IOSR Journal of Electronics and Communication Engineering (IOSR-JECE)
e-ISSN: 2278-2834,p- ISSN: 2278-8735.Volume 9, Issue 6, Ver. I (Nov - Dec. 2014), PP 49-58
www.iosrjournals.org

Analysis of the Far field pattern of Ungrounded Embedded Dipole in different dielectric slabs

G.Anjaneyulu[1], Dr.G.S.N.Raju[2]
[1] *Associate Professor, Department of ECE, MVGR College of Engineering, Vizianagaram*
[2] *Professor in Department of ECE, Andhra University, Visakhapatnam*

Abstract: *The characteristics of dipoles in free space are reported by many researchers. However such characteristics are not considered by many. The data on Far-field patterns of embedded dipoles is generated in the present work. The dipoles are considered to be embedded in different dielectrics, and also they are unique.*

I. Introduction

Antenna is a source as well as a sensor of microwaves. An antenna is basically a transducer. It converts RF electrical current into an electromagnetic wave of same frequency[1].Embedded antenna is a printed type of antenna consisting of a dielectric substrate with dielectric strength ε_r and permeability μ_r (usually μ_r=1) where sandwiched in between a ground plane and metallic dipole.

The embedded antenna is physically very simple and flat, these are two of the reasons for the great interest in this type of antenna. These antennas have several advantages compared to other bulky type of antennas [2]. The main advantages of embedded antennas are that it has low fabrication cost, its light weight, low volume, and low profile configurations that it can be made conformal. It can be easily be mounted on aeroplanes, rockets, missiles and satellites. It does not give rise to aerodynamic drag when used in aircraft. In this case the dipole antenna is embedded in a dielectric slab, the lower conductor is called ground plane [3]. These antennas are commonly used at frequency from UHF to microwave frequency.

The first step in designing embedded antenna is to choose the suitable substrate. There are various types of substrates available in market that provides considerable flexibility in the choice of a substrate for particular applications.

In most cases, consideration in substrate characteristics involved the dielectric constant and frequency. In order to provide support and protection for the dipole, the dielectric substrate must be strong and able to endure high temperature during soldering process and has high resistant towards chemicals that are used in fabrication process.

The substrate thickness and permittivity determine the electrical characteristics of the antenna. Thicker substrate will increase the band width but it will cause the surface waves to propagate and spurious coupling will happen. This problem however, can be reduced or avoided by using a suitably low permittivity substrate.

In this paper loss tangent or loss angle of different dielectric materials are calculated and presented. Although a line of demarcation between good conductors and lossy dielectrics is not easy to make, tanθ or θ may be used to determine how lossy a medium is [12],[14].

A medium is said to be a good (lossless or perfect) dielectric if tan θis very small ($\sigma \ll \omega\varepsilon$) or a good conductor if tan θ is very large ($\sigma \gg \omega\varepsilon$). From the view point of wave propagation, the characteristic behavior of a medium depends not only on its constitutive parameters σ, ε and μ but also on the frequency of operation.

A medium that is regarded as a good conductor at low frequencies may be a good dielectric at high frequencies [4]. The polarization of an antenna in a given direction from the antenna is the polarization of the wave transmitted by the antenna. The polarization in a given direction is that of the local plane wave at points on a radiation sphere centered on the antenna. Thus, polarization is that of what the wave is radiated when the antenna is transmitting. Most antennas are reciprocal, and the transmitting and receiving polarization properties are identical.

There are three most common antenna polarization are linear polarization, elliptical polarization and circular polarization. The polarization of embedded dipole in a dielectric slab is vertically linear.. Radiation of the antenna is mostly resulted from the fringing fields along the open circuited edges of the dipole. This fringing fields can be resolved into two components; vertical and tangential components with the respect to the ground plane. The tangential components, which are horizontal to the ground plane, are in phase and the resulting fields give the maximum radiated field vertical to the surface as well as structure.

In the present paper horizontal and vertical dipole antenna embedded in a dielectric slab with no ground plane is considered. The radiation characteristics of dipole antenna depend on dielectric material characteristics as well as dielectric slab thickness [5-8]. The purpose of this work is to determine far field radiation.

II. Analysis

Now consider a case of embedded horizontal and vertical dipole in a dielectric slab with no ground plane, designated as dipole 'A' embedded in a dielectric slab as shown in figure1. The radiation field of diploe 'A' is to be found. Since the field of dipole is unique every where, according to the reciprocity theorem of Carson [5] [9] using a second dipole 'B' but completely arbitrary (both in magnitude and direction)source, and the field of this source is to find the field of dipole 'A'.

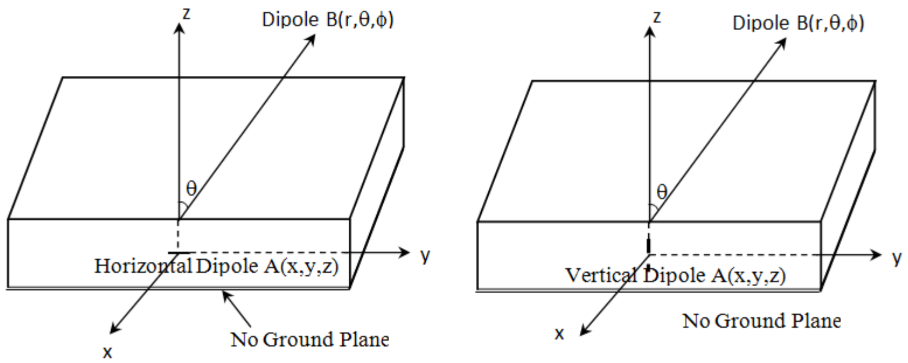


Fig.1- Coordinates of dipole 'A' and ' B'.

Suppose dipole 'B' has been chosen as the second source the r, θ and ϕ components of the electric field of dipole 'A' can be found first by orienting ' B' in the r, θ and ϕ directions respectively and then applying reciprocity theorem each case. It is found that

$$E_{rA} = \frac{l_A I_A}{l_B I_B} \hat{l}_A . E_B^r \tag{1}$$

$$E_{\theta A} = \frac{l_A I_A}{l_B I_B} \hat{l}_A . E_B^\theta \tag{2}$$

$$E_{\phi A} = \frac{l_A I_A}{l_B I_B} \hat{l}_A . E_B^\phi \tag{3}$$

Where E_B^r, E_B^θ and E_B^ϕ are the electric field vectors of r, θ and ϕ oriented dipole 'B' evaluated at dipole 'A' (x, y, z).

$E_{rA}, E_{\theta A}, E_{\phi A}$ is the r, θ and ϕ components respectively of E_a , the electric field of dipole 'A' (x, y, z) evaluated at dipole 'B' (r,θ,ϕ).

Equations (1 -3) are a general expression for the electric field E_A radiated by dipole 'A' as function of position (r, θ, ϕ) where dipole 'B' is located. According geometry show in the figure 1, the far field of E_A are only θ *and* ϕ component. Therefore the incident field generated by dipole 'B' can be approximated as a plane wave near the origin when ϕ oriented corresponds to a plane wave with perpendicular polarization, and that generated by dipole 'B' when θ oriented to a plane wave with horizontal polarization.

1.1 Vertical dipole embedded in a dielectric slab with no ground plane

As shown in fig 2 θ oriented dipole 'B' is generated uniform plane wave at a distance 'r' from the origin incident on a plane dielectric slab in the YZ plane. Since the plane wave is with horizontal polarization the field in the slab is given by

$$E_B^\theta = E_{Bx}^\theta \hat{a}_x + E_{By}^\theta \hat{a}_y + E_{Bz}^\theta \hat{a}_z \tag{4}$$

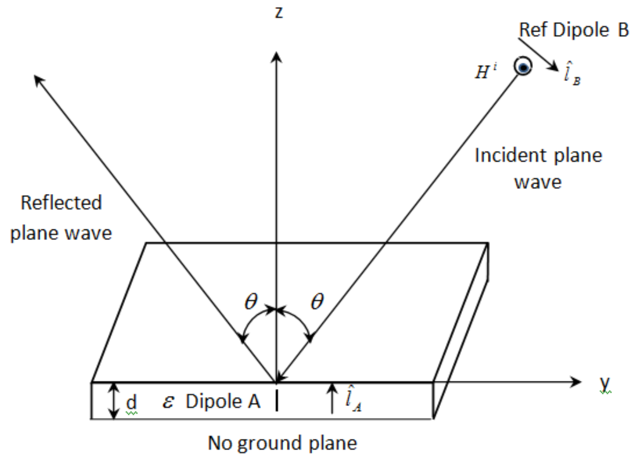


Fig. 2-Uniform plane wave incident on a plane dielectric slab with vertical polarization.

When no ground plane is presented at z= - d, the field in the slab is given by

$$E_{Bx}^{\theta} = 0 \tag{5}$$

$$E_{By}^{\theta} = \frac{\beta N H_0^i}{\omega\varepsilon}\left(Pe^{j\beta Nz} - Qe^{-j\beta Nz}\right)e^{j\beta y\sin\theta} \tag{6}$$

$$E_{Bz}^{\theta} = -\frac{\beta\sin\theta\, H_0^i}{\omega\varepsilon}\left(Pe^{j\beta Nz} + Qe^{-j\beta Nz}\right)e^{j\beta y\sin\theta} \tag{7}$$

Where H_0^i is the magnetic field intensity of dipole 'B' (r, θ, ϕ) evaluated at the origin.

$$H_0^i = j\beta l_B i_B \frac{e^{-j\beta r}}{4\pi r} \tag{8}$$

$$P = \frac{1+\rho_p}{1-{\rho_p}^2\, e^{-j2\beta Nd}} \tag{9}$$

$$Q = \frac{-\rho_p(1+\rho_p)e^{-j2\beta Nd}}{1-{\rho_p}^2 e^{-j2\beta Nd}} \tag{10}$$

ρ_p = boundary reflection coefficient with horizontal polarization

$$= \frac{\varepsilon_r\cos\theta - N}{\varepsilon_r\cos\theta + N} \tag{11}$$

$$N = \sqrt{\varepsilon_r - \sin^2\theta} \tag{12}$$

From above analysis the radiation pattern of a vertical dipole in a dielectric slab is given by

$$E_{\phi A} = 0 \tag{13}$$

$$E_{\theta A} = \frac{-j\beta^2\sin\theta\, l_A i_A e^{-j\beta r}}{4\pi\omega\varepsilon_r}\left(Pe^{j\beta Nz} + Qe^{-j\beta Nz}\right)e^{j\beta y\sin\theta} \tag{14}$$

1.2 The radiation pattern of a horizontal dipole embedded in a dielectric Slab with no ground plane

The electric field in the dielectric slab in YZ plane due to plane wave generated by ϕ-oriented dipole ' B' at a great distance 'r' from the origin as shown in fig.3 is given by

$$E_B^{\phi} = E_{Bx}^{\phi}\hat{a}_x + E_{By}^{\phi}\hat{a}_y + E_{Bz}^{\phi}\hat{a}_z \tag{15}$$

where

$$E_{Bx}^{\phi} = -E_0^i\left(Me^{j\beta Nz} + Ne^{-j\beta Nz}\right)e^{j\beta y\sin\theta} \tag{16}$$

$$E_{By}^{\phi} = 0 \tag{17}$$

$$E_{Bz}^{\phi} = 0 \tag{18}$$

Where E_0^i = the electric field intensity of dipole 'B' evaluated at the origin.

$$E_0^i = j\omega\mu_0 l_B i_B \frac{e^{-j\beta r}}{4\pi r} \tag{19}$$

$$M = \frac{1+\rho_\perp}{1-\rho_\perp^{\ 2}\ e^{-j2\beta Nd}} \tag{20}$$

$$D = \frac{-\rho_\perp(1+\rho_\perp)e^{-j2\beta Nd}}{1-\rho_\perp^{\ 2}\ e^{-j2\beta Nd}} \tag{21}$$

$\rho_\perp$ = boundary reflection coefficient with perpendicular polarization.

$$= \frac{\cos\theta - N}{\cos\theta + N} \tag{22}$$

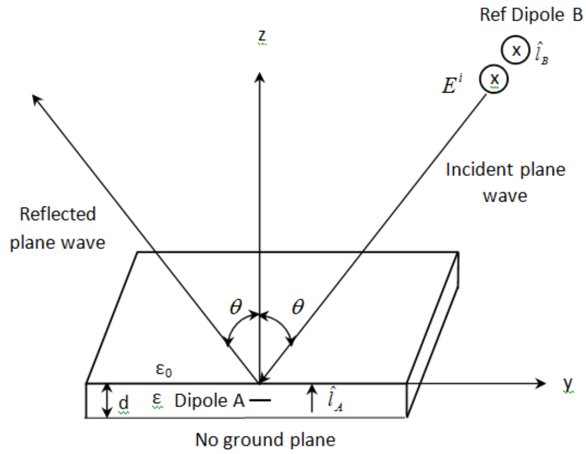


Fig.3-Uniform plane wave incident on a plan dielectric slab with horizontal polarization.

For a horizontal dipole with $\hat{l}_A = \cos\phi_0 \hat{a}_x + \sin\phi_0 \hat{a}_y$ in a dielectric slab with ground plane, the radiation pattern is found to be

$$E_{\phi A} = \frac{-j\omega\mu_0 l_A i_A \cos\phi_0 e^{-j\beta r}}{4\pi r}\left(Me^{j\beta Nz} + Ne^{-j\beta Nz}\right)e^{j\beta y\sin\theta} \tag{23}$$

$$E_{\theta A} = \frac{j\beta^2 N l_A i_A \sin\phi_0 e^{-j\beta r}}{4\pi r\omega\varepsilon}\left(Pe^{j\beta Nz} - Qe^{-j\beta Nz}\right)e^{j\beta y\sin\theta} \tag{24}$$

The general solution for a dipole at (x, y, z) and the field point at (r, θ, ϕ) can be obtained simply by transformation of coordinates due to rotation of x-y plane around the z- axis. This is done simply by replacing $(\phi_0 - \pi/2)$ by $(\phi_0 - \phi)$,or ϕ_0 by $(\phi_0 - \phi) + \pi/2$ and y by $(x\cos\phi + y\sin\phi)$. Again by equations (1), (2) and (3) the radiation patterns of perpendicular and horizontal dipoles are readily found.

Vertical dipole in a dielectric slab with ground plane.

$$E_{\phi A} = 0 \tag{25}$$

$$E_{\theta A} = \frac{-j\beta^2 \sin\theta l_A i_A e^{-j\beta r}}{4\pi r\omega\varepsilon}\left(Pe^{j\beta Nz} + Qe^{-j\beta Nz}\right).e^{j\beta(x\sin\theta\cos\phi + y\sin\theta\sin\phi)} \tag{26}$$

Horizontal dipole with $\hat{l}_A = \cos\phi_0 \hat{a}_x + \sin\phi_0 \hat{a}_y$ in a dielectric slab with ground plane.

$$E_{\phi A} = \sin(\phi_0 - \phi)\frac{j\omega\mu_0 l_A i_A e^{-j\beta r}}{4\pi r}\left(Me^{j\beta Nz} + Ne^{-j\beta Nz}\right).e^{j\beta(x\sin\theta\cos\phi + y\sin\theta\sin\phi)} \tag{27}$$

$$E_{\theta A} = \cos(\phi_0 - \phi)\frac{j\beta^2 N l_A i_A e^{-j\beta r}}{4\pi r\omega\varepsilon}\left(Pe^{j\beta Nz} - Qe^{-j\beta Nz}\right).e^{j\beta(x\sin\theta\cos\phi + y\sin\theta\sin\phi)} \tag{28}$$

III. Formulation & Results

By taking the magnitudes of equations (27) and (28) the following expressions are obtained for the computation of far field pattern and they are listed below for a dipole in a dielectric slab. In these expressions subscript 'A' is suppressed since there is one dipole at –d < z < 0 radiates.

2.1 Dielectric slab with no ground plane

i)Vertical dipole $(E_\phi = 0)$

$$|E_\theta(\theta)| = \frac{K}{2}\frac{\sin\theta(1+\rho_p)}{\varepsilon_r}\frac{\left[(1-\rho_p)^2\cos^2\beta N(d+z) + (1+\rho_p)^2\sin^2\beta N(d+z)\right]^{1/2}}{\left[(1-\rho_p)^2\cos^2\beta Nd + (1+\rho_p)^2\sin^2\beta Nd\right]^{1/2}}$$

(29)

ii)Horizontal dipole

$$|E_\theta(\theta,\phi)| = \frac{K}{2}\frac{N(1+\rho_p)\cos(\phi_0-\phi)}{\varepsilon_r}\frac{\left[(1-\rho_p)^2\cos^2\beta N(z+d) + (1+\rho_p)^2\sin^2\beta N(z+d)\right]^{1/2}}{\left[(1-\rho_p)^2\cos^2\beta Nd + (1+\rho_p)^2\sin^2\beta Nd\right]^{1/2}}$$

(30)

$$|E_\phi(\theta,\phi)| = \frac{K}{2}\sin(\phi_0-\phi).(1+\rho_\perp)\frac{\left[(1-\rho_\perp)^2\cos^2\beta N(z+d) + (1+\rho_\perp)^2\sin^2\beta N(z+d)\right]^{1/2}}{\left[(1-\rho_\perp{}^2)^2\cos^2\beta Nd + (1+\rho_\perp{}^2)^2\sin^2\beta Nd\right]^{1/2}}$$

(31)

Where $K = \dfrac{2\omega\mu_0 l_A i_A}{2\pi r}$.

Based on above formulae the far field patterns of dipole in a dielectric slab for different dielectric slabs and different dielectric slab thickness with no ground plane is considered and graphs are plotted.

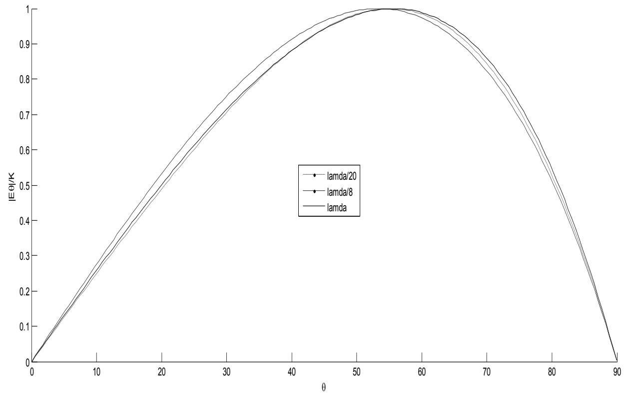


Fig:1 The vertical dipole far field pattern of different dielectric slab thickness d=λ, λ/8, λ/20 ε_r= 9.5 (Alumina)

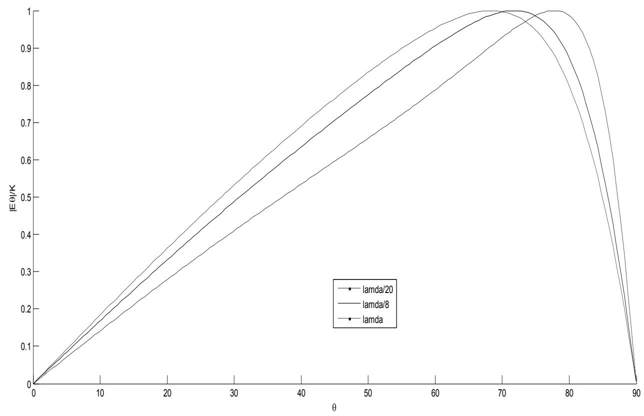


Fig:2 The vertical dipole far field pattern of different dielectric slab thickness d=λ, λ/8, λ/20, ε_r =2.08 (Teflon)

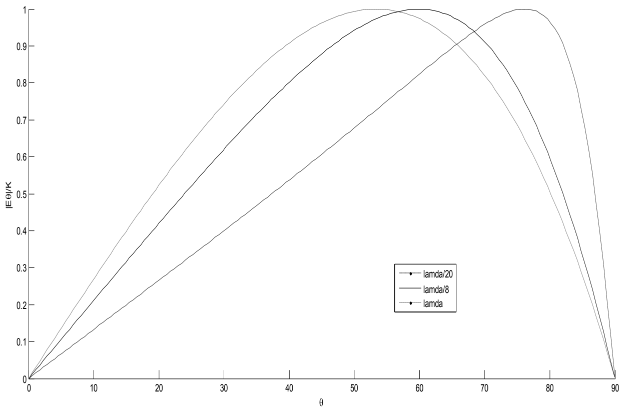


Fig:3 The vertical dipole far field pattern of different dielectric slab thickness d=λ, λ/8, λ/20 ,ε_r=16 (Ferrite)

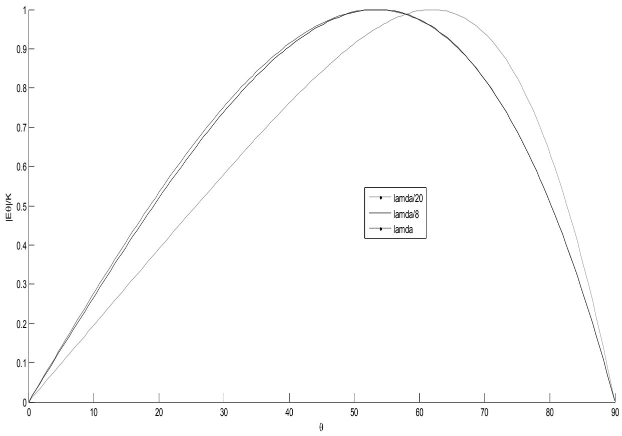


Fig:4 The vertical dipole far field pattern of different dielectric slab thickness d=λ, λ/8, λ/20,ε_r=11.9 (Silicon)

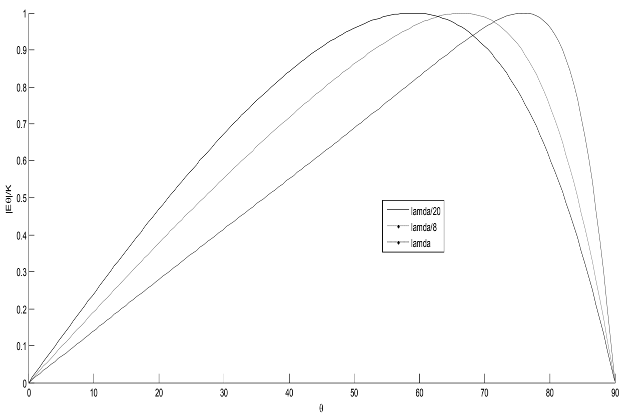


Fig : 5 The vertical dipole far field pattern of different dielectric slab thickness d=λ, λ/8, λ/20 ,ε_r=4.882 (Woven fiber glass)

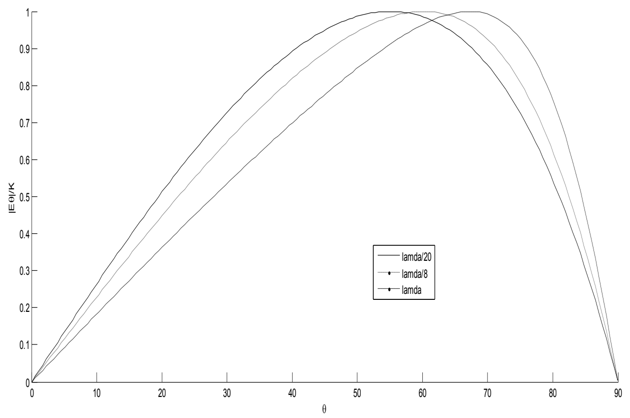


Fig : 7 The vertical dipole far field pattern of different dielectric slab thickness d=λ, λ/8, λ/20,ε_r=6.0 (Duroid)

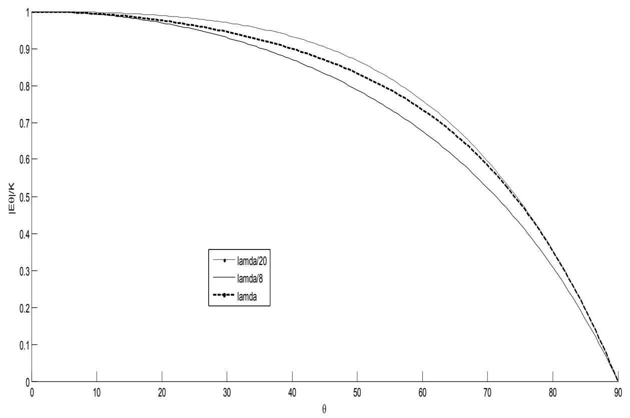


Fig. 8 The horizontal dipole far field pattern of different dielectric slab thickness d=λ, λ/8, λ/20, ε_r=9.5(Alumina)

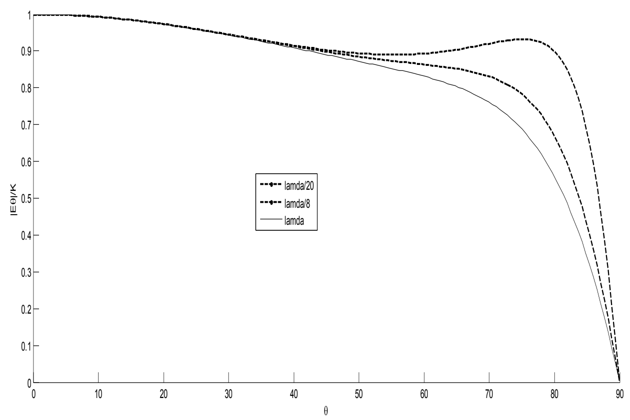


Fig. 9 The horizontal dipole far field pattern of different dielectric slab thickness d=λ, λ/8, λ/20,ε_r=2.08(Teflon)

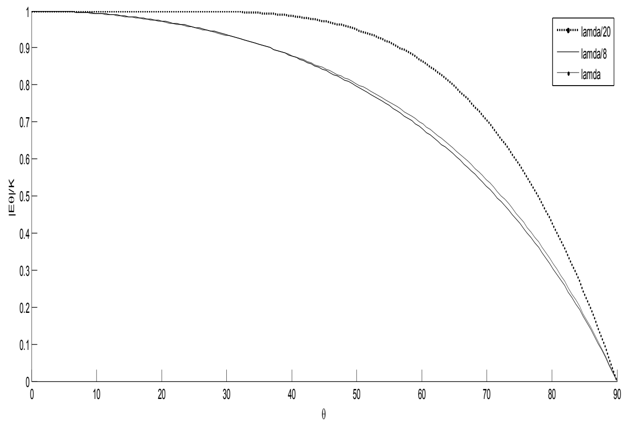


Fig.10 The horizontal dipole far field pattern of different dielectric slab thickness d=λ, λ/8, λ/20,ε_r=10.8 (Duroid)

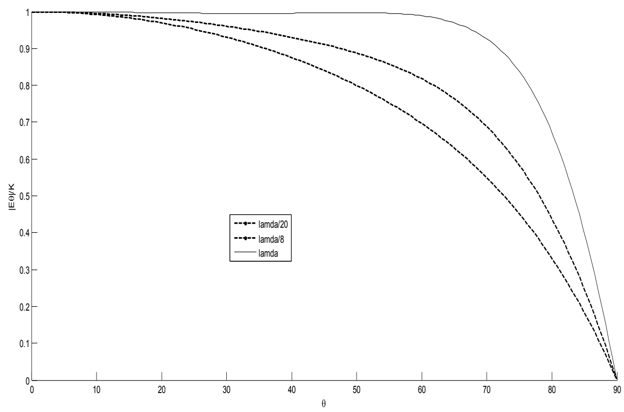


Fig.11 The horizontal dipole far field pattern of different dielectric slab thickness d=λ, λ/8, λ/20,ε_r=6.0 (Duroid)

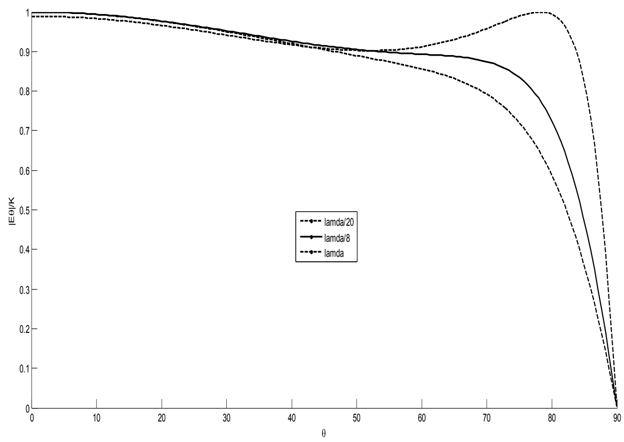


Fig.12 The horizontal dipole far field pattern of different dielectric slab thickness d=λ, λ/8, λ/20.ε_r=2.2 (Duroid)

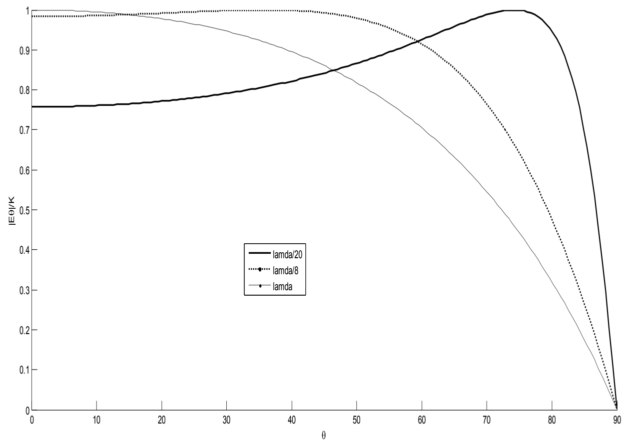


Fig.13 The horizontal dipole far field pattern of different dielectric slab thickness d=λ, λ/8, λ/20 ,ε_r=16 (Ferrite)

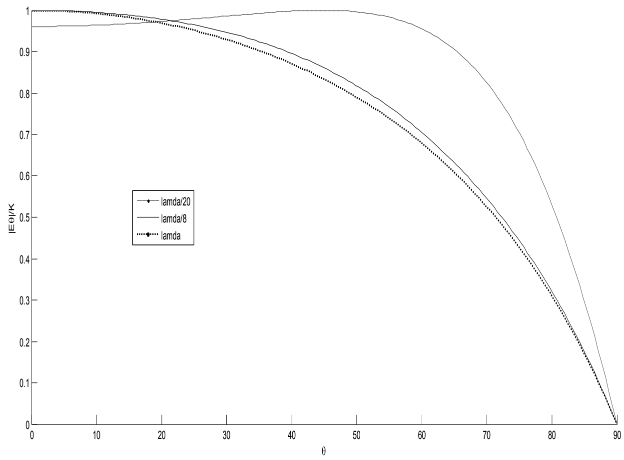


Fig.14 The horizontal dipole far field pattern of different dielectric slab thickness d=λ, λ/8, λ/20,ε_r=11.9 (Silicon)

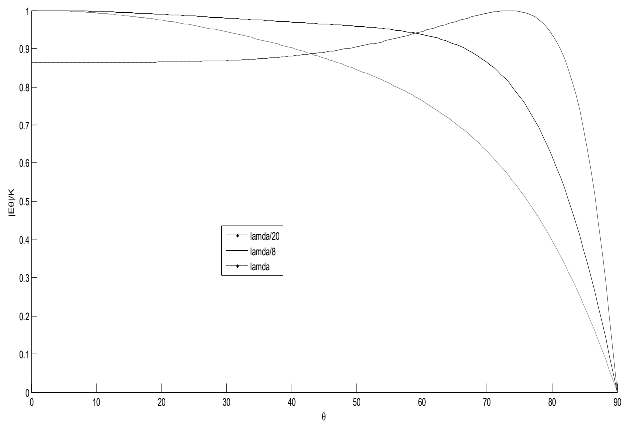


Fig.14 The horizontal dipole far field pattern of different dielectric slab thickness d=λ, λ/8, λ/20,ε_r=4.882 (Woven fiber glass)

IV. Conclusion

It is evident from the results that the phases θ and ϕ are generally not equal. As a result horizontal dipole in a dielectric slab with no ground plane is elliptically polarized and is more advantageous than that of vertical dipole in certain aspects. The far field of a vertical dipole in a dielectric slab has only a θ component, hence it is linearly polarized. Due to the discontinuity of vertical component of E across the boundary the dielectric has a stronger effect on the gain of a vertical dipole than that of horizontal dipole. For six different dielectric materials as well as different values of slab thickness (λ,λ/8,λ/20)are considered in this paper and the far field patterns of vertical and horizontal dipoles in a dielectric slab with no ground plane are generated. Based on the above results i.e. from figures 1 to 14, dielectric constant of dielectric materials between 1 to 9 are suitable for embedded antennas.

References:

[1] G.S.N.Raju "Microwave Engineering" IK International Publishers New Delhi.

[2] Maryam Rahimi, et.al "Miniaturization of Antenna for wireless applications with different Metamaterial structures" PIER Vol.145, 19-28,2014.

[3] Chjin Chung, "The radiation pattern of an array of dipoles in a dielectric slab" Proc. Antennas and Propagation, IEE, vol -12, Issue-4, July 1964.

[4] G.S.N.Raju "Antenna and wave propagation," Pearson Education, Singapore, 2005

[5] J.R.Carson, "Reciprocal theorems in radio communication," PROC.IRE, vol. 17, p. 952-956; June, 1929

[6] G.N.Tsandoulas "Excitation of a Grounded Dielectric slab by Horizontal dipole" IEEE Transactions on Antennas and Propagation, Vol.Ap-17, No.2 March 1969.

[7] E.H.Newman, "Strip antennas in a Dielectric slab" IEEE Transactions on Antennas and Propagation, Vol.Ap-2, No.5 Sep 1978

[8] D.B.Brick, "The radiation of a Hertzian dipole over a coated conductor," Proc. IEE, London, vol. 102, pt. C, p. 104; 1955

[9] R.F.Harrington, "Time Harmonic Electromagnetic Fields" McGraw-Hill Book Co., New York, N.Y., p.117; 1961.

[10] J.D.Kraus, "Antennas," McGraw-Hill Book co., New York, N. Y., p.77; 1950

[11] E.H.Newman, "Strip antennas in a Dielectric slab" IEEE Transactions on Antennas and Propagation, Vol.Ap-2, No.5 Sep 1978

[12] Matthew N.O.Sadiku, "Principles of Electromagnetics"Oxford University press 16th impression New Delhi, 2012.

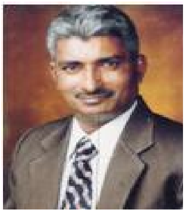
[13] G.S.N.Raju, et.al "Radiation Patterns of arbitrarily oriented radiating elements" proc.EMI/EMC,P.458-465.

[14] G.S.N.Raju, "Electromagnetic field theory and Transmission lines" Pearson Education Singapore, 2008 2nd Edition.

[15] G.S.N.Raju,et,al "The Far-Field Pattern Analysis of Vertical and Horizontal Dipole Embedded in a Dielectric Slab" IJEST Vol-6, Issue-8,Aug 2014.

Author's Information

G.Anjaneyulu did his B.Tech in Electronics and Communication Engineering from Nagarjuna University in 1994. In 2002, he obtained his M.E (Electronic Instrumentation) degree from Andhra University College of Engineering (A). He is having 15 years of teaching experience and presently he is working as an Associate Professor in Department of ECE, MVGR College of Engineering, Vizianagaram. He is also pursuing Ph.D in the Department of ECE, Andhra University College of Engineering (A), Andhra University, Visakhapatnam. He presented many papers in various national and international conferences and journals of repute. His research interests include Applied Electromagnetics, Array Antennas and EMI/EMC. Mr. Anjaneyulu is the life member of IETE,ISTE,SEMCE,ISOI.



Dr. G.S.N. Raju received his B.E., M.E. with distinction and first rank from Andhra University and Ph.D. from IIT, Kharagpur. He is presently Vice-Chancellor, Andhra University Visakhapatnam, India. He is in teaching and research for the last 30 years in Andhra University. He guided 29 Ph.D.s in the fields of Antennas, Electro Magnetics, EMI/EMC and Microwave, Radar Communications, Electronic circuits. Published about 300 technical papers in National/International Journals/Conference Journals and transactions. He is the recipient of The State Best Teacher Award‟ from the Government of Andhra Pradesh in 1999, ‟The Best Researcher Award‟ in 1994, ‟Prof. Aiya Memorial National IETE Award‟ for his best Research guidance in 2008 and Dr. Sarvepalli Radhakrishnan Award for the Best Academician of the year 2007, He was a visiting Professor in the University of Paderborn and also in the University Karlsruhe, Germany in 1994. At present he holds the positions of Vice-Chancellor, Andhra University, Visakhapatnam. He was Chief Editor of National Journal of Electromagnetic Compatibility. Prof. Raju has published five textbooks Antennas and Wave Propagation, Electromagnetic Field Theory and Transmission Lines, Electronics Devices and Circuits, Microwave Engineering, Radar Engineering and Navigational Aids. Prof. Raju has been the best faculty performer in Andhra University with the performance index of 99.37.