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Calculating the parameters of a circular microstrip antennas CMSAs by using the Simple Cavity Model SCM.

حساب معاملات الهوائيات الشريطية الدائرية CMSAs باستخدام انموذج الفجوة البسيطة SCM.

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Abstract

Simple Cavity Model (SCM) was used to solve the problems related to the measurement of the characteristics of microstrip antennas MSAs, where the electric and magnetic fields were calculated **.** The programming of the SCM equations was done using MATLAB language.

The antenna parameters such as: (input impedance, return loss ,bandwidth, resonance frequency and radiation patterns for both TM_{11} mode and TM_{21} mode) were computed and plotted. From which the bandwidth and directivity of the circular microstrip antennas have been determined. We found the increasing in the bandwidth value was obtained from increasing the thickness of the dielectric substrate in the CMSA and decreasing the dielectric constant.

الخلاصة.

استخدم في هذا البحث أنموذج الفجوة البسيطة SCM لحل المسائل المتعلقة بحساب خواص الهوائيات الشريطية(MSAs)، حيث تم حساب كل من المجال الكهربائي والمجال المغناطيسي المنبعثين من الهوائي . برمجت المعادلات الخاصة بحل مسائل الهوائيات الشريطية الدائرية بطريقة SCM باستخدام لغة MATLAB. تم حساب ورسم معاملات الهوائي الشريطي الدائري وهي ممانعة الادخال وعامل الفقد العكسي (return loss) وتردد الرنين و الهياكل الإشعاعية للأنماط المستعرضة مغناطيسيا(للنمط TM_{11} والنمط TM_{21})، وكذلك تم حساب عرض الحزمة (bandwidth) والاتجاهية Directivity الخاص بالهوائي, حيث وجدنا ان عرض الحزمة يزداد كلما قلت قيمة ثابت العزل.

1-Introduction

Microstrip antenna (MSA) is a device using to radiate or receive radiation power, consist of a dielectric substrate on one side radiating material called patch and another side perfect conductor called ground plane .The dielectric substrate has a value of dielectric constant $\epsilon_r \leq 10$,but in practical should be low($\epsilon_r \sim 2.5$), the dielectric substrate thickness(h)must be small($h \ll \lambda$), where λ is the wavelength at the corresponding resonant frequency[1].Microstrip antennas divided into two principle types, planar and non-planar microstrip antennas. The planar microstrip antennas are divided into several categories: microstrip patch antennas, microstrip dipole antennas ,microstrip traveling-wave antennas, inverted L/F shape antennas and microstrip slot antennas.

Non-planar microstrip antennas were differed from the planar by the surface curvature of patch and the surface curvature determine the name of the microstrip antennas. There are virtually unlimited numbers of patch shapes for which radiation characteristics may be calculated. Several shapes has been shown in reference [2], such as rectangular, circular, pentagonal, triangular,ring… etc.

2- Radiation mechanism of a microstrip antenna

According to the equivalent principle, if electromagnetic fields were located in a volume, the actual source could be replaced by fictitious surface currents on a surrounding closed surface. Within a specific region, the fields generated by the fictitious currents represent the original field. Only surface electric currents exist on a perfect electric conductor, and only surface magnetic currents exist on a perfect magnetic conductor, both surface electric and magnetic currents exist on dielectric material.

Because of the electric field occurs between patch and ground plane in microstrip antennas, and the substrate thickness is very small$(h \ll \lambda)$, the electric currents on the surface between the patch and the air was very small compared with the electric currents between the dielectric and the patch, so only the magnetic currents was considered to be radiated from the fringing fields between the edge of the patch and the ground plane[3]. The radiation of the microstrip antennas can be explained as a simple case of a rectangular patch spaced a small fraction of a wavelength above the ground plane. Assuming that there is no variation of the electric field along the thickness of the microstrip structure, the electric field configuration of the radiator can be represented as shown in figure (1). The fields vary along the patch length of about half a wavelength $(\lambda/2)$. Radiation may be ascribed mostly to the fringing fields at the open-circuit edges of the patch. The fields at the end can be resolved into normal edges and tangential components with respect to the ground plane. The normal components are out of phase because the patch line is $\lambda/2$long, therefore, the far field produced by them cancel in the broadside direction. The tangential components are in phase, and the resulting fields combine to give maximum radiated field normal to the surface of the structure; i.e., the broadside direction[4].

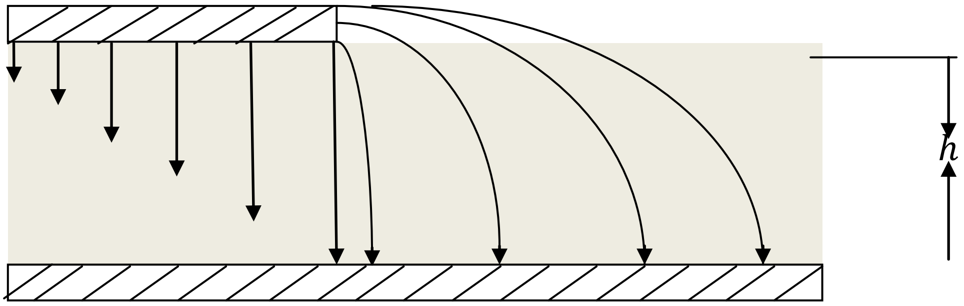


Figure 1:The electric field in microstrip[5]

3- Feeding techniques

The MSAs can be excited directly either by a coaxial probe or by microstripline. It can also be excited indirectly using electromagnetic coupling or aperture coupling and a coplanar waveguide feed, in which case there is no direct metallic contact between the feed line and the patch [6].

The coaxial feeding is perhaps the most common practical excitation of microwave printed circuits and antennas. In most cases, this feeding technique consists of a coaxial cable whose outer conductor is connected to the ground plane of the structure, while the inner conductor penetrates the dielectric substrate and contacts the printed structure , forming a coaxial probe feed for the signal-carrying conductors or radiating patches[7].

In line feed a conducting strip, much smaller in width compared to the patch, is connected directly to the edge of the patch. This kind of geometry allows the patch and feed to be etched on the same substrate[8].

4– Simple Cavity model.

There are many numerical methods and mathematical analyzes such as Cavity Model with source, Wire Grid Model and Green Function Method, these methods are using to studying and calculating the antenna's parameter. In this paper has been used Simple Cavity model (SCM) to calculate the characters for circular microstrip antenna. In this method assumes that the electric field of the electromagnetic wave scattered within the layer of dielectric material of the microstrip antenna has one component Z-axis direction, while, the magnetic field that is it, he owns two components, one towards the X- axis and the other toward the Y- axis . Approaching component tangential of magnetic field equal zero at the edge of the patch, so it can represent the microstrip antenna as a cylindrical cavity determines the top and bottom walls electric , and magnetic side walls.

5- Analysis of Radiation Formula for Circular Microstrip Antenna.

The circular microstrip antenna (CMSA)as shown in Figure (2) has a circular patch of radius (a) stick on the dielectric layer which is installed on the base of the antenna .

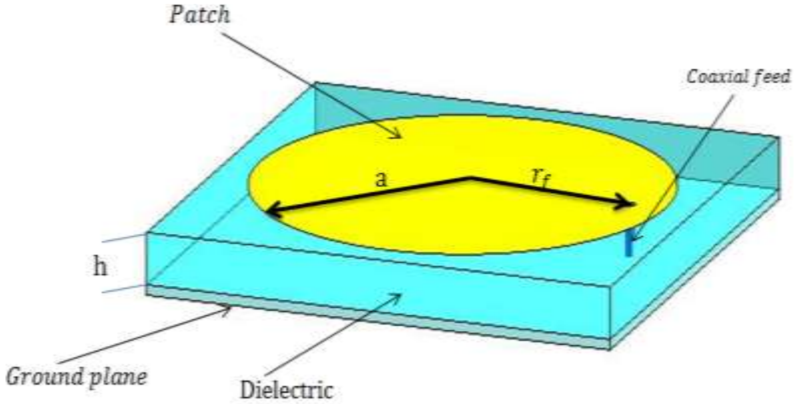


Figure2: Circular microstrip antenna

By using (SCM) for the analysis of this antenna (Z- axis) and is it's aperture in the X-Y plane, the current source is equal to zero and that the wave equation becomes:

$$(\nabla^2 + K^2)\bar{E} = 0 \qquad \dots\dots\dots\dots\dots(1)$$

Where K = ω √ με represent a diffusion constant in the dielectric material , ($\bar{E}$) represent electric field component towards the axis –Z,and (∇^2)is Laplacian operator. To find the fields scattered within the antenna cavity must solve the above equation (1), where appropriate solved using cylindrical coordinates as follows:

$$E_z = E_\circ J_n(k\rho)\cos n\acute{\Phi} \qquad \dots\dots\dots\dots\dots\dots.(2)$$

$$H_\rho = -\frac{jn}{\omega\mu\rho} E_\circ J_n(k\rho)\sin n\acute{\Phi} \qquad \dots\dots\dots\dots\dots\dots\ (3)$$

$$H_{\acute{\Phi}} = -\frac{jk}{\omega\mu_\circ} E_\circ J_n'(k\rho)\cos n\acute{\Phi} \qquad \dots\dots\dots\dots\dots..(4)$$

Where that (J_n)is Bessel function of the first type and it's mode(n), either (J_n') is a derivative Bessel function , k is wave number and ($\acute{\Phi}$ =0→ 2π).

Apply the following boundary condition for the magnetic field on the equation (4)[9]

$H_{\acute{\Phi}}|_{\rho=a} = 0$

We get:

$$J_n'(ka) = 0 \qquad \dots\dots\dots\dots\dots\dots.(5)$$

By calculating the roots of the equation above for each mode can calculate the radius of patch antenna (a).The fields of the circular patch were found by knowing the type a density of the surface currents generated at the edge of a patch .

When applying the equivalence principle on the surface, the surface currents magnetic coupling and is given by[10] :

$$\bar{M} = -2\hat{n} \times \bar{E} = 2E_z\hat{\acute{\Phi}} \qquad \dots\dots\dots\dots.. (6)$$

where $\hat{n}$ and $\hat{\acute{\Phi}}$ are the unit vectors .From the density of the surface currents, the electric vector potential($\bar{F}$) is resulting as[10]:

$$\bar{F} = \frac{\varepsilon}{4\pi}\frac{e^{-jk_\circ r}}{r}\iint \bar{M}\, e^{jk_\circ(\bar{r}.\bar{\acute{r}})}\, ds \qquad \dots\dots\dots\dots\dots\dots.(7)$$

where ($\bar{\acute{r}}$) is refers to the vector of source point position , $k_\circ$ is wave number in space.By using the spherical coordinates can be written components the vector potential ($\bar{F}$):

$$\bar{F} = \hat{r}F_r + \hat{\theta}F_\theta + \hat{\Phi}F_\Phi$$

$$F_r = -\frac{2hE_\circ\varepsilon}{4\pi}\,\frac{e^{-jk_\circ r}}{r}\,a\,J_n(Ka)\int_0^{2\pi}\cos n\acute{\Phi}\;\;\sin\theta\sin(\acute{\Phi}-\Phi)\;\;e^{jK_\circ\rho\sin\theta\cos(\acute{\Phi}-\Phi)}\;\;d\Phi$$

$$F_\theta = -\frac{2hE_\circ\varepsilon}{4\pi}\,\frac{e^{-jk_\circ r}}{r}\,a\,J_n(Ka)\int_0^{2\pi}\cos n\acute{\Phi}\;\;cos\,\theta\sin(\acute{\Phi}-\Phi)\;\;e^{jK_\circ\rho\sin\theta\cos(\acute{\Phi}-\Phi)}\;\;d\acute{\Phi}$$

$$F_\Phi = \frac{2hE_\circ\varepsilon}{4\pi}\,\frac{e^{-jk_\circ r}}{r}\,a\,J_n(Ka)\int_0^{2\pi}\cos n\acute{\Phi}\;\;\cos(\acute{\Phi}-\Phi)\,e^{jK_\circ\rho\sin\theta\cos(\acute{\Phi}-\Phi)}\;\;d\Phi$$

…………….(8)

The relationship between the electric vector potential and electric field is:

$\bar{E} = -\frac{1}{\varepsilon}\,\nabla\times\bar{F}$

Accordingly, the two components of radiation in the far field are devolve to:

$E_\theta = -jK_\circ F_\Phi$

$E_\Phi = jK_\circ F_\theta$

and thus can be written the tow field components :

$$E_\theta = j^n\,\frac{V_\circ K_\circ}{2}\,a\,\frac{e^{-jk_\circ r}}{r}\cos n\Phi\,\left(J_{n+1}(K_\circ a\sin\theta)-J_{n-1}(K_\circ a\sin\theta)\right)\qquad\dots\dots\dots\dots\dots(9)$$

$$E_\Phi = j^n\,\frac{V_\circ K_\circ}{2}\,a\,\frac{e^{-jk_\circ r}}{r}\cos\theta\,\sin n\Phi\,\left(J_{n-1}(K_\circ a\sin\theta)+J_{n+1}(K_\circ a\sin\theta)\right)\qquad\dots\dots\dots..(10)$$

Where (V) is the voltage at the edge of circle (a, 0) is equal to

$V_\circ = hJ_n(Ka)$

the input impedance(p)of the circular microstrip antenna was calculated by sum of the following three relationships[10]:

$$P_r = \frac{(V_\circ\cdot K_\circ\cdot a)^2}{960}\int_0^{\pi/2}[(J_{n-1}(K_\circ a\sin\theta)+J_{n+1}(K_\circ a\sin\theta))^2 + cos^2\theta(J_{n-1}(K_\circ a\sin\theta)+J_{n+1}(K_\circ a\sin\theta))^2]\,\sin\theta\,d\theta\qquad\dots\dots\dots.(11)$$

$$P_c = \pi\cdot(\pi\cdot f\cdot\mu_\circ)^{-3/2}\,\frac{V_\circ^2}{8\cdot h^2\cdot\sqrt{\sigma}}[(Ka)^2-n^2]\qquad\dots\dots..(12)$$

$$P_d = \frac{V_\circ^2\cdot\tan\delta}{8\cdot\mu_\circ\cdot h\cdot f}\,[(Ka)^2-n^2]\qquad\dots\dots\dots\dots(13)$$

Can get the directivity of antenna from the ratio of maximum value to the radiation density(U_m) to radiation rate($U_\circ$) as in the equation:

$$D = \frac{U_m}{U_\circ}\qquad\dots\dots\dots\dots(14)$$

.

$U_\circ = \frac{1}{2\eta_0}\left(|E_\theta|^2+|E_\phi|^2\right)r^2 \qquad ,\eta_0 = 120\pi\,\Omega$

$U_m = U_\circ(\theta,\Phi)_{max}$

The return loss that can be expressed as[11]

$R(\varphi) = e^{-2\frac{\sigma cos\varphi}{\varepsilon_0 c}h}$

where $\varphi$is the angle of the incident wave with respect to the normal direction of Perfectly Matched Layers PML surface, σ is the conductivity of the PML medium and $\varepsilon_\circ$ is permittivity of free space .

6-Results and discussion:

We will prove the activation of SCM by calculating the resonance frequency and the radiation pattern for CMSA. A circular shape is design to enhance the bandwidth of CMSA by solving the problem using SCM .To solve the problem; firstly drawing the patch of microstrip antenna and secondly determining the thickness of the dielectric and the magnitude of dielectric constant and boundary conditions of the structure. Then localization the feed at a specific position (the position of the feed chosen to give $50\,\Omega$ as input impedance), and where frequency range been selected. The program will calculate the characteristics of microstrip such as the input impedance, transverse radiation fields and other parameters.

6.1.Circular MSA.

To ensure the validity of the SCM for CMSA, applied to CMSA whose specifications as follows: the radius $a = 19.05\,mm$, substrate thickness $h = 1.524\,mm$, magnitude of its dielectric constant $\varepsilon_r = 2.5$ and feed point at $r_f = 5\,mm$ from the center of the circular patch .This antenna has a resonance frequency of about $2.76GHz$[12].
By choosing $\Delta x = \Delta y = 0.47625\,mm$ and $\Delta z = 0.508\,mm$. Figure (3) show that the resonance frequency calculated by SCM is $2.734\,GHz$ and the bandwidth is about $\approx 0.73\%$. It should be noted here the result is have good convergence compared with the previous research[9].This means, that the error about 1%, and the method gives excellent results

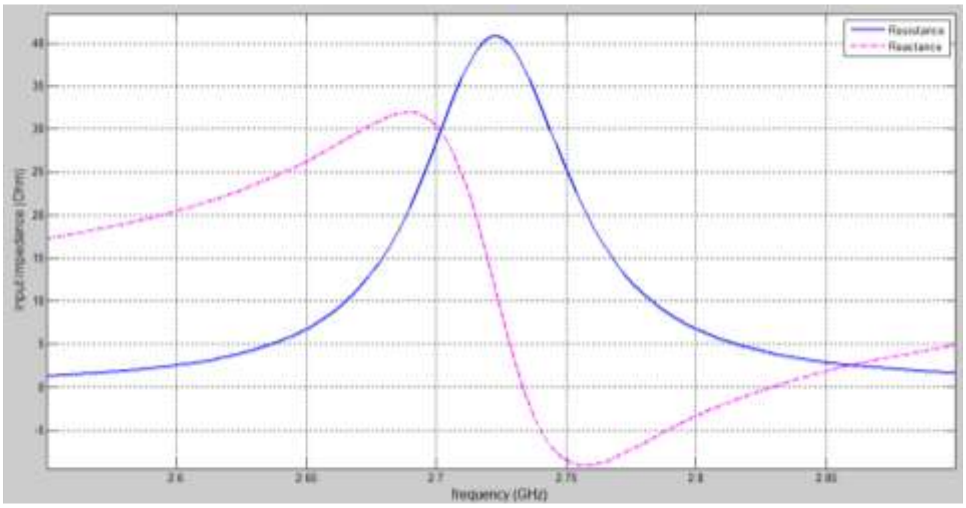


Figure 3: Input impedance of the CMSA calculated by SCM

Figure (3) was shows the input impedance of the CMSA in the case of resonance, which represents pure resistance as a function of the feeding position and TM_{11} mode .It follows from this form to determine feeding position for any CMSA if the input impedance equal to (Ω50) , (the frequency, conductivity(to copper),dielectric constant ,return loss and type mode spreads) are knowing. For a CMSA of resonance frequency $2.4\,GHz$, dielectric constant $\varepsilon_r = 1.07$,radius $a = 34\,mm$, substrate thickness $h = 1.61\,mm$, the feed point at $r_f = 8.5\,mm$ from center of circular patch ground plane dimensions $91.8 \times 91.8\,mm^2$, and the choosing value $\Delta x = \Delta y = 1.7\,mm$ and $\Delta z = 0.38\,mm$,the results obtained by SCM is shown in figure (4) and figure (5) which show that the resonance frequency is about $f_0 \approx 2.35GHz$ and the bandwidth is about $\approx 1.17\%$. Since the less dielectric constant and increasing the thickness of the dielectric substrate in the CMSA are increasing the bandwidth value, therefore a low dielectric constant was chosen.

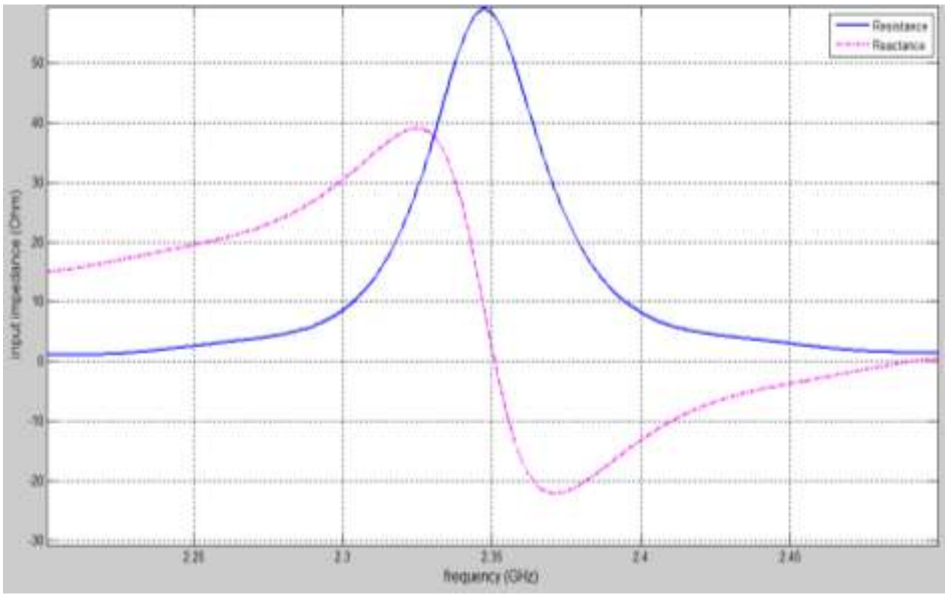


Figure 4: Input impedance of the CMSA calculated by SCM

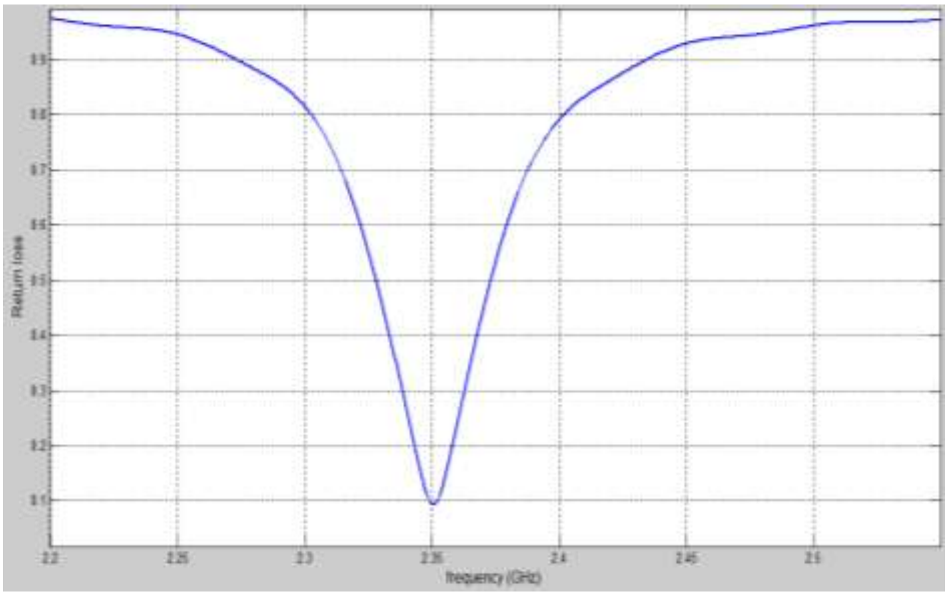
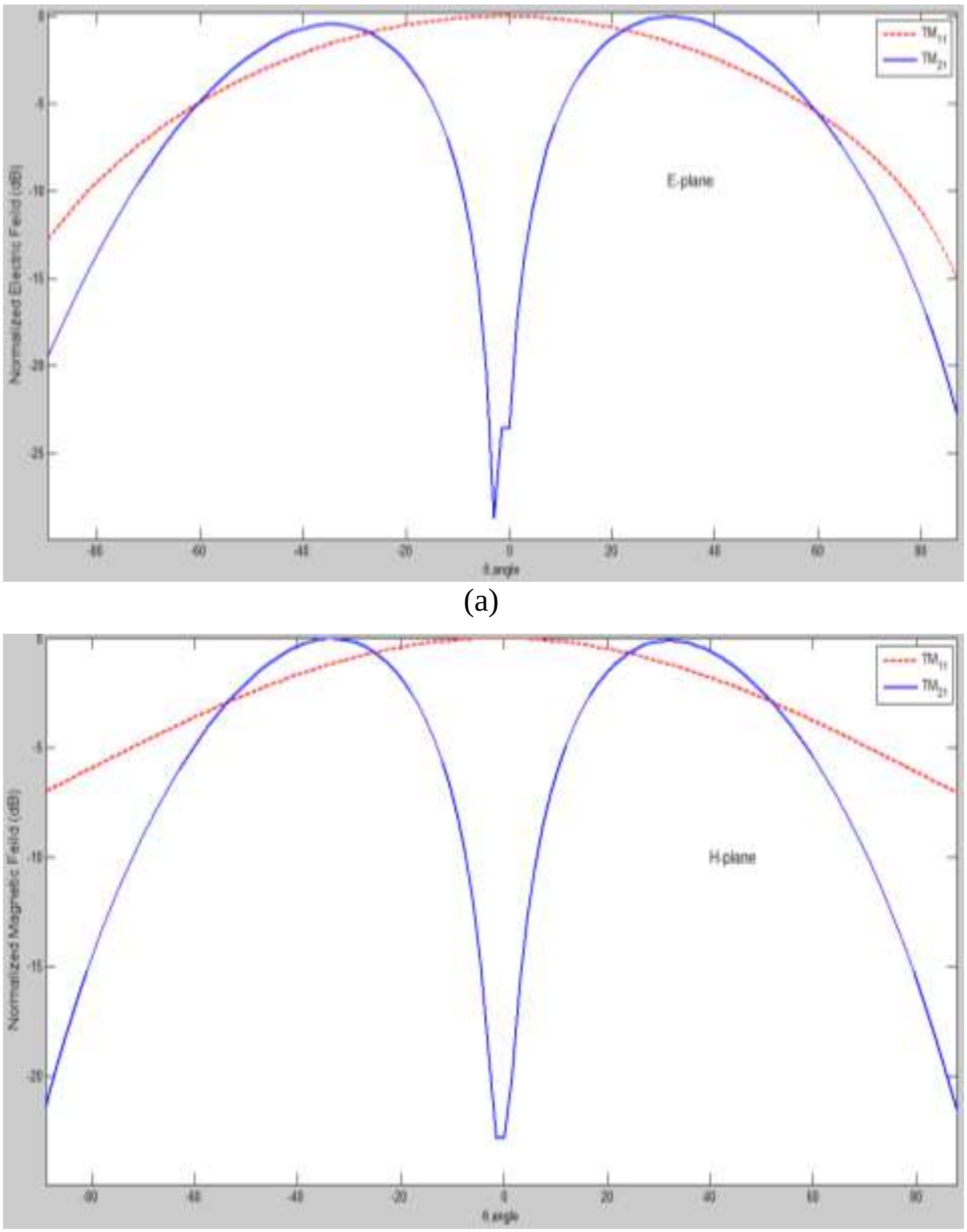


Figure 5: Return loss of the CMSA using SCM.

6.2. **Radiation pattern for CMSA.**

In this paper the radiation pattern was plotted in the principle planes(E and H- planes) for a CMSA of $a = 34\,mm$, dielectric constant 1.07, the feed point at $r_f = 8\,mm$and substrate thickness $h = 1.61\,mm$. The resonance frequency in this case selected to be $2.32\,GHz$. The radiation pattern for TM_{11} and TM_{21}modes were shown in figure (6).



(a)

(b)

Figure 6:The radiation pattern of CMSA, (a) E-plane forTM_{11} and TM_{21}modes, (b) H-plane for TM_{11} and TM_{21}modes.

Notes from figure, the pattern radiation for TM_{11} mode contains a beamwidth (fundamental lobe)for E-plane and H-plane, but for TM_{21} mode, we note the decrease limited of a radiation's width (Beamwidth) at H-plane than it is in the TM_{11} mode as well as a substantial decrease in bandwidth the E-plane.

6.3. Directivity

The gain of antenna was determined from antenna's efficiency and the value of **directivity** , so that the power received from the antenna was determined from the directivity. Figure (6) shows that the beamwidth of this antenna in E-plane and H- plane is $\theta_{pE} = 88$ and $\theta_{pH} = 92$ respectively, so the directivity is calculated from equation (14) and has the value of about 5.07 dB.

7. Conclusions

1. In this paper the SCM was applied to analyze the CMSA. The input impedance, radiation pattern, resonance frequency and bandwidth of this antennas were calculated.

2.The increase in the bandwidth value was obtained from , increasing the thickness of the dielectric substrate in the CMSA and decreasing the dielectric constant .
3.The decreasing in the bandwidth value was obtained by varying TM_{11} mode to TM_{21} mode.
4. The feeding position for any CMSA was determined in terms an input impedance.
5. The power received from any CMSA was determined from the directivity.

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