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BANDWIDTH ENHANCEMENT OF CIRCULAR MICROSTRIP ANTENNAS

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ABSTRACT

Microstrip Antennas have many advantages such as low profile, light weight, can be easily matched with microwave integrated circuits which leads to use this type of antennas in different applications, on the other side, the great disadvantage of these antennas is the narrow bandwidth which is 2 to 5 %. In this paper a single element circular Microstrip antenna has been designed which had a narrow bandwidth and then two methods of bandwidth enhancement had been designed and compared to the single patch, these two techniques gave a bandwidth of 10% and 38 %, respectively. The three designs had been simulated using Microwave Office Package.

Keywords: circular microstrip antennas, bandwidth enhancement, stacked patches.

1. INTRODUCTION

The circular microstrip antennas are one of the different shapes of microstrip antennas which are widely used due to their advantages , in spite of these advantages there is some drawbacks that may affect their wide usage, one of these drawbacks is the narrow bandwidth which is < 2 % for a single patch, many techniques suggested to enhance this narrow bandwidth such as using a thick substrate [1], stacked configuration[2], capacitive feed [3], proximity coupling ,these techniques lead to a bandwidth improvement of 15~20 %.

In order to further increase the bandwidth, a combination of two or more of these methods may be used which leads to an increase in bandwidth.

The circular patch is as shown in Figure-1, it consists of a circular patch of radius (r) printed on a substrate of a dielectric layer of thickness (t) with a dielectric constant (ε_r),the lower order modes of this type of microstrip patch are TM_{11} , TM_{21}, TM_{01}, TM_{31}.

The circular patch is designed depending on the derivative of Bessel function which is shown in Figure-4, the Figure shows the derivative of Bessel functions with the orders 0 to 5, in which each order is represented by a curve with a different color, each intersection of the curve with the x-axis gave a value of x_{nm} ,this intersection represent a mode, if order 1 was taken as an example, so the first intersection is TM_{11} , and the second intersection is TM_{12} and so on .

The resonance frequency of a circular antenna for the TM_{nm} mode can be evaluated from the basic relation $X_{nm} = ka$ and k defined as [3].

$$k = 2\pi\sqrt{\varepsilon_r}/\lambda_0 \qquad \text{.......(1)}$$

And the resonance frequency is

$$f_{nm} = \frac{X_{nm}\, c}{2\pi a\sqrt{\varepsilon}} \qquad \text{.......(2)}$$

$$C = \frac{1}{\sqrt{\mu_0\varepsilon_0}} \qquad \text{.......(3)}$$

Where X_{nm} is the mth zero of $J_n'(k\,a)$ and c is the velocity of light in free space.

According to the values of (2), the first four modes in ascending order are TM_{11} , TM_{21},TM_{01}, TM_{31}, where TM_{11} is the dominant mode [4].

An effective radius a_e has been given in (4) to account for the fringe fields along the edge of the resonator. For the TM_{11} mode of the disk it has been suggested that.

$$a_e = a\{1 + \frac{2h}{\pi a \varepsilon_r}\ (ln\ \frac{\pi a}{2h} + 1.7726)\}^{1/2} \qquad \text{.......(4)}$$

This expression predicts the radius with an error of less than 2.5% for a/h >> 1, Equation (4) is used as a design guide for determining the radius of the disk .A number of modifications of (4) has been suggested.
For thick substrates one may use (5) [5]

$$a_e = a[1 + \frac{2h}{\pi a \varepsilon_r}\ \{ln\left(\frac{\pi a}{2h}\right) + (1.41\varepsilon_r + 1.7726) + \frac{h}{a}\ (0.268\varepsilon_r + 1.65\ \}]^{1/2} \qquad \text{..(5)}$$

Where (a) is the radius of the circular patch, ε_r is the relative permittivity, h is the thickness of the substrate which the patch is printed on it.
The far field of circular microstrip antenna is given by

$$E_\phi = j^n\ (V_0\, a\, k_0/2)\ (e^{-j k_0 r}/r)\cos\theta \sin n\phi\ [J_{n+1}(k_0\, a \sin\theta) + J_{n-1}(k_0\, a\sin\theta) \qquad \text{.......(6)}$$

$$E_\theta = j^n\ (V_0\, a\, k_0/2)\ (e^{-j k_0 r}/r)\cos n\phi\ [J_{n+1}(k_0 a\sin\theta) - J_{n-1}(k_0 a\sin\theta) \qquad \text{.......(7)}$$

The radiated power is

$$P_r = [(V_0 k_0\, a)^2/1920] \int_0^{\pi} [J_{n+1}(k_0\, a\sin\theta - J_{n-1}(k_0\, a\sin\theta)]^2 + cos^2\theta\ \ \{J_{n+1}(k_0\, a\sin\theta) + J_{n-1}(k\, a\sin\theta)\}^2 \sin\theta\, d\theta \qquad \text{.......(8)}$$

Where $V_0 = h\, E_0\, J_n(k\rho_0)$

And the conductor power loss is calculated from

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$P_c = [\sqrt{(\pi f \mu/\sigma)}\,]\,(E_0^2/(\mu\omega)^2) * \pi\,[\,(1/2)\, J_n^2\,(k a)\{(ka)^2 - n^2\}]$ ......(9)

And dielectric loss can be found from eq. (10)

$P_d = [(E_0^2 \tan\delta\, h)/8\,\mu\, f] * [J_n^2\,(k a)\,\{(ka)^2 - n^2\}]$ ....(10)

And the total power is

$P_T = P_r + P_c + P_d$
.......(11)

The Input impedance of the disk antenna can be defined as

$$Z_{in} = \frac{V_0^2}{2P_T}$$ ....(12)

And since $V_0 = h\, E_0\, J_n(k\rho_0)$ So

$$Z_{in} = \frac{h^2 E_0^2 J_n^2(k\rho_0)}{2P_T}$$ ....(13)

2. SIMULATION PROCEDURE

In order to be confident in Microwave Office results, two different published papers were been simulated using the package and the results were compared with the published results, it gave a good matching

The first paper is of (LO) [5] in which a circular patch with a radius of 8 cm printed on a dielectric substrate of a dielectric constant of (ε_r = 2.62) and a thickness of (h = 0.159) cm and works on a resonance frequency of (f_r = 794 MHz) had been simulated for three different feed locations as shown in Figure-5.

The other paper is of Rod B. Waterhouse [6], it consists of a feeding patch with r = 0.7 cm printed on a substrate of ε_r = 2.2 and h = 0.1524 cm and a radiating patch with r = 0.74 cm and ε_r = 1.07 and h = 0.25 cm and a resonance frequency (f_r =) and compared to the published results as shown in Figure-6.

3. DESIGN PROCEDURE

A circular microstrip antenna has been designed using the equations above, it consists of a circular patch of radius (r) printed on a dielectric substrate of thickness (h) and relative permittivity constant (ε_r). The antenna was fed by a coaxial feed and the feed position was chosen by trial and error in order to give a good matching which is 50Ω and the parameters of the antenna are calculated using the equation above and they are:

a) The radius of the circle (R) is 8 cm;
b) Relative permittivity is 2.32;
c) Thickness of the substrate (h) is 0.14;
d) Loss tangent (δ) is 0.001;
e) Feed point location is (0,4.25 cm) where (0,0) is the center of the circle;
f) The mode of the patch is TM_{11}; and
g) Resonance frequency 710 MHz.

The top layer of the enclosure has the properties of air (which has a dielectric constant of 1).

In order to increase the bandwidth of the antenna, a capacitive feed has been added as shown in Figure-2, this was done by printing a capacitor patch on a substrate above the ground plane with a thickness h_{cg} = 0.96 cm and the thickness between the capacitive patch and the circular patch was set to h_{cp} = 0.02 cm, This configuration was found to give the maximum bandwidth.

The second method of bandwidth enhancement was using of two combined methods of stacked patches and Capacitively-fed patches as shown in Figure-3, The design of this technique was done by putting a capacitive patch on a substrate material of dielectric constant of 2.32 and thickness of h_{cg} = 1 cm with a probe feed as the feed source, above this patch another patch(the feeding patch) having a radius of r_f = 6.75 cm is printed on a substrate with a dielectric constant of ε_{rf} = 2.32 and a thickness of h_{fc} = 0.05 cm, followed by another circular patch of radius of r_r = 8 cm printed on a substrate material of dielectric material of ε_{rr} = 1.07 and thickness of h_{rf} = 0.96 cm, the upper layer was set to have the properties of air (h = 1 cm) and (ε_r = 1).

4. RESULTS

Figure-7 represents the return loss of the single circular patch, and the -10 dB return loss bandwidth is 10 MHz (which is 1.408% with respect to the resonance frequency). Figure-8 represents the input impedance of the circular patch, and Figure-9 (a and b) represents the E-plane and H-plane of the radiation pattern.

The first technique of bandwidth enhancement gives a bandwidth of 69 MHz (which is 10.28 % with respect to the resonance frequency which is 671 MHz). The return loss and input impedance and the radiation pattern is shown in Figures (10, 11 and 12).

The second technique considered the best technique, because it gives a bandwidth of 334 MHz (which is 38% with respect to the resonance frequency which is 880 MHz), the Figures (13, 14 and 15) represent the return loss, input impedance and radiation pattern, respectively.

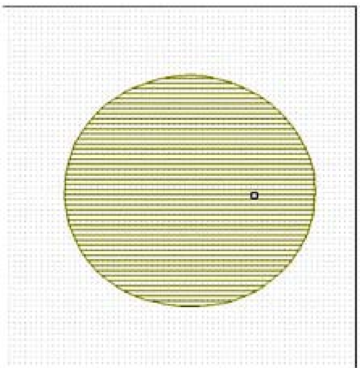

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Figure-1. Circular microstrip antenna.

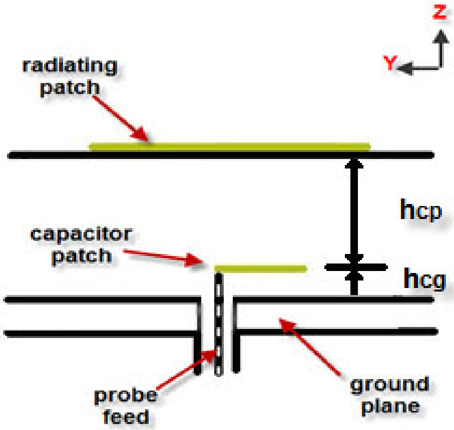


Figure-2. The structure of capacitevely-fed microstrip antenna.

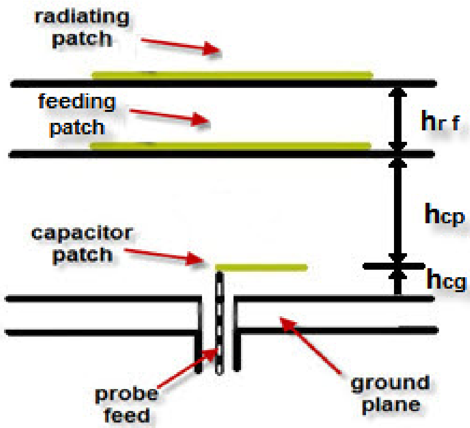


Figure-3. The structure of capacitively-fed stacked patch.

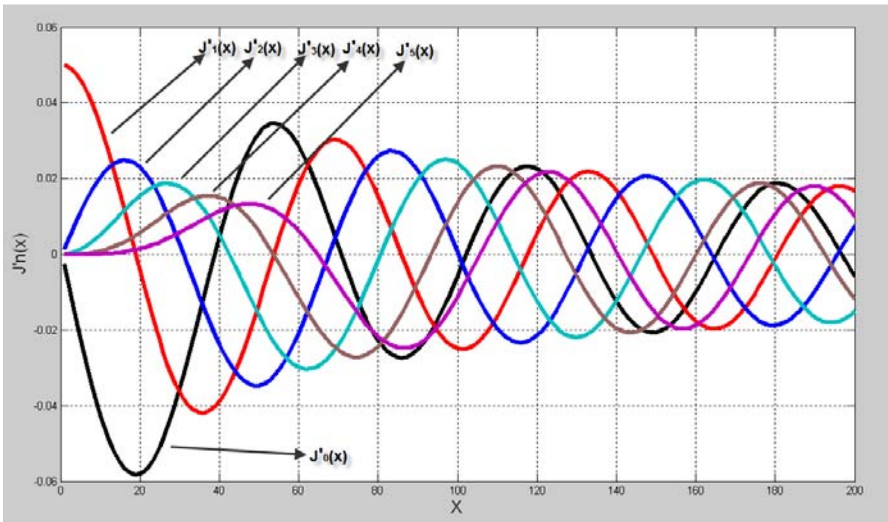
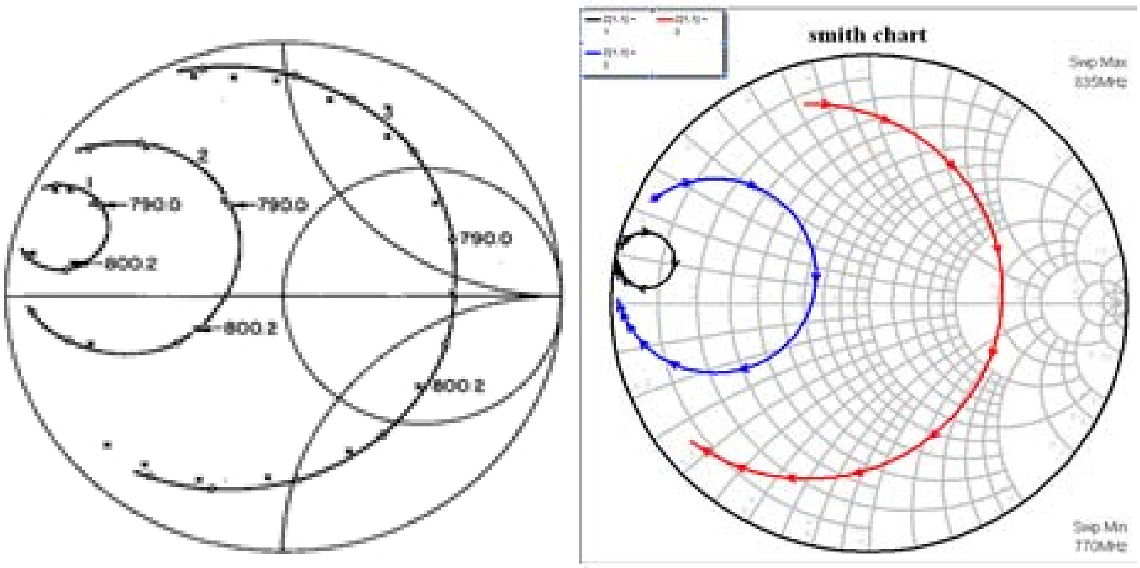


Figure-4. The derivative of Bessel function.



(a) (b)

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Figure-5. (a) Impedance loci as measured by LO [5]; (b) Impedance loci as measured in Microwave Office.

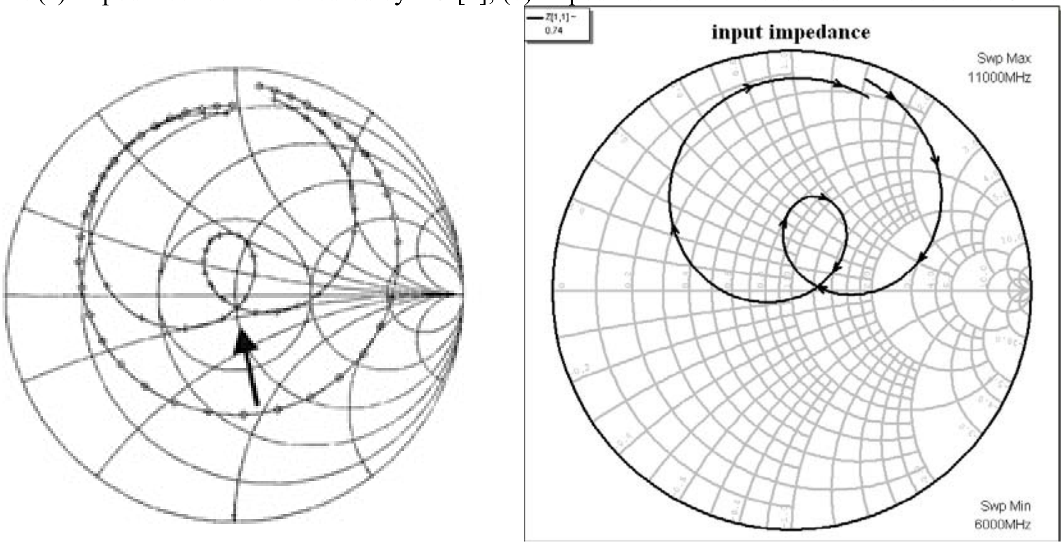


Figure-6. (a) Impedance loci as measured by Waterhouse [6]; (b) Impedance loci as measured in Microwave Office.

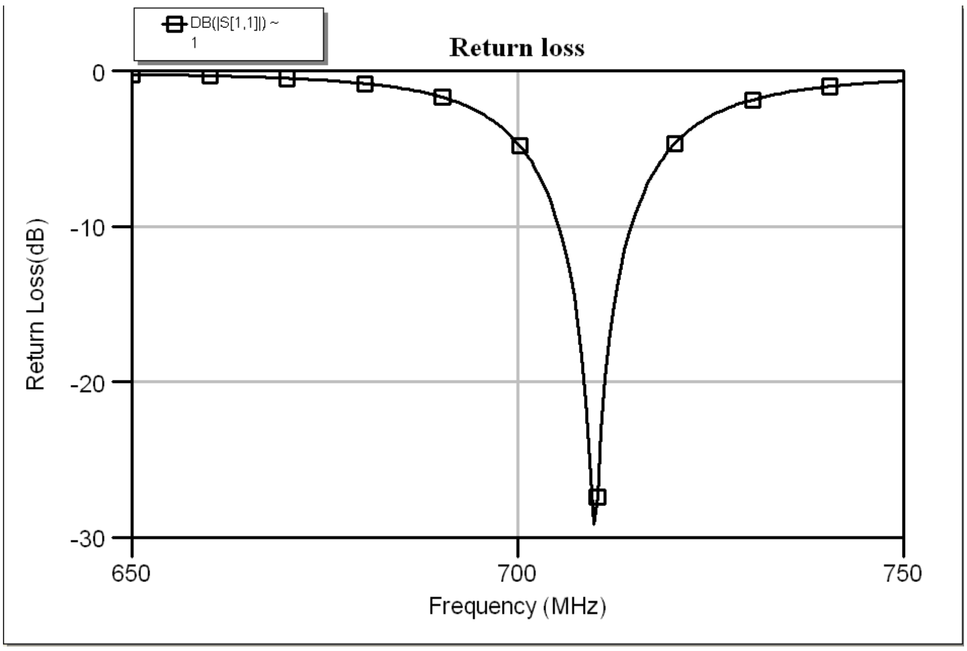


Figure-7. The return loss for a circular patch with r = 8 cm, h = 0.14 cm,
ε_r = 2.32, f_r = 710 MHz, δ = 0.001.

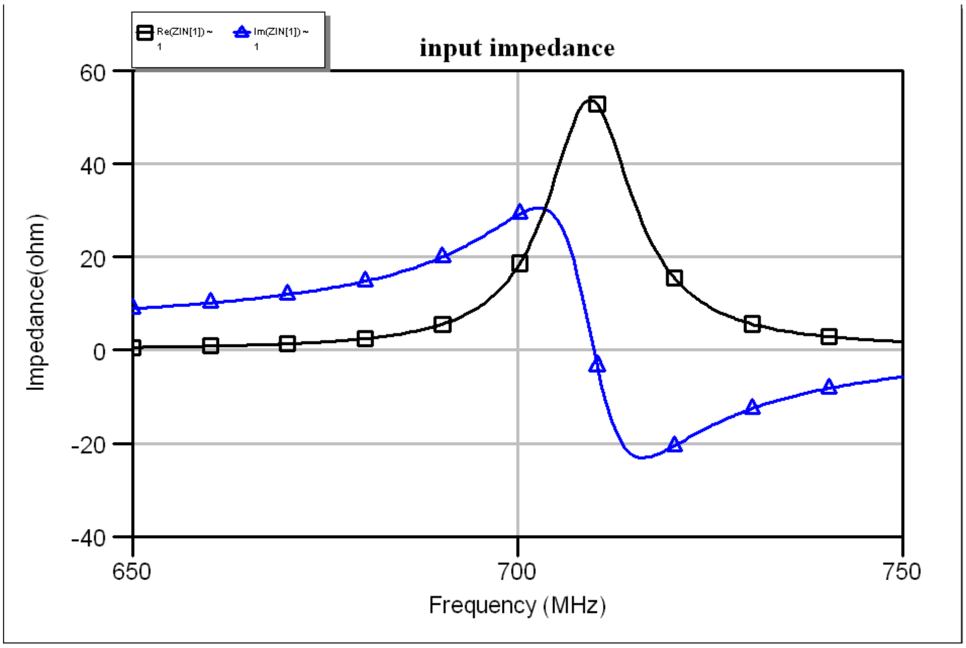
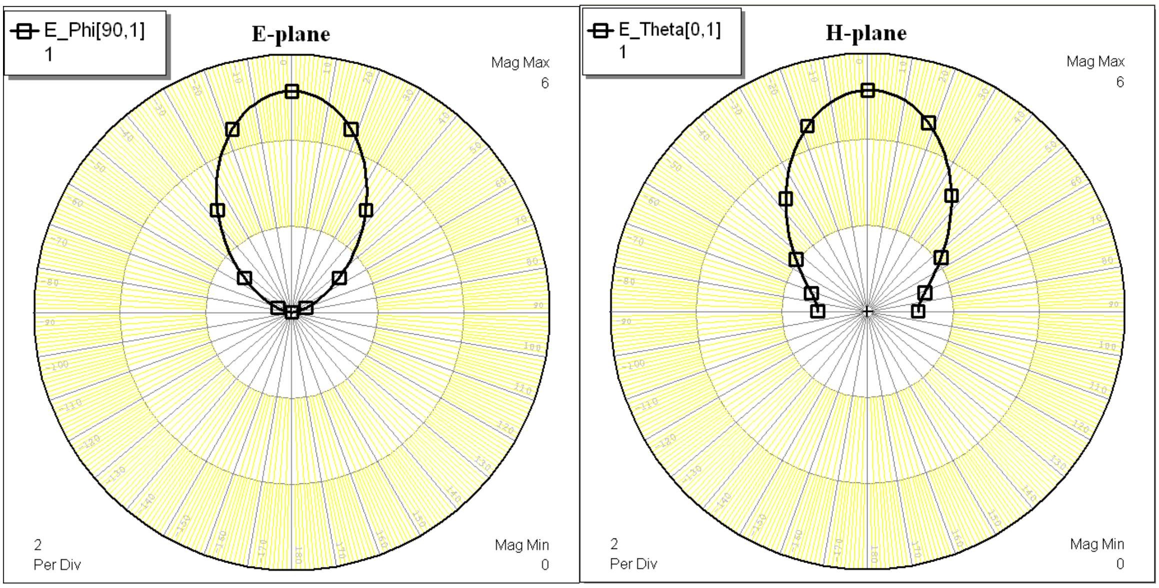


Figure-8. The real and imaginary parts of the input impedance of a circular patch with r = 8 cm, h = 0.14 cm, ε_r = 2.32, f_r = 710 MHz, δ = 0.001.



(a) (b)

Figure-9. The radiation pattern of a circular patch (a) E-plane (b) H-plane with r = 8 cm, h = 0.14 cm, ε_r= 2.32, f_r= 710 MHz, δ = 0.001.

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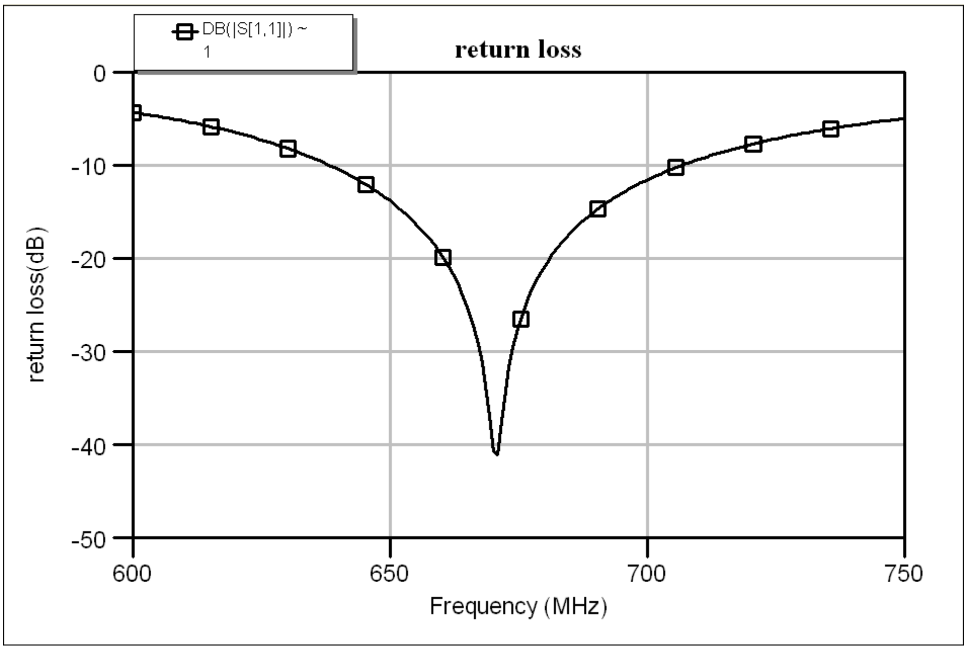

Figure-10. The return loss of a capacitevely-fed circular patch with r = 8 cm, h_{cg}= 0.96 cm, h_{cp}= 0.02, ε_r= 2.32, f_r= 671 MHz, δ = 0.001.

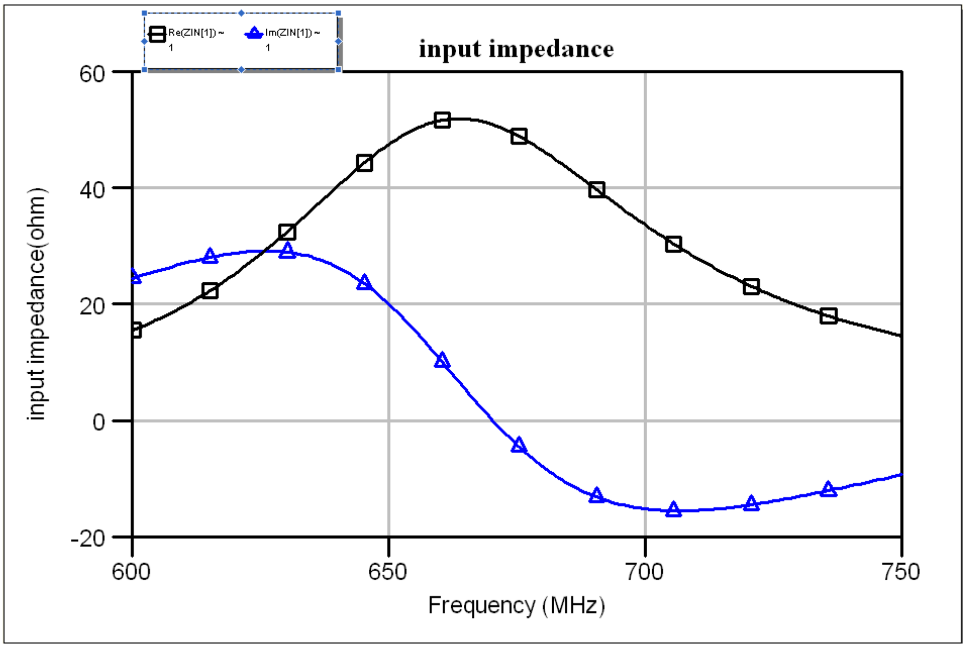

Figure-11. The input impedance of a capacitevely-fed circular microstrip antenna with r = 8 cm, h_{cg}= 0.96 cm, h_{cp}= 0.02, ε_r= 2.32, f_r= 671 MHz, δ = 0.001.

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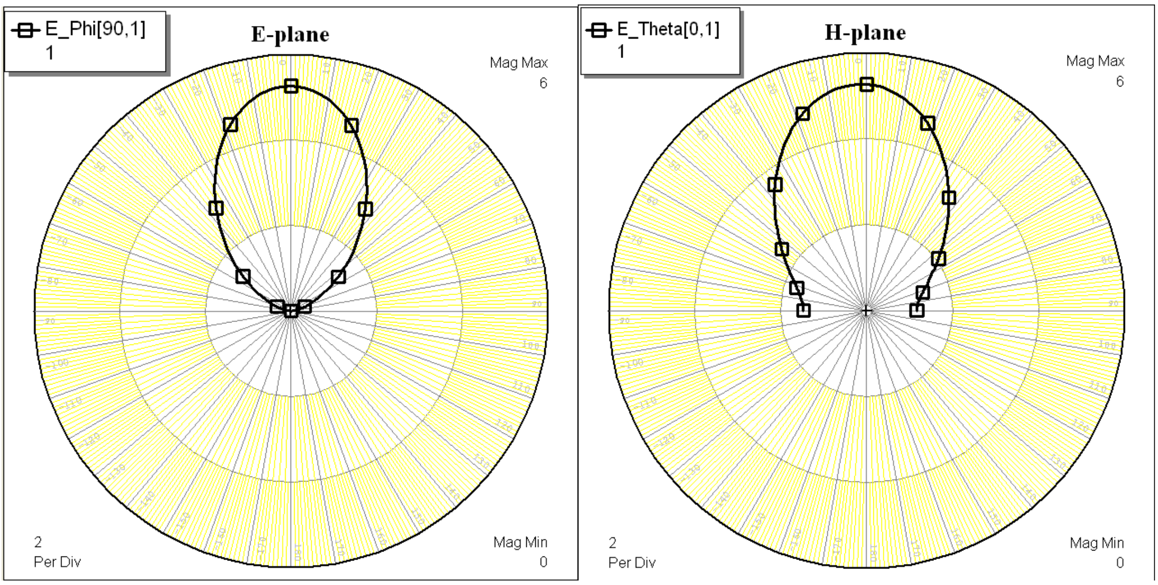

(a) (b)

Figure-12. The radiation pattern of a capacitively-fed circular patch (a) E-plane (b) H-plane with r = 8 cm, h_{cg}=0.96 cm, h_{cp}= 0.02, ε_r= 2.32, f_r= 671 MHz, δ = 0.001.

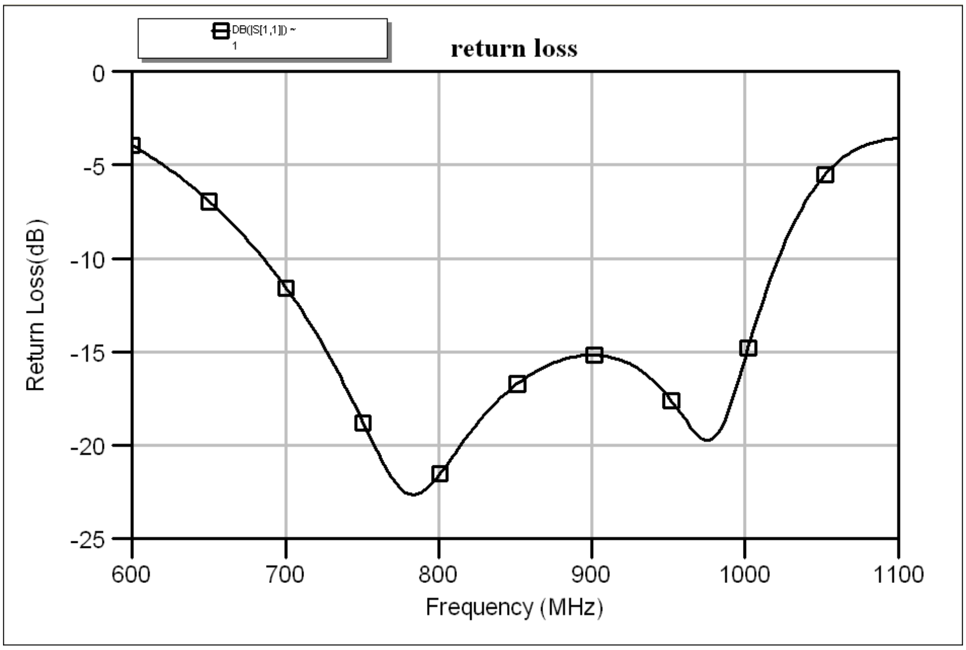

Figure-13. The return loss of a capacitively-fed stacked circular microstrip antenna with r_f = 6.75 cm, h_{cg} = 1 cm, h_{fc} = 0.05 cm, ε_{rf} = 2.32, r_r = 8 cm,

h_{rf} = 0.96 cm ε_{rr} = 1.07, f_r = 880 MHz, δ = 0.001.

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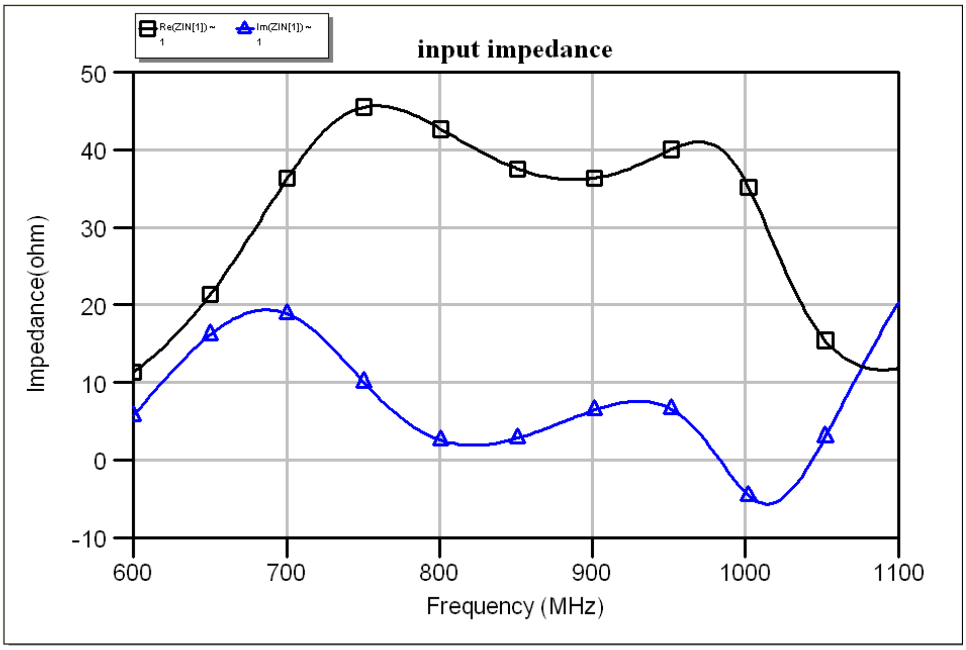

Figure-14. The input impedance of a capacitively-fed stacked circular microstrip antenna with r_f = 6.75 cm, h_{cg} = 1 cm, h_{fc} = 0.05 cm, ε_{rf} = 2.32, r_r = 8 cm, h_{rf} = 0.96 cm ε_{rr} = 1.07, f_r = 880 MHz, δ = 0.001.

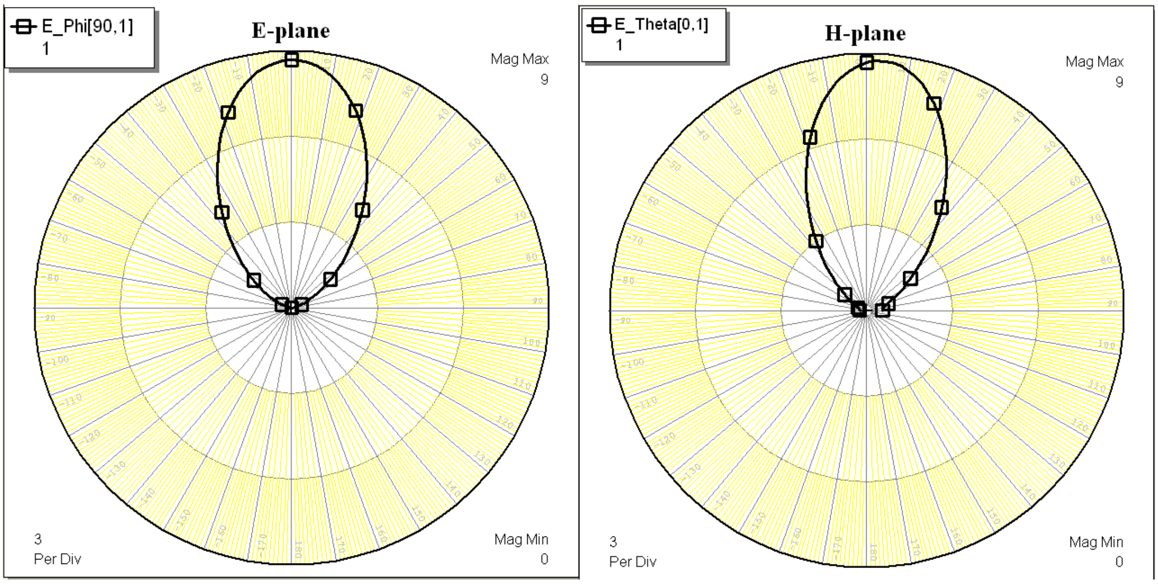

Figure-15. The radiation pattern of a capacitively-fed stacked circular microstrip antenna (a) E-plane (b) H-plane with r_f = 6.75 cm, h_{cg} = 1 cm, h_{fc} = 0.05 cm, ε_{rf} = 2.32, r_r = 8 cm, h_{rf} = 0.96 cm ε_{rr} = 1.07, f_r = 880 MHz, δ = 0.001.

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