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Abstract—- **The circular microstrip antenna element is formed by radiating disk closely spaced above a ground plane. It is modeled as a cylindrical cavity with magnetic walls which can be resonant in the transverse magnetic modes. This circular shape microstrip antenna is analysed using cavity model and fields within the cylindrical cavity, radiation pattern and resonant frequency have been calculated. In this paper the circular microstrip antenna is designed at resonant frequency f_r = 2.5 GHz. A suitable substrate of relative permittivity ε_r = 4.2 and of thickness h = 1.6 mm is used to design the antenna. The simulation of this microstrip antenna is done on IE3D software and matlab. At last the simulation result and practical result of return loss are compared.**

***Keywords-** Circular microstrip antenna; Radiation pattern; Resonant frequencies; IE3D*

I. INTRODUCTION

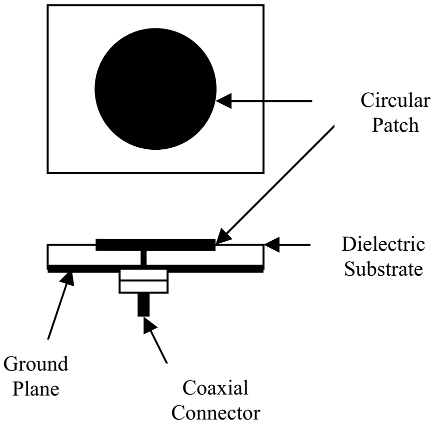

Fig. 1. Probe Fed Circular Microstip Antenna

In the last few years, wireless communication along with its various forms has become a part of everyday life. This dependency on wireless devices made it necessary to find antennas of small size and light weight. All these requirements are met through the use of microstrip antennas [1]. Microstrip antennas are used in communication systems due to simplicity in structure, low manufacturing cost, small size and ease of installations [2][3].

Circular microstrip antenna in its simplest form consists of a sandwich of two parallel conducting layers seprated by a single thin dielectric substrate. The lower conductor function as a ground plane and the upper conductor is a simple circular patch [5].

II. FIELDS WITHIN CYLINDRICAL CAVITY

The modes that are supported by a circular microstrip antenna whose substrate height is small (h« λ)are TM^z where z is taken perpendicular to the circular patch.For TM^z we need to first find the magnetic vector potential A_z,which must satisfy, in cylindrical coordinates, the homogeneous wave equation [2]

$$\nabla^2 A_z(\rho,\phi',z)+k^2 A_z(\rho,\phi',z)=0 \qquad (1)$$

Where ρ,ϕ',z are cylindrical coordinates of a point on the circular disk and $k^2=\omega^2\mu\varepsilon$

For TM^z modes the electric and magnetic fields are related to the vector potential A_z by [2]

$$E_\rho = -j\,\frac{1}{\omega\mu\varepsilon}\,\frac{\partial^2 A_z}{\partial\rho\partial z} \qquad (2)$$

$$E_{\phi'} = -j\,\frac{1}{\omega\mu\varepsilon}\,\frac{1}{\rho}\,\frac{\partial^2 A_z}{\partial\phi'\partial z} \qquad (3)$$

$$E_z = -j\,\frac{1}{\omega\mu\varepsilon}\left(\frac{\partial^2}{\partial z^2}+k^2\right)A_z \qquad (4)$$

$$H_\rho = \frac{1}{\mu}\,\frac{1}{\rho}\,\frac{\partial A_z}{\partial\phi'} \qquad (5)$$

$$H_{\phi'} = -\,\frac{1}{\mu}\,\frac{\partial A_z}{\partial\rho} \qquad (6)$$

$$H_z = 0 \tag{7}$$

Subject to the boundry conditions of

E_ρ (0≤ $\rho \le a$,0≤Φ′≤2л ,z =0) = 0 (8)

E_ρ (0≤ $\rho \le a$,0≤Φ′≤2л , z =h) = 0 (9)

$H_{\phi'}$ ($\rho = a$, 0≤Φ′≤2л , 0≤z≤h) = 0 (10)

Where a is radius of circular patch and '**h**' is thickness of substrate.

The solution of equation (1) is given by

$$A_z = E_{mnp} J_m(k_\rho \rho)[C\cos(m\phi') + D\sin(m\phi')]$$

$$[A\cos(k_z z) + B\sin(k_z z)] \tag{11}$$

Where E_{mnp}, A,B,C and D are constant and $J_m(x)$ is Bessel function of first kind of order m

Using equation (2) and equation (8) we get
C≠0, B=0

Using equation(2) and equation (9) we get

$$k_z h = p\pi \tag{12}$$

Using equation (6) and equation (10) we get
$J'_m(k_\rho a) = 0$ which gives

$$k_\rho a = \chi_{mn} \tag{13}$$

Where χ_{mn} represents the zeroes of the derivative of the Bessel function $J_m(x)$
Now take D= 0 then equation (11) reduces to

$$A_z = E_{mnp} J_m(k_\rho \rho) C\cos(m\phi') A\cos(k_z z) \tag{14}$$

With the constraint equation of

$$k_\rho^2 + k_z^2 = k^2 = \omega^2 \mu\varepsilon \tag{15}$$

Where k is propagation constant, μ is permeability and ε is permittivity of substrate

$$k_\rho = \chi_{mn} / a \tag{16}$$

$$k_z h = \frac{p\pi}{h} \tag{17}$$

m=0,1,2,3 …
n=1,2,3 …
p=0,1,2,3 …

Using equation (14) and equation from (2) to (7) the fields within the cavity for dominant TM_{110} mode can be written as [2]

$$E_\rho = E_{\phi'} = H_z = 0 \tag{18}$$

$$E_z = E_0 J_1(k\rho)\cos\phi' \tag{19}$$

$$H_\rho = -j\frac{E_0}{\omega\mu}\frac{1}{\rho} J_1(k\rho)\sin\phi' \tag{20}$$

$$H_{\phi'} = -j\frac{E_0}{\omega\mu} k J'_1(k\rho)\cos\phi' \tag{21}$$

Where Φ′ is the azimuthal angle along the perimeter of the patch

III. RADIATION PATTERN

The radiation pattern of the circular disk in the upper half space is derived using image theory. At the edge of the disk, the magnetic current density can be written as [2]-[4]-[7]

$$M_S = -2\hat{n} \times \vec{E} \tag{22}$$

Where $\vec{E}$ is the electric field at aperture and $\hat{n}$ is a normal unit vector pointing into the external region.
Using equation (19) and (22) the magnetic current density at the edge $\rho = a$ is given by

$$M_S = \hat{a}_\phi 2E_0 J_1(ka)\cos\phi' \tag{23}$$

Since the height of substrate is very small and the current density is uniform along the z direction,the equation (23) can be approximated by a filamentary magnetic current [2]

$$I_m = hM_S = \hat{a}_\phi 2hE_0 J_1(ka)\cos\phi'$$

Or $I_m = \hat{a}_\phi 2V_0 \cos\phi'$ (24)

Where V_0 is the edge voltage at Φ′= 0^0 and is defined as [2]-[4]-[7]

$$V_0 = hE_0 J_1(ka) \tag{25}$$

The far fields in standard spherical coordinates (r,θ,Φ) may be found from a potential function.
Thus the far fields of circular microstrip antenna excited in TM_{110} mode are calculated as [2]

$$E_r = 0 \tag{26}$$

$$E_\theta = \frac{-jke^{-jkr}}{4\pi r}\left[\eta N_\theta + L_\phi\right] \tag{27}$$

Where η is intrinsic impedance

Since only magnetic current is present so $N_\theta = 0$.

Now transforming cylindrical component of magnetic current I_m into spherical component which gives [4]

$$\left(I_M\right)_\theta = -2V_0 \sin(\phi' - \phi)\cos\phi' \cos\theta \quad (28)$$

$$\left(I_M\right)_\phi = 2V_0 \cos(\phi' - \phi)\cos\phi' \quad (29)$$

Now

$$L_\phi = \int_0^{2\pi} \left(I_M\right)_\phi e^{jka\sin\theta\cos(\phi'-\phi)} a d\phi' \quad (30)$$

Now putting the value of $\left(I_M\right)_\phi$ in equation (30) and solve the integration , we get

$$L_\phi = -2\pi V_0 a\left[J_2\left(ka\sin\theta\right) - J_0\left(ka\sin\theta\right)\right]\cos\phi \quad (31)$$

Putting the value of L_ϕ and N_θ in equation (27)

We get

$$E_\theta = \frac{jkaV_0 e^{-jkr}}{2r}\cos\phi\left[J_2\left(ka\sin\theta\right) - J_0\left(ka\sin\theta\right)\right] \quad (32)$$

Now

$$E_\phi = \frac{jke^{-jkr}}{4\pi r}\left[L_\theta - \eta N_\phi\right] \quad (33)$$

Since only magnetic current is present so

$$N_\phi = 0$$

$$L_\theta = \int_0^{2\pi} \left(I_M\right)_\theta e^{jka\sin\theta\cos(\phi'-\phi)} a d\phi' \quad (34)$$

Now putting the value of $\left(I_M\right)_\theta$ in equation (34) and solve the integration,

we get

$$L_\theta = 2\pi V_0 a \cos\theta \sin\phi\left[J_2\left(ka\sin\theta\right) + J_0\left(ka\sin\theta\right)\right] \quad (35)$$

Putting the value of L_θ and N_ϕ in equation (33)

We get

$$E_\phi = \frac{jkaV_0 e^{-jkr}}{2r}\cos\theta\sin\phi \left[J_2\left(ka\sin\theta\right) + J_0\left(ka\sin\theta\right)\right] \quad (36)$$

Hence the far fields of circular microstrip antenna excited in TM_{110} mode are given by [2]-[4]-[7]

$$E_r = 0$$

$$E_\theta = \frac{jkaV_0 e^{-jkr}}{2r}\cos\phi \left[J_2\left(ka\sin\theta\right) - J_0\left(ka\sin\theta\right)\right]$$

And

$$E_\phi = \frac{jkaV_0 e^{-jkr}}{2r}\cos\theta\sin\phi \left[J_2\left(ka\sin\theta\right) + J_0\left(ka\sin\theta\right)\right] \quad (37)$$

IV. RESONANT FREQUENCIES

The resonant frequencies of microstrip antenna is found using equation (15) to (17). Since for most typical microstrip antennas the substrate height h is very small , the fields along z are essentially constant and are presented by p = 0 which gives $k_z = 0$. Therefore the resonant frequencies for the TM^z_{mn0} can be written using equation (15) as [2]-[6]

$$(f_r)_{mn0} = \frac{1}{2\pi\sqrt{\mu\varepsilon}} \frac{\chi_{mn}}{a} \quad (38)$$

Where χ_{mn} represents the zeroes of the derivative of the Bessel function $J_m(x)$ and a is radius of circular patch

For the circular patch a correction is introduced by using an effective radius a_e to replace the actual radius a given by [2]-[4]-[7]

$$a_e = a\left\{1 + \frac{2h}{\pi a \varepsilon_r}\left[\ln\left(\frac{\pi a}{2h}\right) + 1.7726\right]\right\}^{1/2} \quad (39)$$

Where h is thickness of substrate and ε_r dielectric constant of substrate.

Therefore the resonant frequency for the dominant mode TM^z_{mn0} should be modified and expressed as [2]-[4]-[7]

$$(f_r)_{mn0} = \frac{1}{2\pi\sqrt{\mu\varepsilon}} \frac{\chi_{mn}}{a_e}$$

Or

$$(f_r)_{mn0} = \frac{\chi_{mn}\vartheta_0}{2\pi a_e\sqrt{\varepsilon_r}} \quad (40)$$

Where ϑ_0 is speed of light in free space.

V. DESIGN OF CIRCULAR MICROSTRIP ANTENNA

In order to design a circular microstrip antenna operating at resonant frequency f_r = 2.5 GHz, a suitable dielectric substrate of relative permittivity ε_r= 4.2 and of thickness h=1.6 mm is chosen. Now we uses following two equations to calculate the radius of circular patch [1]-[2]

$$a = F \ \{ 1+ \frac{2h}{\pi F \varepsilon_r} [\ln (\frac{\pi F}{2h}) + 1.7726]\}^{-1/2} \qquad (41)$$

Where

$$F = \frac{8.791 \times 10^9}{f_r \sqrt{\varepsilon_r}} \qquad (42)$$

Remember that in above equations 'h' must be in cm and f_r in Hz . Using above equations the radius is found to be a =17.046 mm at resonant frequency f_r =2.5 GHz

VI. IE3D SIMULATION

The simulation of circular microstrip antenna is done on IE3D software and we get simulation results of return loss , VSWR, polar plot of E- fields and plot of 3D E- fields [8]. Fig. 2. shows the circular microstrip antenna with probe feed at (8mm, 15mm).Fig.3. shows the polar plot of E- fields and plot of 3D- E fields . Fig.4. shows the plot of return loss and VSWR.

VII. MATLAB SIMULATION

The simulation of circular microstrip antenna is also done in matlab. The matlab programs are prepared for return loss and radiation pattern for circular shape microstrip antenna. Fig.5 and Fig.6 shows the matlab simulated result of return loss and radiation pattern of circular microstrip antenna.

VIII. PRACTICAL RESULT

After simulation the circular shape microstrip antenna is fabricated on double sided PCB.Then antenna is tested on spectrum analyzer. On spectrum analyzer we measure the return loss of antenna. After that the measured result and simulation result of return loss are compared.Fig.7 shows the measurement result of return loss. Fig. 8. shows the comparison of measurement and simulated result of return loss.

IX. CONCLUSION

Thus using cavity model for analysis of circular shape microstrip antenna the expressions of fields within cavity, far fields and resonant frequencies are obtained. A probe fed circular microstrip antenna is designed at 2.5 GHz using dielectric substrate of dielectric constant ε_r= 4.2 and thickness h = 1.6mm. At these parameters the radius of circular patch a= 17.046mm.This antenna is simulated on IE3D software and also simulated on matlab. This antenna is tested on spectrum analyzer. From simulation it is found that return loss is equal to – 11.19 dB at resonant frequency 2.5 GHz. From measurement result it is found that return loss is equal to -12.5 dB.

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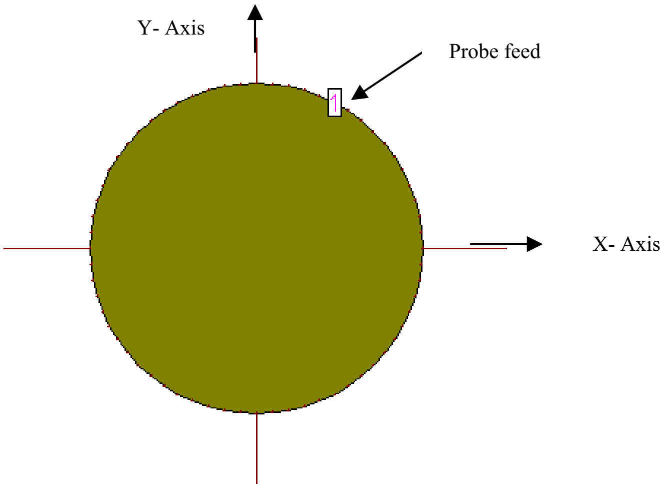
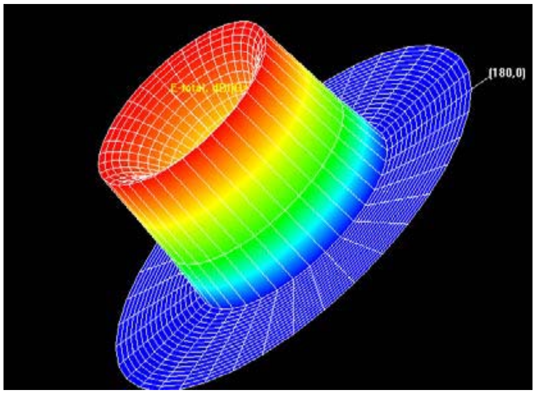
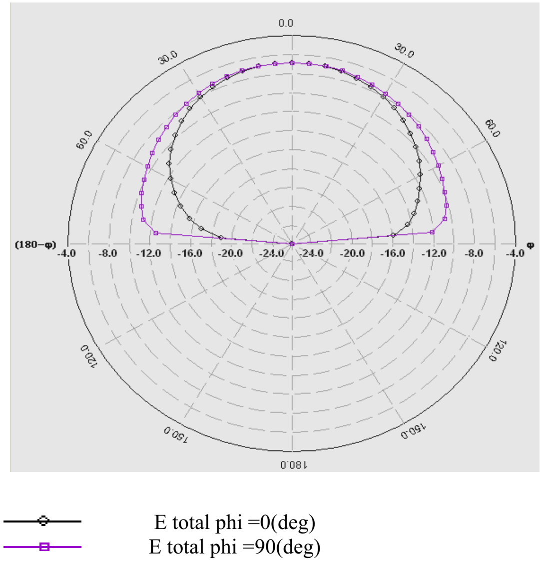


Fig.2. Circular microstrip antenna with probe fed at (8mm, 15mm)

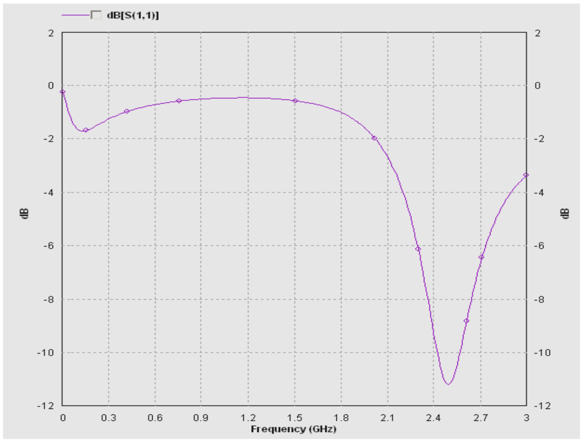


(b)

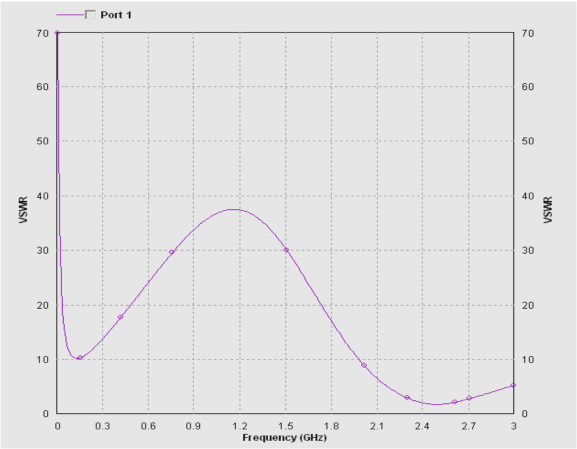
Fig. 3. IE3D Simulation results of (a) polar plot of E- fields and (b) 3D- plot of E-fields



(a)



(a)



(b)

Fig. 4. IE3D Simulation results of (a) return loss and (b) VSWR

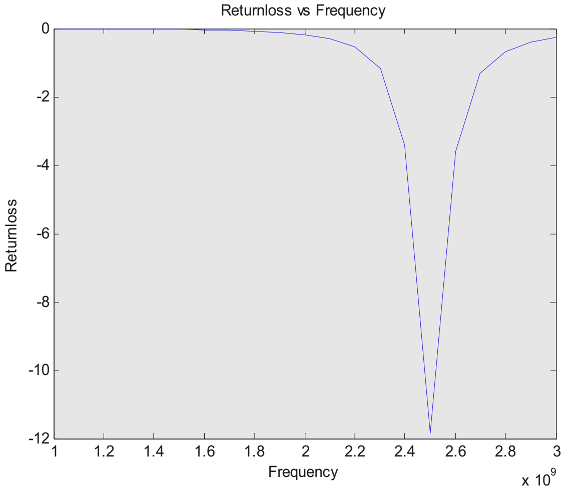
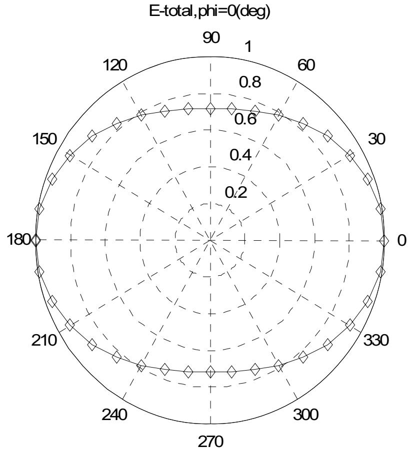
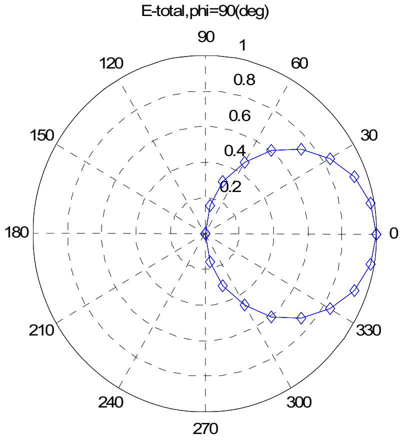


Fig. 5. Matlab simulated result of return loss



(a)



(b)

Fig. 6. Matlab simulated result of (a) E-total phi=0(deg) and (b) E-total phi=90(deg)

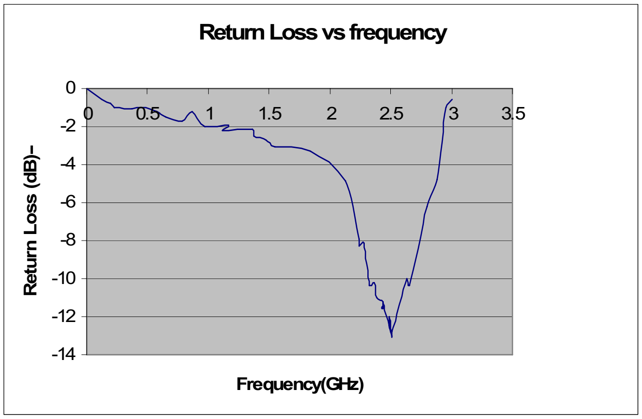


Fig. 7. Measurement result of return loss

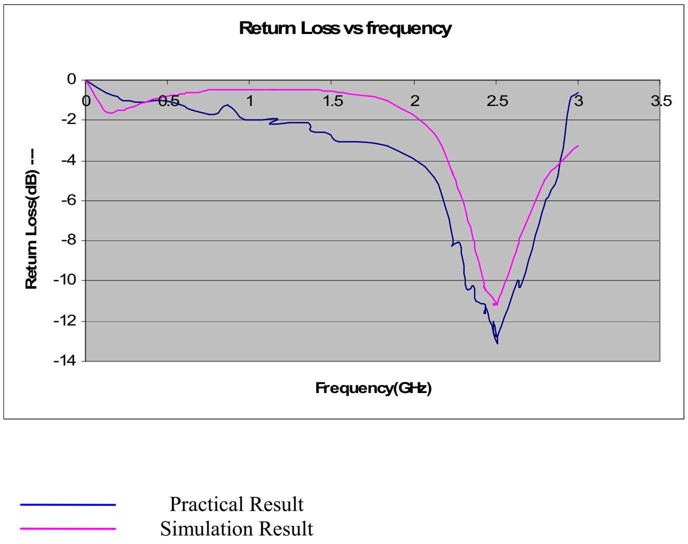


Fig. 8. Comparison of measurement result and simulation result of return loss