Comparative Study of Rectangular and Circular Microstrip Patch Antennas in X Band

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***Abstract*— A comparative performance study of rectangular and circular shape microstrip patch antennas at an X band frequency is presented in this paper. The resonant frequency is chosen at 10 GHz which is suitable for a variety of wireless applications. CST Microwave Studio is used as the software environment to design and compare the performance of the antennas. It is found that the rectangular patch antenna shows about 3.0 dB higher return loss than the return loss of circular patch antenna. In addition, the rectangular patch antenna has an improved VSWR value of 1.18 than that of the circular patch with VSWR 1.27. However, circular patch antenna offers about 8% higher bandwidth and nearly 2.0dB less side lobe power than that of rectangular patch antenna.**

Keywords—microstrip patch antenna; rectangular patch antenna; circular patch antenna; x band

I. Introduction

In the era of modern world where communication has become indispensable, antennas are rightly to be said as electronic eyes and ears of the world due to their undeniable place in the communication technology. While, the revolution in antenna engineering leads the fast growing communication systems, Microstrip Patch Antennas have been one of the most innovative developments in the era of miniaturization. Microstrip Patch Antennas are increasingly finding their applications in a broad range of microwave systems from radars, telemetry, navigation, biomedical systems, mobile and satellite communications, missile systems, global positioning system (GPS) for remote sensing and etc. because of their light weight, low volume, low cost, low profile, ease of fabrication, conformability to mounting hosts and ability to be printed directly onto a circuit board.

The conventional structure of a Microstrip Patch antenna comprises of a metallic radiating patch element, embedded into a grounded dielectric substrate. The shape of the conducting patch can be of any geometrical form among which rectangular and circular are the most common. The rectangular and circular Microstrip patch antennas are used as simple and for the extensive and most demanding applications as they easily provide with feed line flexibility, multiple frequency operation, linear and circular polarizations, frequency agility, good bandwidth etc. A circular patch antenna fed by an aperture coupled microstrip line has been demonstrated in [1]. In [2] a rectangular microstrip patch antenna with EBG structure has been presented. Rectangular and circular microstrip patch antenna can be employed for multi-frequency operation. A dual band circular patch antenna is presented in [3] which is smaller than the conventional antenna for wideband application and a triple band capacitive-fed circular patch antenna with arc-shaped slots that covers 2380 – 2508 MHz and 5100 – 6030 MHz is proposed in [4]. By introducing a twin-diamond-shaped patch and a gap-coupled feed structure, a left-handed circularly polarized (LHCP) antenna has been obtained in [5]. Even six linear polarizations are also possible with a circular patch antenna using coaxial-fed at center with 12 p-i-n diodes placed across a circular ring slot on the patch, as proposed in [6].

Another reason for the popularity of the rectangular and circular patch antenna is their compatibility to array configurations. Rectangular and circular patches are very popular shapes for microstrip patch antenna array constructions. The design of a four by one (4×1) patch array microstrip rectangular antenna with microstrip line feeding based on quarter wave impedance matching technique and with center frequency at 2.5GHz for WiMAX application has been presented in [7]. In [8] 1×4 rectangular microstrip array antennas have been designed at 16 GHz resonant frequency for Ku Band usage and for each antenna ,electrical parameters like S11 response, directivity, gain, radiation efficiency etc. are investigated for 26 array antennas in simulation media HFSS v12 by changing the feed line widths systematically.

However, Microstrip patch antennas have some major disadvantages as narrow bandwidth, low gain and low power handling capability. A narrow BW of approximately 1-5% is the most major limiting factor for the widespread applications of Microstrip Patch antennas. Therefore, to overcome these limitations several methods have been introduced which includes modification of the patch shapes for wide band [9-12], different types of feeding mechanisms for high gain [13-14] and introduction of different types of slots and cuts [15-16].

This paper work involves a comparison study of a rectangular and a circular patch antenna with line feed, both resonant at the frequency of 10 GHz, in the X band which has applications in Satellite Communication, Radar Engineering, Space Communications etc. The comparison has been done on the simulated results obtained from the simulation software Computer Simulation Technology (CST) Microwave Studio. The organization of the paper is as follows, Section II presents the design formulations of the two antennas, design specifications of the antennas are provided in Section III. The simulated results are discussed in Section IV and finally Section V provides the conclusion.

II. Antenna Design

A. Rectangular Patch Antenna

The formulas to determine the dimensions of a rectangular antenna are as follows [17],

$$W = \frac{v_0}{2f_r}\sqrt{\frac{2}{\varepsilon_r + 1}} \tag{1}$$

$$\varepsilon_{eff} = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2}\left[1 + 12\frac{h}{W}\right]^{-\frac{1}{2}} \tag{2}$$

$$\Delta L = 0.412h\frac{(\varepsilon_{reff} + 0.3)\left(\frac{W}{h} + 0.264\right)}{(\varepsilon_{reff} - 0.258)\left(\frac{W}{h} + 0.8\right)} \tag{3}$$

$$L_{eff} = L + 2\Delta L \tag{4}$$

$$L = \frac{v_0}{2f_r\sqrt{\varepsilon_{eff}}} - 2\Delta L \tag{5}$$

Here, W is the width of the patch, v_0 is the free space velocity of light, ε_r is the dielectric constant of the substrate, f_r is the resonant frequency, ε_{reff} is the effective dielectric constant, h is the height of the substrate, ΔL is the extension in length due to fringing effect, L_{eff} is the effective length of the patch and L is the actual length of the patch.

B. Circular Patch Antenna

The radius of the circular patch is given by [17]:

$$a = \frac{F}{\left\{1 + \frac{2h}{\pi\epsilon_r F}\left[\ln\left(\frac{\pi F}{2h}\right) + 1.7726\right]\right\}^{1/2}} \tag{6}$$

Where,

$$F = \frac{8.791 \times 10^9}{f_r\sqrt{\epsilon_r}}$$

III. Design Parameters

The antennas have been designed on the substrate Roger RT5880 for a good dielectric constant of 2.2. The other parameters used to design the two configurations of the antenna have been shown in table I.

TABLE I List of Design Parameters

Parameter	Rectangular	Circular
Operating Frequency	10 GHz	10 GHz
Patch Size	Length , L = 8.8 mm Width, W= 9.95 mm	Radius ,a = 5.25 mm
Substrate Height, h	1.588 mm	1.588 mm
Patch Thickness, M_t	0.05 mm	0.05 mm
Transmission Line Length, L_f	4.4 mm	4.4 mm
Transmission Line Width, W_f	1.2 mm	1.2 mm
Dielectric Constant, ε_r	2.2	2.2

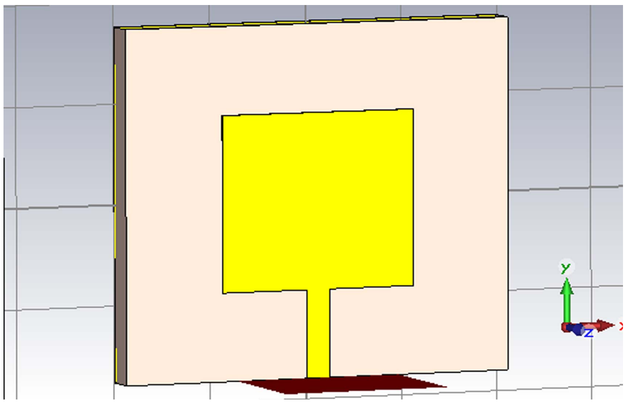

Fig. 1 Structure of Rectangular Patch Antenna

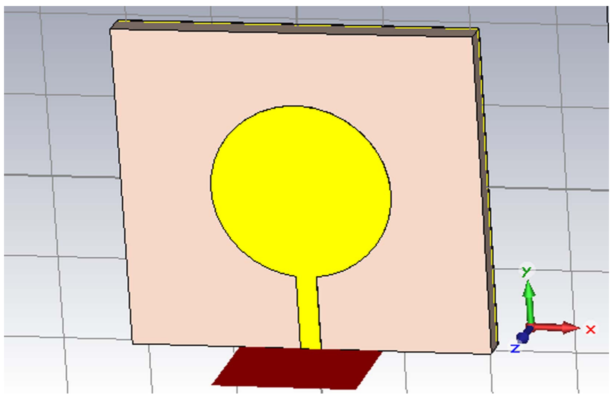

Fig. 2 Structure of Circular Patch Antenna

IV. Simulation Results and Discussion

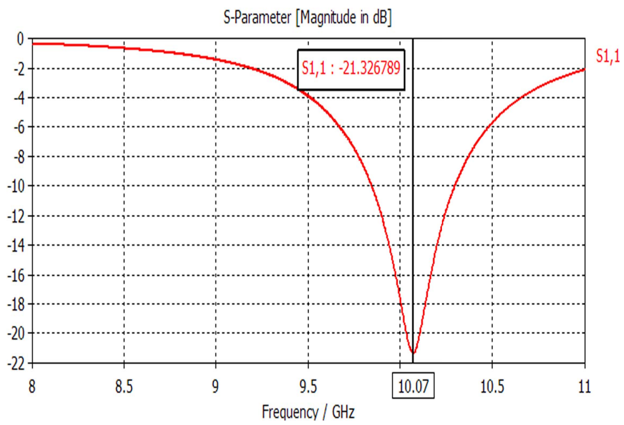

Fig. 3 S- Parameter Plot of Rectangular Patch Antenna

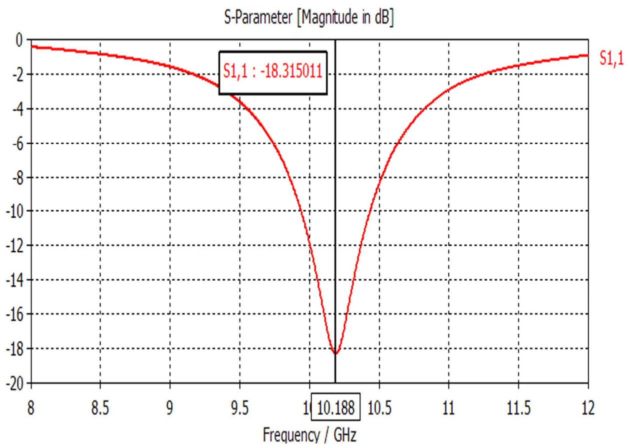

Fig. 4 S- Parameter Plot of Circular Patch Antenna

Fig.3 and Fig.4, shows that at the resonant frequency the minimum return loss value of the rectangular patch antenna is -21.3 dB, whereas for circular patch antenna the return loss has a minimum value of -18.3 dB at the resonant frequency, specifying that a 3 dB of better return loss value occurs for the rectangular patch antenna at the same resonant frequency.

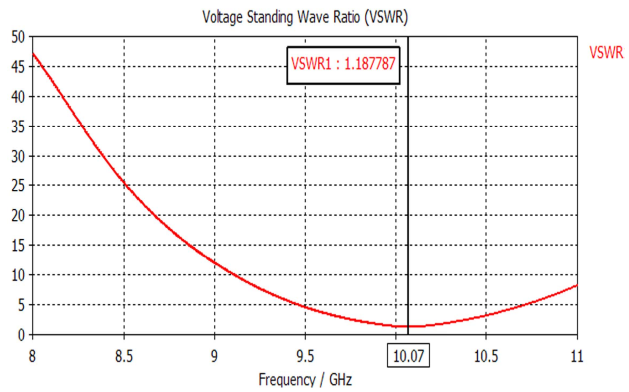

Fig. 5 VSWR Plot of Rectangular Patch Antenna

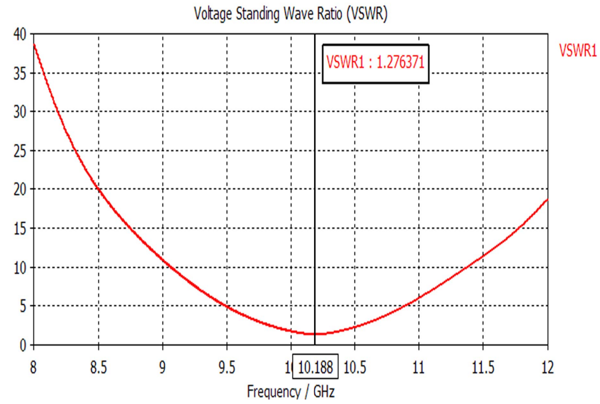

Fig. 6 VSWR Plot of Circular Patch Antenna

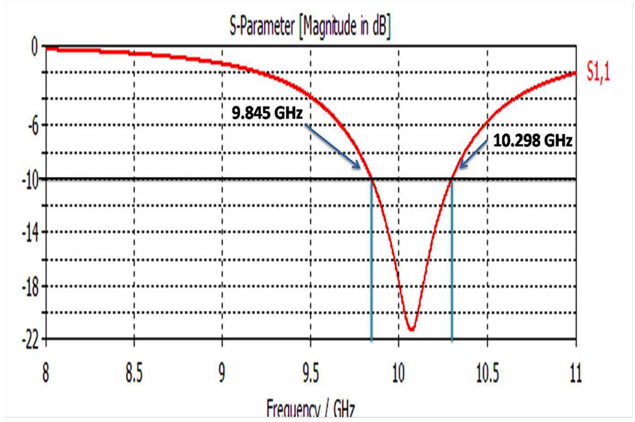

Fig. 7 Bandwidth Calculation of Rectangular Patch Antenna

The VSWR plots of both the antennas (Fig.5 and Fig.6) points that at the same resonant frequency the rectangular patch antenna has a better VSWR value of 1.18 than that of the circular patch with VSWR 1.27 as the VSWR of the rectangular patch antenna is more closer to the ideal value of VSWR=1 for an antenna.

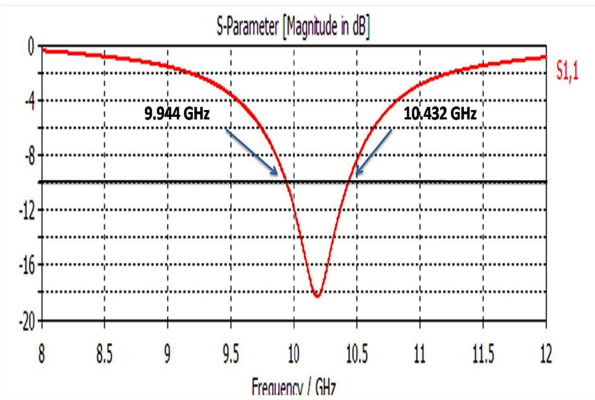

Fig. 8 Bandwidth Calculation of Circular Patch Antenna

In case of -10 dB bandwidth (Fig.7 and Fig.8) consideration the circular patch antenna shows a bandwidth of 488 MHz which is approximately 8% better than the 453 MHz bandwidth offered by the rectangular patch antenna.

From the polar plot of radiation pattern (Fig.9 and Fig.10) it can be seen that the directivity occurs with approximately same value for both rectangular and circular patch antenna. However, the 3dB angular beamwidth (i.e. HPBW) of circular patch antenna has a better value of 75.8 deg than the rectangular patch with 74 deg. beamwidth. Again the side lobe level for the circular patch is approximately 2 dB lower than the rectangular patch. Therefore, the circular patch antenna has a better radiation pattern when compared to the rectangular patch antenna.

From the radiation pattern plot (Fig.11 and Fig.12) the gain of both antennas can be calculated. The rectangular patch antenna has a gain of 7.7 dB while the gain of circular one is 7.52 dB.

The smith chart (Fig.13 and Fig.14) shows that better impedance matching occurs for the circular patch antenna instead of using same feed length for both the configurations.

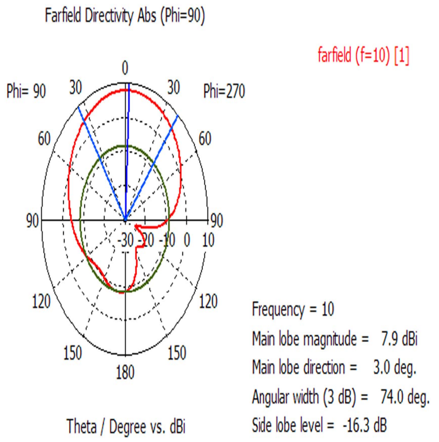

Fig. 9 Polar Plot of Radiation Pattern of Rectangular Patch Antenna

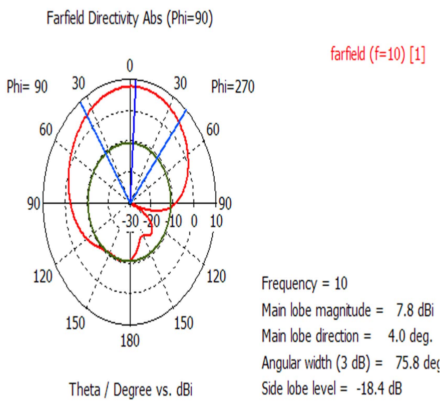

Fig. 10 Polar Plot of Radiation Pattern of Circular Patch Antenna

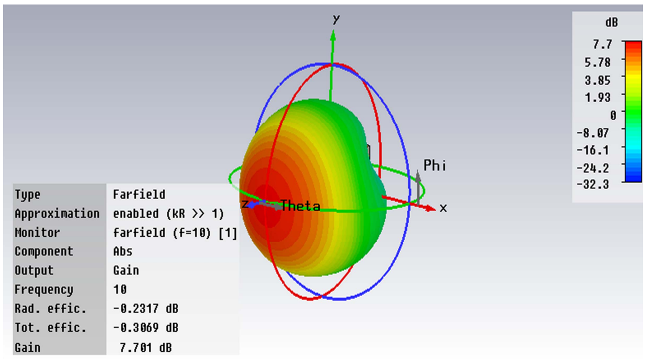

Fig. 11 3D Radiation Pattern of Rectangular Patch Antenna

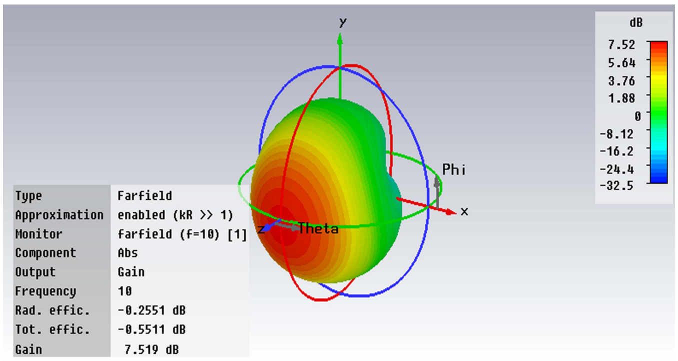

Fig. 12 3D Radiation Pattern of Circular Patch Antenna

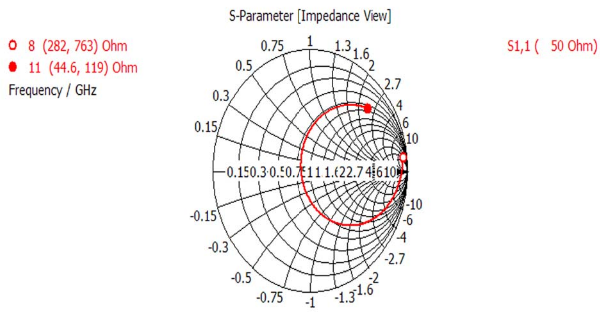

Fig. 13 Smith Chart of Rectangular Patch Antenna

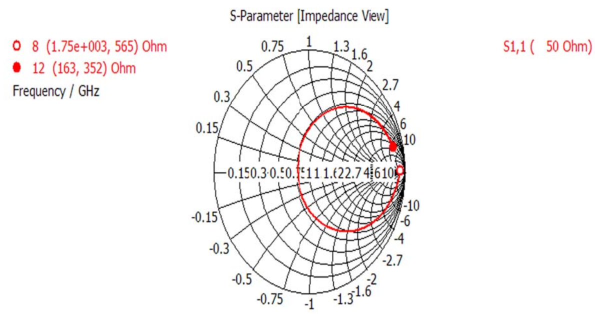

Fig. 14 Smith Chart of Circular Patch Antenna

TABLE II COMPARISON OF PERFORMANCE PARAMETERS

Parameters	Rectangular	Circular
Return Loss	-21.3 dB	-18.3 dB
VSWR	1.18	1.27
Bandwidth	453 MHz	488 MHz
Directivity	7.9 dBi	7.8 dBi
HPBW	74 degree	75.8 degree
Side Lobe Level	-16.3 dB	-18.4 dB
Gain	7.7 dB	7.52 dB
Radiation Efficiency	94.8%	94.4%
Total Efficiency	88%	88%

The overall comparison of different performance parameters of rectangular and circular patch antennas have been summarized in table II. From perspective of return loss and VSWR, rectangular antenna shows superiority over the circular one and when bandwidth and side lobe levels are considered circular patch antenna becomes superior over the rectangular. However, both the antennas exhibit same radiation efficiency and total radiation efficiency and nearly same directivity which make them compatible for similar applications.

V. CONCLUSION

Comparison between a rectangular patch antenna and a circular patch antenna using the simulation results obtained from CST Microwave studio has been carried out. Both the antenna configurations show quite good results on perspectives of return loss, VSWR, gain and radiation efficiency, for X band applications and can be used for same applications of Satellite Communication, Radar Engineering etc. However, from the perspective of return loss, VSWR and gain the rectangular patch configuration shows better performance, while the circular patch configuration shows better results on bandwidth, radiation pattern, side lobe levels and smith chart i.e. in impedance matching.

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