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Design and Analysis of a Circular Patch Antenna for Mobile Communication at 7.6 GHz

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***Abstract* – Wireless Technology is one of the main areas of research in the world of communication systems today and a study of communication systems is incomplete without an understanding of the operation and fabrication of antennas. In wireless applications, antennas play the most vital role in transmitting and receiving of information or signals. This work was aimed at designing and simulating a polarized circular patch antenna for mobile communications operating at 7.6GHz.Computations and simulations using a program developed in Higher Frequency Structure Simulator (HFSS) were done. Alongside these, other parameters such as effective patch radii, conductance, directivity, input resistance and quality factor, which dictate the ultimate performance of the antenna were also determined. It was observed that directivity was seen to increase with resonant frequency, but at the expense of increase in conduction and dielectric losses.**

***Keywords* – Communication, Circular Patch Antenna, Simulation Analysis, Mobile.**

I. Introduction

Antenna is one type of transducer that converts the electrical energy into the electro-magnetic energy in form of electromagnetic waves. The use of wireless technology which was as a result of advancement in Radio Frequency (RF) has really help in many application like satellite, Radar, space rocket, mars rovers .Antennas play a very important role in the field of wireless communications. Antennas are the backbone and almost everything in the wireless communication systems without which the world could have not reached at this age of technology (4).A patch antenna is a popular type of microstrip antenna that is also known as a flat panel antenna. Though earlier work was done by (2). It consists of a thin metallic patch separated from the ground plane by a dielectric layer and usually used at microwave frequencies. Some patch antennas use dielectric spacers between the two plates instead of a continuous sheet in order to achieve better bandwidth. The most commonly used microstrip patch antennas are rectangular and circular patch antennas. These patch antennas are used for the widest and most demanding applications. Dual characteristics, circular polarizations, dual frequency operation, frequency agility, broad band width, feed line flexibility, beam scanning can be easily obtained from these patch antennas (4).They are often mounted on the exterior of aircraft and spacecraft, or are incorporated into mobile radio communications devices. When the antenna is loaded with a dielectric as its substrate, the length of the antenna decreases as the relative dielectric constant of the substrate increases.

II. Methods of Analysis

The most important step in designing a circular patch antenna operating at 7.6 GHz was to first calculate its radius follow by the other parameters such as slot, substrate, resonant frequencies, conductance and directivity.

The initial value for the radius of circular microstrip antenna to operate at 7.6 GHz was determined by (3)

$$radius(a) = \frac{F}{\left\{1+\frac{2h}{\pi\varepsilon_r F}\ln\left(\frac{\pi F}{2h}\right)+1.7726\right\}^{\frac{1}{2}}} \quad (3.1)$$

Where F= Resonant Frequency given by:

$$F = \frac{8.791\text{ x}10^9}{f_r\sqrt{\varepsilon_r}} \quad (3.2)$$

f_r = design frequency, and h = the dielectric substrate height. The substrate used was (RT/duroid 5880) with height h = 0.52mm and ε_r = dielectric constant = 2.2

But the patch in equation (3.1) is electrically larger due to fringing effect which was not been considered. The effective radius of the patch is given by (3)

$$a_{eff} = a\left\{1+\frac{2h}{\pi\varepsilon_r a}\left[\ln\left(\frac{\pi a}{2h}\right)+1.7726\right]\right\}^{\frac{1}{2}} \quad (3.3)$$

So, the resonant frequency for the dominant TM^z_{110} is given by (3)

$$(f)_{110} = \frac{1.8412\,C_0}{2\pi a_{eff}\sqrt{\varepsilon_r}} \quad (3.4)$$

Where C_0 is the free space speed of light.

2.1 Directivity

This is a measure of the concentration of radiation in the direction of the maximum (5) and it also measure how antenna places power in the main lobe rather than side lobes. It is one of the most important parameter in antenna design and was given by (3)

$$D_0 = \frac{U_{max}}{U_0} = \frac{4\pi U_{\max}}{P_{rad}} \quad (3.5)$$

where D_0 = Maximum directivity (dimensionless), U_{max} = maximum radiation intensity (W/unit) , U_0 = radiation intensity of isotropic source (W/unit) and P_{rad} = total radiated power (W)

2.2 Conductance

The conductance G of the dielectric materials separating the two conductors is termed shunt between the two conductors. The conductance due to the radiated power of the circular microstrip patch antenna can be computed using (3)

$$P_{rad} = |V_0|\frac{(k_0 a_e)^2}{960}\int_0^{\frac{\pi}{2}}\left[{J'_{02}}^2+\cos^2\theta {J'_{02}}^2\right]\sin\theta\,d\theta \quad (3.6)$$

equation (3.6) can be further broken down to (1)

$$P_{rad} = |V_0|^2\frac{(k_0 a_e)^2}{960}\left\{\begin{matrix}\left[1-\frac{3}{2^3}\alpha^2\sin^2\theta+\frac{1}{3\text{x}2^3}\alpha^4\sin^4\theta-\frac{7}{12\text{x}2^{10}}\alpha^6\sin^6\theta\right]+\\ 0.333\left[1-\frac{3}{2^3}\alpha^2\sin^2\theta+\frac{1}{3\text{x}2^3}\alpha^4\sin^4\theta-\frac{7}{12\text{x}2^{10}}\alpha^6\sin^6\theta\right]\end{matrix}\right\} \quad (3.7)$$

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where $V_0 = hE_0J_1(ka_e), \alpha = k_0a_e and k_0 = \frac{2\pi f_r}{v_0}$ (3.8)

k_0 is the free space phase constant. The conductance across the gap between the patch and the ground plane at $\emptyset' = 0^0$ is given by (3) as

$$G_{rad} = \frac{(k_0a_e)^2}{480}\int_0^{\frac{\pi}{2}}\left[J_{02}'^{\,2} + \cos^2\theta J_{02}'^{\,2}\right]\sin\theta\, d\theta \quad (3.9)$$

Equation (3.9) further reduces to (1)

$$G_{rad} = \frac{(k_0a_e)^2}{480}\left\{\begin{matrix}\left[1 - \frac{3}{2^3}\alpha^2\sin^2\theta + \frac{1}{3x2^3}\alpha^4\sin^4\theta - \frac{7}{12x2^{10}}\alpha^6\sin^6\theta\right] + \\ 0.333\left[1 - \frac{3}{2^3}\alpha^2\sin^2\theta + \frac{1}{3x2^3}\alpha^4\sin^4\theta - \frac{7}{12x2^{10}}\alpha^6\sin^6\theta\right]\end{matrix}\right\} \quad (3.10)$$

G_{rad} accounts for radiation and dielectric losses and are expressed as (3)

$$G_c = \frac{\varepsilon_{mo}\,\pi(\pi\mu_0(f_r)_{10})^{\frac{-3}{2}}}{4h^2\sqrt{\sigma}}[(ka_e)^2] - m^2 \quad (3.11)$$

$$G_d = \frac{\varepsilon_{mo}\tan\delta}{4\mu_0 h(f_r)_{10}}[(ka_e)^2 - m^2] \quad (3.12)$$

where G_c is the conductance due to conduction losses, G_d is the conductance due to dielectric losses and f_r is the resonant frequency of the mode. The total conductance can been expressed as (1)

$$G_t = G_{rad} + G_c + G_d \quad (3.13)$$

The conductivity of the substrate,

$$\sigma = \frac{G_1 l}{A}, \text{and skin dept}, \delta = \sqrt{\frac{2}{(\omega\mu_0\sigma)}} \quad (3.14)$$

2.3 Resonant input impedance

The input impedance of a circular patch at resonance is real and the input power is independent of the feed point position on the circumference (3). Taking the reference of the feed point at $\emptyset = 0^0$, the input resistance at any radial distance $\rho' = \rho_0$ from the center of the patch can be written as (3)

$$R_{in}(\rho' = \rho_0) = \frac{1}{G_t}\frac{J_m^2(k\rho_0)}{J_m^2(ka_e)} \quad (3.15)$$

For the circular patch antenna, the resonant input resistance with an inset feed is (3)

$$R_{in}(\rho' = \rho_0) = R_{in}(\rho' = a_e)\frac{J_m^2(k\rho_0)}{J_m^2(ka_e)} \quad (3.16)$$

$$R_{in}(\rho' = a_e) = \frac{1}{G_t}$$

where the radial distance is given as

$$\rho = \frac{2(2a)}{\lambda} \quad (3.17)$$

2.4 Quality factor

The quality is another way of expressing efficiency. It is a figure of merit that is representative of the antenna losses like radiation conduction (ohmic), dielectric and surface wave losses (1). The summation gives the total quality factor Q_t, which is influenced by all these losses (1)

$$Q_t^{-1} = Q_{rad}^{-1} + Q_c^{-1} + Q_d^{-1} + Q_{sw}^{-1} \quad (3.18)$$

For thin substrate, losses due to surface waves are very small. So, $h \ll \lambda_0$ and may be represented as (1)

$$Q_c^{-1} = h\sqrt{\pi f\mu\sigma} \quad (3.19)$$

$$Q_d^{-1} = \frac{1}{\tan\delta} \quad (3.20)$$

$$Q_{rad}^{-1} = \frac{2\omega\varepsilon_r}{h\left(\frac{G_{rad}}{2a}\right)}\left(\frac{a}{2}\right) \quad (3.21)$$

tanδ is the loss tangent of the substrate materials, δ is the conductivity of the conductors associated with the patch and the ground plane and $\frac{G_t}{2a}$ is the total conductance per unit length of the radiating aperture. G_{rad} is usually the dominant factors since it is inversely proportaional to the patch height (1).

III. Design Procedure

The radius of the circular microstrip antenna operating at 7.6 GHz was calculated using equations (3.1) and (3.3) for effective radius. It was calculated to be 0.440318mm and 0.73165mm respectively. The substrate used was (RT/duroid 5880) with height h = 0.52mm and dielectric constant ε_r =2.2. The result of calculated resonant frequency using equation (3.2) was 0.77985. The outer layer (Jacket) feed, cladding and the core were first design. The Jacket was assigned copper while the cladding was assigned Teflon. Another circle (named Substrate) was designed and merged with core. Roger/duroid- 5888 was assigned to the substrate. The position of the patch and the vertical stub together with their height along X-axis was later determined using 3D coordinate. This was found to be (-0.2, -1.25, 11) and (-0.2, -0.25, 12) while their height were (x, 1, 1) and (x, 0.5, -8) respectively. A coaxial probe type feed was used in this design. The center of the patch was taken as the origin and the feed point location was given by the coordinates (x, y, z). The probe was located on (-0.2, -0.15, 4) from the point of vertical stub. The feed point was located where the impedance was 50 ohms. The patch, probe and vertical stub were united together and assigned Perfect E Boundary. A rectangular box was later constructed and assigned radiation and air. Solution setup was performed after the whole process was completed.

Table 1: show the results of calculated parameters

Characteristics	RT/duroid -5580, ε_r=2.2
a(mm)	0.440318
a_{eff}(mm)	0.73165
F	0.77985
K_o	1.59174
E_o	≈ 3.9383
V_o	0.87599
α	1.16456
σ	0.006986
ω	4.77522×10^{10}
ρ	0.58709
P_{rad} (W)	0.00000216
G_{rad}(S)	0.004832
G_c(S)	3.864189×10^{-14}
G_d(S)	1.8×10^{-14}
G_t(S)	0.004832
D_o(dB)	2.3389
R_{in}(Ω)	206.9828
Q_C^{-1}	0.0013283
Q_d^{-1}	1.206×10^{-5}
Q_{rad}^{-1}	6.1681×10^{-14}
$(fr)_{110}$	2.03057×10^{10}

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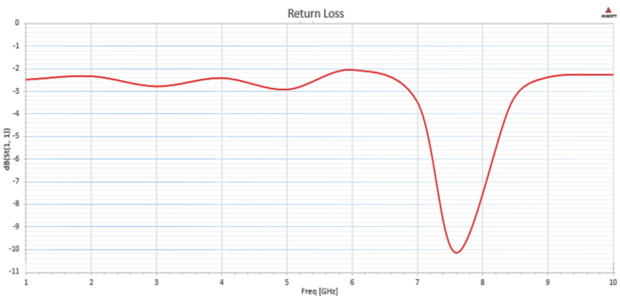
Table 2: Show the Antenna Parameters

Quantity	Value	Units
Max U	0.003409	
Peak Gain	0.054524	
Peak Realized Gain	42.839	
Radiated Power	0.754556	W
Accepted Power	0.785690	W
Incident Power	1.000000	W
Radiation efficiency	0.984756 %	



Graph of return loss of the simulated antenna.

Antenna patterns

The antenna pattern describes the relative strength of the radiated field in various directions from the antenna at a constant distance.

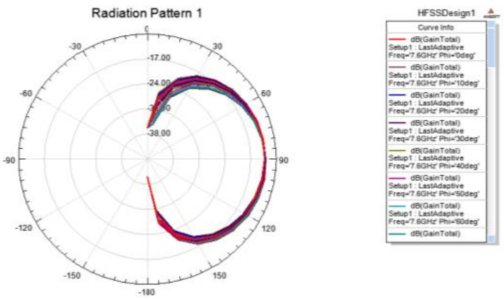


Fig.1. Showing the radiation pattern of gain total

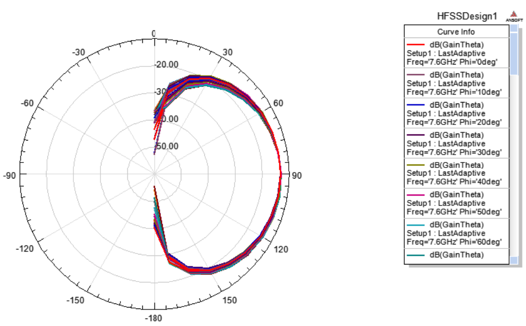


Fig.2. showing the radiation pattern of gain theta

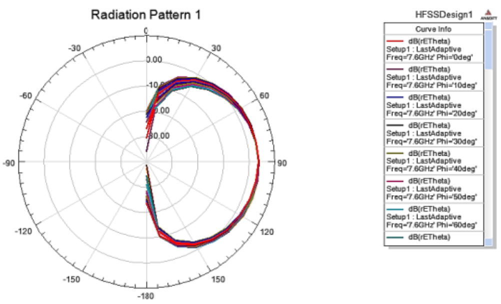


Fig.3. Showing radiation pattern of rETheta.

Fig.4. showing 3D gain of the antenna

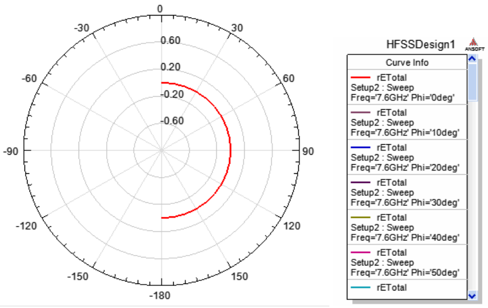


Fig.5. Showing the radiation pattern

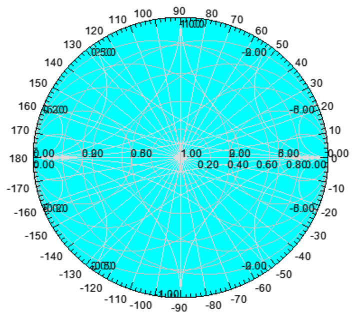


Fig.6. Showing the Smith chart of the S-Parameter (S 11)

IV. Conclusion

The aim of this work was to design a circular patch microstrip antenna for use in wireless communication. After designing the antenna, it was simulated using HFSS V13 and radiated power was obtained, peak realized gain, radiation efficiency which gives a satisfactory results.

With the ground plane dimensions 30mm by 40mm and the patch dimensions 1mm by 1mm, the antenna was rightly fits into various wireless communication equipment. A gain of 2.06dB and directivity of 2.3389 dB were obtained. The bandwidth obtained for this antenna was 20.3 MHz

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