1 FDTD Method in spherical coordinates

FDTD method is very suitable for analysing and optimizing the antenna for UWB radio technology. The method becomes one of the attractive methods due to its programming simplicity and flexibility in analyzing wide range of electromagnetic structures. Cartesian grid FDTD technique utilizes a cubic prism as a unit cell. Thus, it may produce significant errors when modeling perfect electric conductors with curved surfaces and edges because of the staircase approximation introduced in the process. In this section, the FDTD algorithm in spherical coordinates is described following the lines of (Liu & Grimes, 1999; Brocato, 2004). The Maxwell's equations in finite difference form, the suitable absorbing boundary conditions and the input voltage source model are presented.

3.2 Absorbing Boundary Conditions (ABC) treatment

In order to study antenna matching and pulse fidelity in the time domain, any spurious reflections had to be eliminated using suitable absorbing boundary conditions (ABC). Because we treat the problem using spherical coordinates, the absorbing boundary layer should be spherically symmetric as shown in Fig. 9. The purpose of the PML is to simulate an infinite simulation space, that is, outgoing waves are absorbed by the PML and cannot reflect back into simulation space. A unique feature of the PML is that plane waves of arbitrary incidence, polarization and frequency are matched at the boundary in a reflection- less manner. The boundary of the computational space must be sufficiently far from the antenna, usually in a distance at least ten times the free space operating wavelength.

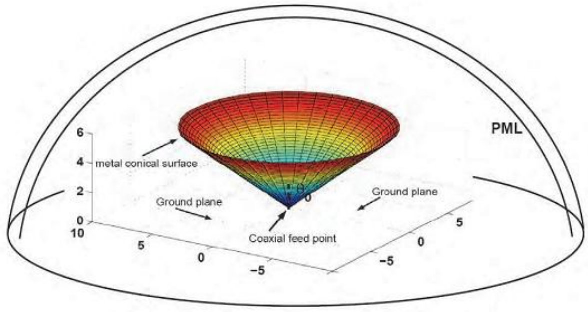

Figure 2: Spherical perfectly matched layer at the edge of the simulation space

3.3 Antenna characteristics

There are general factors determining the antenna performance for UWB applications (Stuzman & Thiele, 1997). Those are input matching representedby the input impedance, Voltage Standing Wave Ratio (VSWR) and Return Loss, frequency dependence of the maximum gain, radiation pattern determining the available beam angle for distortionless wave received from the transmitter, as well as, waveform fidelity which describes the distortion of radiated impulses. All the necessary frequency domain parameters can be calculated from the time domain parameters using a Fast Fourier Transformation code in MATLAB.

The input impedance of the antenna Zinis calculated in the center of feeding line over a range of frequencies. It is determined from the ratio of the Fourier transform of the voltage wave and that of the input current wave

$$Z_{in}(f) = \frac{V_{in}(f)}{I_{in}(f)} \exp(-j\pi f \Delta t)$$

……………………………………………………………..……(1)

where the exponential term accounts for the half-time step difference between the electric and magnetic field computation.

IV. SIMULATION OF THE CONICAL ANTENNA CHARACTERISTICS

Parametric studies concerning both time domain and frequency domain characteristics of the dielectric covered conical antenna were performed using the above described sphericalcoordinate FDTD algorithm implemented in MATLAB. A flowchart of the FDTD algorithm is given in Fig.10.

The FDTD cell dimensions are Δr=3 mm and $\Delta\theta$=1^o. The antenna sits on top of a perfectly conducting ground plane that extends 360^o
in all directions for a distance of $R_m=10\iota$. Just before the maximum radial distance R_m is reached, the simulation space is terminated by a PML section of thickness 20Δr.The maximum reflection coefficient at normal incidence is chosen to be $R(0) = 10^{-14}$. The time step is taken Δt=0.2 psec, sufficient to satisfy Courant's criterion. An UWB Gaussian pulse (FWHM = 64 psec) modulated by a continuous sine wave carrier of frequency fcis used in our simulations, that is,

$$V_s(t) = V_m \exp\left(-\frac{(t-t_0)^2}{t_d^2}\right) \sin\left(2\pi f_c (t-t_0)\right)$$

where τ = 64psec,$t_o = 4*\tau$, 6.5GH and V_m = 0.1V,

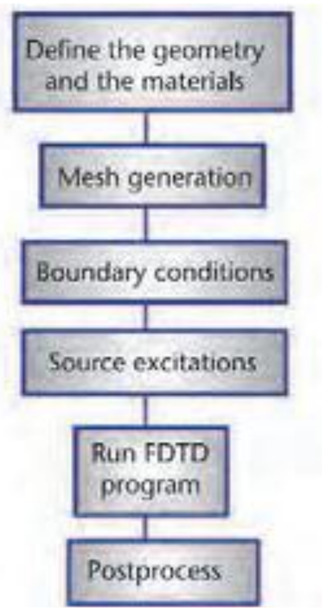

Figure 3: Flowchart of the FDTD algorithm.

To verify the FDTD steady-state calculations, time-domain fields are transformed to the frequency domain by a Fast Fourier Transform routine. The MATLAB code was run for a wide range of different antenna's parameters combinations in an effort to find the antenna with the best match to a 50 ΩSMA-connector. FDTD has the ability to get the frequency response in one run. Accurate simulations require 2^{14}= 16384 time steps to achieve a complete decay of the fields in the structure. The code was run on a computer equipped with an AMD Athlon 64X2 Dual Core Processor at 1.9 GHz and 2 GB of RAM memory and the computing time required to obtain a result, for specific antenna's parameters, is less than 3.5 minutes.

In the following sub-sections, we present both time-domain and frequency-domain results for a spherically dielectric covered antenna with arm's length ι =45 mm (~njc=c0/fc), for different loading dielectrics εrand different flare angles θ0. In all simulations the antenna is a small cone made of copper with conductivity of 5.8×10^7mhos/m place at the center of the simulation space. The simulations were performed in spherical coordinates and then remapped to Cartesian coordinates. Finally, the Fourier transforms forward and backward are the operations to switch from frequency domain to time domain, and vice versa.

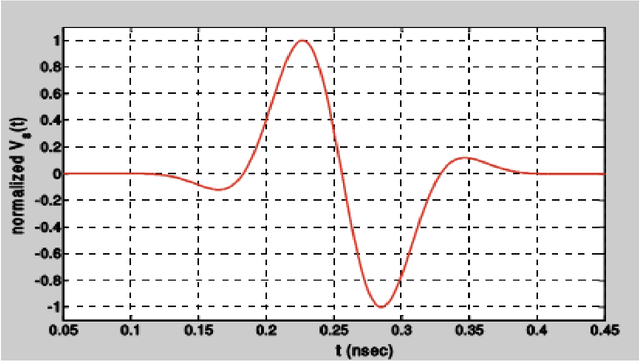

Figure 4 :. Excitation UWB pulse driving the conical antenna

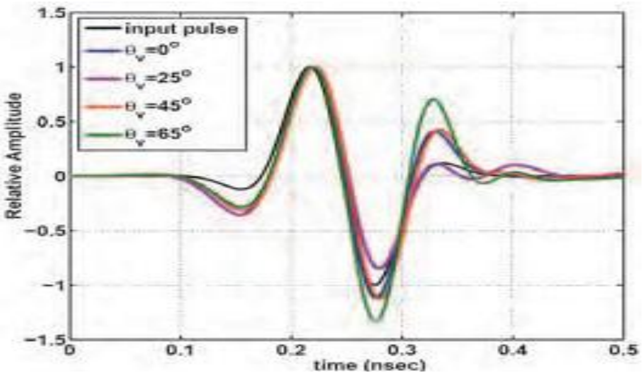

Figure 5: Excitation and radiated pulses versus the elevation angle. It can clearly be seen that the radiated signals are elevation angle dependent.

V. FREQUENCY DOMAIN CHARACTERISTICS

In this subsection, we present our parametric study concerning the impedance, VSWR and maximum gain of the spherically covered conical antenna varying the dielectric constant εr of the cover material or the cone flare angle .As it is seen in Fig.14, the impedance bandwidth (VSWR < 2 or input return loss S11< -10 dB)of the covered antenna, with dielectric of εr=3, increases as the flare angle increases until reaches its maximum at θ^0=47°. As it is expected, the corresponding real part of input impedance (Figure 8) varies with the flare angle. It is observed that an optimum flare angleθ^0=47° exists for 50 Ωmatched impedance in a frequency band from about 5.5 to 17 GHz. Therefore, the Synthesised antenna can provide more than 100% impedance bandwidth**.**

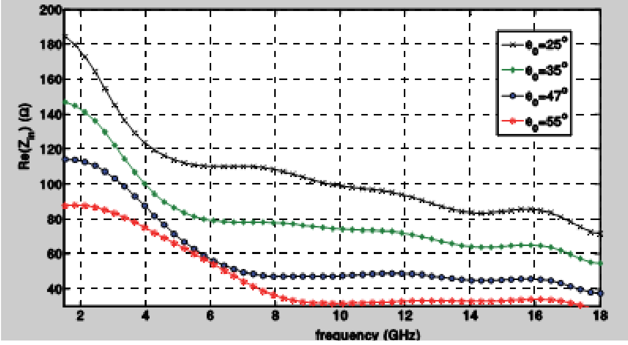

Figure 6: Input impedance for various flare angles and εr=3.0.

Fig.15 shows the evolution of maximum gain in the elevation plane (E-plane) versus frequency. Gain gradually increases with frequency from 10 dBi to about 14 dBi in the frequency range from 5.5 to 8.5 GHz and remains almost frequency independent at 14 dBi in the frequency range from 8.5 to 17 GHz. Furthermore, the power radiation patterns in the elevation plane are calculated in the above frequency range, although for brevity, only the patterns at 4.5, 6.5, 8 and 10 GHz are shown in Fig.17. Obviously, the power radiation patterns present quasi-perfect omni-directional (monopole-like) behaviour but gradually degrade with increasing frequency. The radiation lobe enlarges downwards up to 6.5 GHz, and above 10 GHz a 'null' appears near $\theta=35^o$while the beamwidth decreases slowly with frequency. These variations are attributed to the fact that the antenna's electrical size increase with frequency. It is also observed that the radiation patterns are slightly upward looking. This feature could be useful for radar sensor network applications.

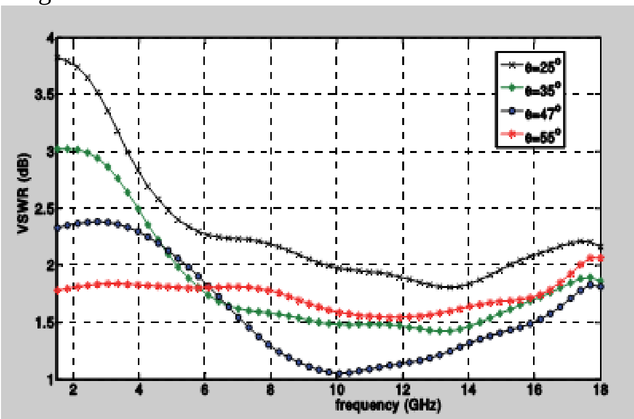

Figure 7: Simulated VSWR for various flare angles and εr=3.0.

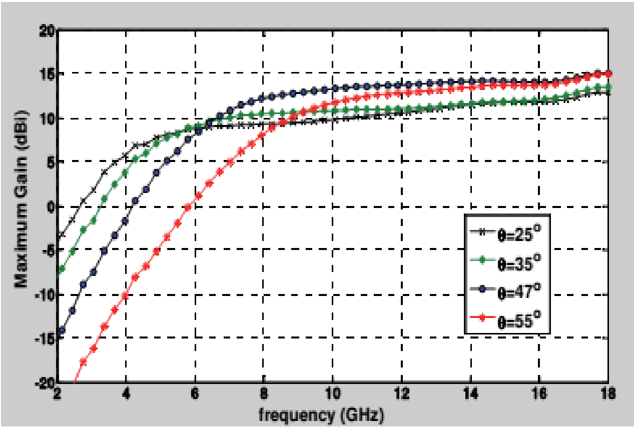

Figure 8: Maximum gain for various flare angles and εr=3.0.

The influence of the dielectric cover on the frequency domain characteristics of the Synthesised antenna are investigated next. For a conical antenna with fixed flare angle $\theta=47^o$, five materials of increasing dielectric constants εr= 1, 2.2, 3, 4.4 and 9.8 have been considered.

As it is seen in Figs.18 and 19, the ultra wide-band characteristics of the antenna are not sensitive to the variation of dielectric constant εr. Some ripples appeared in both real part of impedance and VSWR are smoothed out when the dielectric cover is present. As it is seen, when εris reasonably small, the antenna's input impedance remains close to a constant (~50 Ω) within a wide frequency band. However, because of the dielectric-air interface, the reflection and scattering at the end of the conical radiator is stronger making the antenna less matched to free space. Consequently, a wide range of dielectric materials can be used to construct the spherical cover of the antenna.

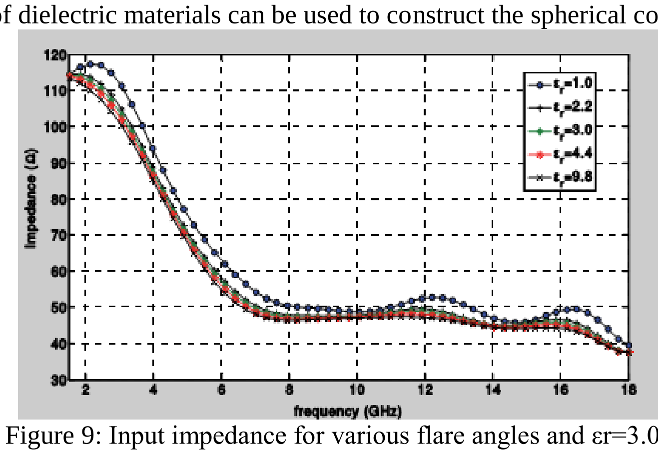

Figure 9: Input impedance for various flare angles and εr=3.0.

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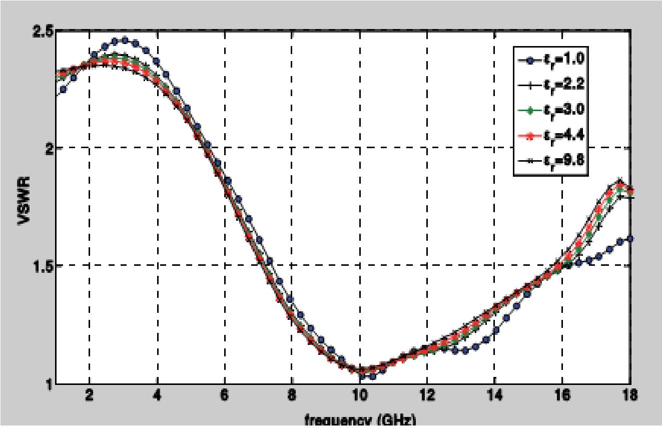

Figure 10: Simulated VSWR for various flare angles and εr=3.0.

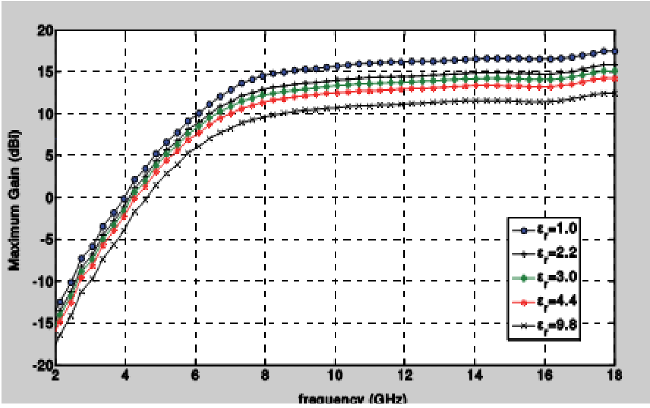

Figure 11: Maximum gain for various flare angles and εr=3.0

VII. CONCLUSION

In this Chapter, we present a FDTD code in spherical coordinates implemented in MATLAB in order to simulate the radiation characteristics of conical antennas. MATLAB provides an interactive environment for algorithm development, data post-processing and visualization. The spherical FDTD equations can be found using a modified Yee cell in spherical coordinates. Spherical Berenger's perfectly matched layer (PML) is applied as absorbing boundary condition where a parabolic conductivity profile in the spherical PML-region is used. The code is used to Synthesis and simulate a conical antenna covered by a spherical dielectric structure and placed above a large ground plane.

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