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Design and Analysis of Circular Shape Microstrip Patch Antenna for C-band Applications

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Abstract
In this paper we have designed a Circular microstrip patch antenna operating at 5GHz using FEM based EM simulator software – Ansoft's HFSS v13.The circular patch antenna is designed on a FR4 substrate with dielectric constant ε_r = 4.4 and height of the substrate is 1.6mm. Several antenna characteristics such as return loss, radiation pattern, percentage bandwidth, directivity, antenna gain, radiation efficiency etc. are studied. The designed circular patch antenna shows return loss value well below -30dB and a percentage bandwidth equal to 3.79% is achieved. Also, a good directivity value of 4.5dBi and antenna gain equal to 2.66dBi is observed. Since the circular microstrip patch antenna is designed at C band it is applicable in different satellite communication applications such as transponder etc.

Keywords
Circular Microstrip Patch Antenna, Percentage Bandwidth, Directivity, Antenna Gain, HFSS.

I. Introduction

Microstrip antennas have profound applications especially in the field of medical, military, mobile and satellite communications. Their utilization has become diverse because of their small size and light weight. Rapid and cost effective fabrication is especially important when it comes to the prototyping of antennas for their performance evaluation. As wireless applications require more and more bandwidth, the demand for wideband antennas operating at higher frequencies becomes inevitable. Inherently microstrip antennas have narrow bandwidth and low efficiency and their performance greatly depends on the substrate parameters i.e. its dielectric constant, uniformity and loss tangent [5].

The microstrip antennas are mostly a broadside radiator. The patch is designed in such a way so that its pattern is maximum normal to it. End-fire radiator can also be chosen by proper mode selection. The microstrip patch antennas is one of the most useful antennas working at microwave frequencies (f > 1 GHz). It consists of a metallic "patch" on top of the dielectric substrate and below the dielectric material it has ground plane. The position of the feed has to be changed as before to control the input impedance [7, 8]. The patch, microstrip transmission line (or input, output pin of coaxial probe), and ground plane are made of high conductive material (typically copper). The patch may be in a variety of shapes, but rectangular and circular are the most common because ease of analysis and fabrication, attractive radiation characteristics, especially low cross polarization [2].

After rectangular patch the next configuration is the circular patch (as shown in figure 1) which has varying applications as a single patch element as well as in arrays. The modes that are supported primarily by a circular microstrip patch antenna whose substrate height is small ($h << \lambda$) are $TM^z$where z is taken perpendicular to the patch [4]. The circular patch has only one degree of freedom to control i.e. radius of the patch. Though this does not change the order of the modes; however, it does change the absolute value of the resonant frequency [3].

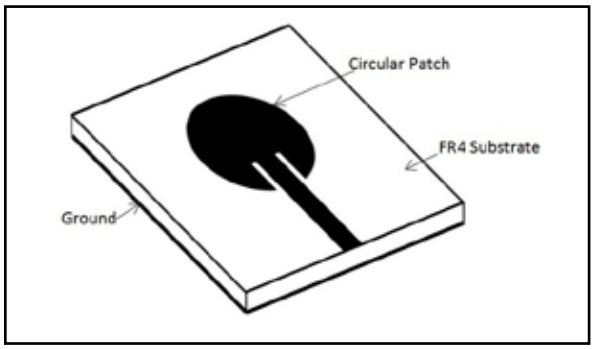

Fig. 1: A Circular microstrip patch antenna

In this paper we have designed a circular microstrip patch antenna operating at a frequency of 5GHz. The patch antenna is designed on a FR4 (Flame Retardant 4) substrate having a dielectric constant, ε_r = 4.4 and height of the substrate h = 1.6mm. For designing patch and ground copper conductor is used with bulk conductivity equal to 5.8×10^7siemens/m. The circular patch antenna is designed using EM (Electromagnetic) simulator software Ansoft's HFSS(High Frequency Structure Simulator)v13, which works on the principle of Finite Element Method (FEM). The FEM technique uses triangular shape meshes for surface meshing and tetrahedron shape meshes for volumetric meshing.Both these geometries are chosen as with these geometries two dimensional and three dimensional regions respectively can be meshed.

II. Design Methodology

A circular microstrip patch antenna designing is easier than other patch configuration as we only need one design parameter i.e. radius of the patch. A schematic of circular patch antenna is shown in figure 2. Based on the cavity model formulation, a design procedure is outlined which leads to practical designs of circular microstrip antennas for the dominant TM_{110} mode [1].

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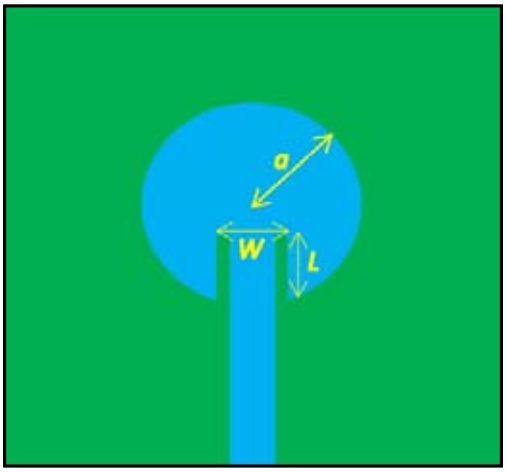

Fig. 2: Schematic of a Circular microstrip patch antenna

The procedure assumes that the specified information includes the dielectric constant of the substrate *(ε_r)*, the operating frequency *(f_r)* and the height of the substrate *(h)*. To find the actual radius '*a*' of the patch we have [1]:

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

Where, $$F = \frac{8.791\times10^9}{f_r\sqrt{\varepsilon_r}} \quad (2)$$

In the above equations we should remember that the operating frequency f_r should be taken in Hertz (Hz) and the height of the substrate *h* should be taken in Centimeters (cm).

III. Electromagnetic Simulation

The circular microstrip patch antenna is designed on a FR4 substrate having a dielectric constant, ε_r = 4.4 and height of the substrate *h* = 1.6mm at an operating frequency of 5GHz. For designing patch and ground copper conductor is used with bulk conductivity equal to 5.8×10^7siemens/m. The circular patch antenna is designed using EM simulator software Ansoft's HFSS *v*13, which works on the principle of Finite Element Method (FEM).

Using equation (1) and (2), and the given specified data the radius of the circular patch *a* = 8.56mm. A FR4 substrate of dimensions 30mm×30mm is taken. The depth (*L*) and width (*W*) of the inset are taken as 7.4mm and 3.6mm respectively. A 50Ω impedance microstrip line is used to feed the circular patch. The length of the feed line is 15.53mm and the width of the line taken is 3mm. For exciting the circular patch a wave port is used.

The circular microstrip patch antenna model designed in HFSS software is shown in figure 3.

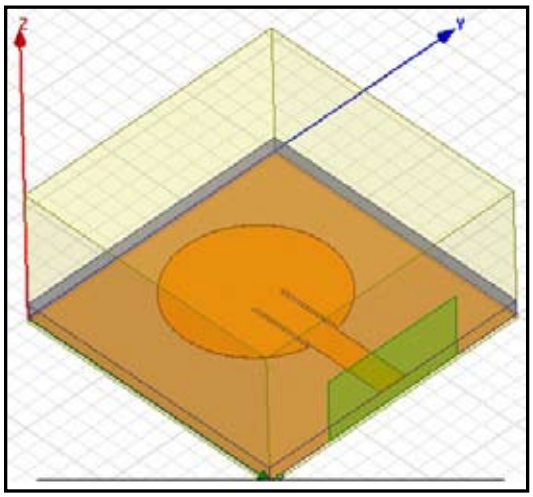

Fig. 3: HFSS model of Circular Microstrip Patch Antenna

IV. Simulation Results and Discussions

The HFSS designed model of circular microstrip patch antenna is simulated and a various antenna characteristics are obtained. Figure 4 shows the return loss plot of the designed circular patch antenna. The circular patch antenna shows a resonance peak at 5.026GHz and gives return loss value equal to -38.09dB. This shows that almost a perfect feed configuration is achieved, i.e. patch and feed line are in perfect impedance matching state. Also, the 10dB frequency bandwidth equal to 190.5MHz is observed which means a percentage bandwidth equal to 3.79% is calculated.

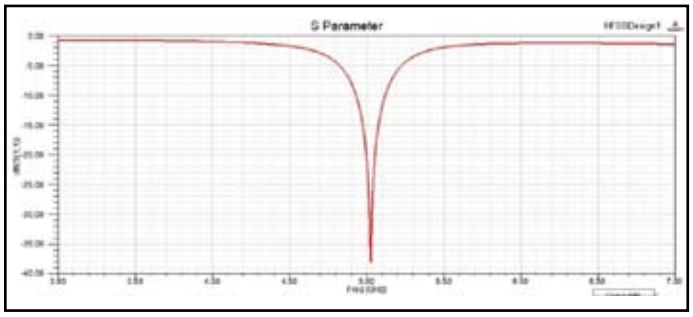

Fig. 4: Return loss plot of Circular Microstrip Patch Antenna

The frequency bandwidth and the percentage bandwidth for a circular Microstrip patch antenna are determined using [6]:

$$\text{Frequency Bandwidth} = f_H - f_L \quad (3)$$

And,

$$\text{Percentage Bandwidth} = \frac{f_H - f_L}{f_c}\times 100\% \quad (4)$$

Where f_H and f_L are the two frequency points on the return loss curve obtained on the -10dB line and f_C is the center frequency at which the resonance peak is observed.

Figure 5 and 6 shows the 3D and 2D plot of the radiation pattern of the designed circular patch antenna. From the radiation pattern plot we can observe that an end-fire radiation plot is achieved and no radiation is observed below the ground, which means a perfect ground condition is achieved. From the radiation plot we have also obtained the directivity and antenna gain of the designed circular patch antenna which are 4.5dBi and 2.66dBi respectively. Also, one more antenna characteristic known as radiation efficiency equal to 59.1% is achieved.

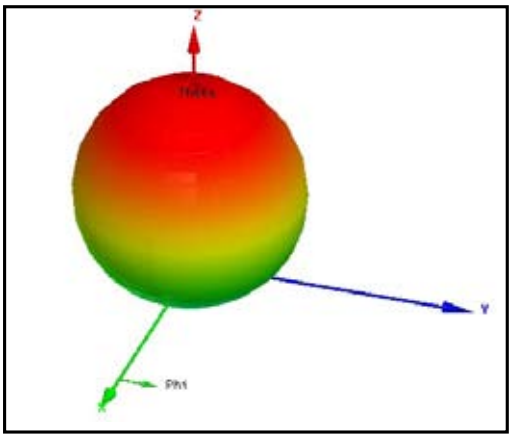

Fig. 5: 3D Radiation Plot of the designed Circular Patch Antenna

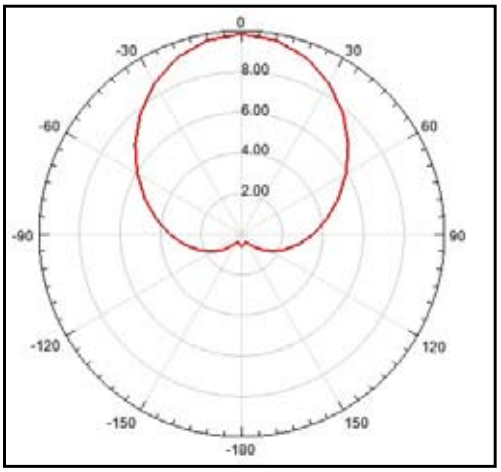

Fig. 6: 2D Radiation Plot of the designed Circular Patch Antenna

V. Conclusion

In this paper, we have presented the design and simulation of a Circular Microstrip patch Antenna at c band frequency region. The simulated results of circular microstrip patch antenna shows good directivity and gain value. The directivity and gain for the circular patch antenna is 4.5dBi and 2.66dBi respectively and a percentage bandwidthachieved is 3.79%. The high return loss value gives perfect impedance matching between patch and feed. Also, designed circular patch antenna gives a radiation efficiency equal to 59.1%. However, we can also improve the antenna characteristics using different known technologies to increse the applicability of this patch antenna. Although, this circular patch antenna may find applications in C-band satellite comunication applications such as transponders.

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