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Performances comparison study between circular and rectangular patch antennas at 2.4 GHz using CST

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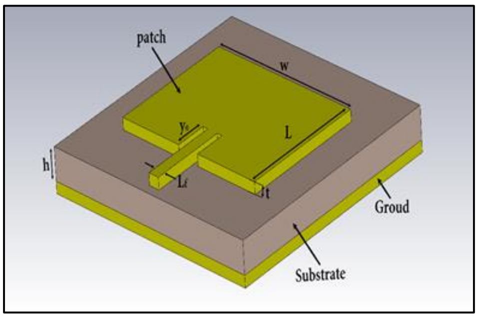
Abstract
A comparative study of inset feed microstrip rectangular and circular antennas for wireless applications is presented in this paper. The design of the antenna is achieved by using FR-4 substrate with dielectric constants of 4.3, thickness of 1.5mm and tangent loss 0.025 and working at 2.4 GHz. The dimensions and performances of the designed antenna are optimized by using (CST) software. A performance comparison between the simulation and the fabrication antennas has been done. The impedance bandwidth of the rectangular patch antenna was 79 MHz, where for the circular patch was 72 MHz. The return loss and the efficiency of E-plane HPBW and H-plane HPBW in the circular patch antenna was very close to the rectangular patch antenna.

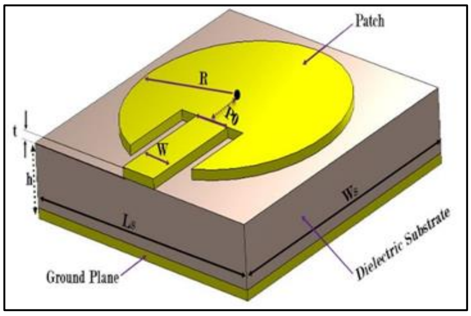
Keywords: antenna, radiation pattern, bandwidth, directivity, gain, return loss

1. Introduction
The microstrip patch antenna got a radiating patch on one side of the dielectric substrate and it has a ground plane on the other side of the substrate the radiation occurs from the fringing fields between the periphery of the patch and the ground plane [1]. The thickness of the metallic patch should be $t << \lambda_o$ (where to is free space wavelength). The height of the substrate, $h << \lambda_o$ (usually $0.003\lambda_o \leq h \leq 0.05\lambda_o$) [2]. There are many substrates available that can be used with dielectric constant which ranges from $(2 \leq \varepsilon_r \leq 12)$ [2]. Microstrip patch antennas are named based on the shape of the radiating patch. There are many available shapes of radiating Patch such as square, rectangular, circular, elliptical, triangular, circular ring, and ring sector square, rectangular and circular microstrip patch antennas are easy to design and analyse all the parameters of the antenna. These features make them more common [2]. The microstrip circular and rectangular patch antennas have several advantages such as being lightweight, low volume, and low profile over conventional microwave antennas [3]. Because of its low profile characteristics, the microstrip antenna is the most widely used in defence, aerospace, military, and satellite communication applications [2]. The Circular microstrip patch antenna is simpler compared to the rectangular antenna microstrip patch since it has one degree of freedom to control (radius) as compared to the rectangular microstrip which has two l Length and width). Therefore, a circular microstrip patch antenna is simpler to design and its radiation can be easily controlled [4]. In addition, the physical size of the circular patch antenna is 16% less than that of the rectangular microstrip antenna at the same design frequency [5]. The proposed circular and rectangular microstrip antennas in this study are chosen to operate at 2.4 GHz to support many applications especially in wireless communication such as Wi-Fi [6], Bluetooth [7] and medical area. A performance comparison between the simulation and the fabrication antennas has been done. The dimensions and performances of the designed antennas are optimized by using Computer Simulation Technology (CST).

2. Design of the rectangular and circular patch.
The inset feed rectangular and circular Patch antenna shown in Fig.1 (a, and b) and in Fig.2 (a, and b). The patch and ground planes for the proposed antennas are assumed to be printed on the different dielectric substrate which has dielectric constant $\varepsilon_r = 4.3$ in order to see the effect of dielectric constant and substrate thickness on the antenna directivity, and the efficiency of the antenna, the total efficiency must be more than -3 dB to get more than 50% antenna efficiency at 2.4 GHz frequency [16].



(a)

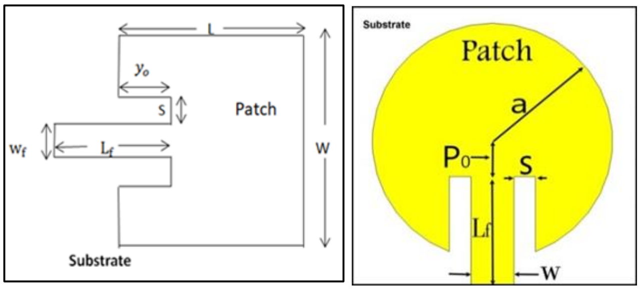


(b)

Fig 1: Geometry of microstrip (a) rectangular and (b) circular patch antenna

The dimensions of rectangular patch antenna structural parameters such as width w, length L, feeding point location γ_o, the width w_f and length L_f of inset feed microstrip transmission line shown Fig.2 (a), should be calculated. The dimensions of circular patch antenna structural Parameters such as patch radius, feeding point location you the width w_f and L_f of inset feed microstrip transmission line shown in Fig2 (a, b) should be calculated.

To achieve the calculation of the previous parameters patch dimensions three important must be available are (the frequency of operation f, the dielectric constant of the substrate ε_r and the thickness of the dielectric substrate h) as in the following subsections.



(a) (b)

Fig 2: The proposed inset feed microstrip (a) Rectangular patch antenna, (b) circular patch antenna patch

The width of the following equation patch is calculated using [6, 8, 9]:

$$w = \frac{c}{2f}\sqrt{\frac{2}{\epsilon_r + 1}} \qquad (1)$$

Where; w=width of the patch, c=speed of light and, ε_r=substrate dielectric constant.

The effective dielectric constant is given by as in, [10].

$$\epsilon_{reff} = \frac{\epsilon_r+1}{2} + \frac{\epsilon_r-1}{2}\left[1 + 12\frac{h}{w}\right]^{-1/2}, {}^{w}/_{h} > 1 \qquad (2)$$

The extended length of the patch is given as, [11];

$$\Delta L = 0.412h\frac{(\epsilon_{reff}+0.3)\left(\frac{w}{h}+0.6\right)}{(\epsilon_{reff}-0.258)\left(\frac{w}{h}+0.8\right)} \qquad (3)$$

The length (L) of the patch is now to be calculated using equation [6, 8, 9],

$$L = \frac{c}{2f\sqrt{\epsilon_{reff}}} - 2\Delta L \qquad (4)$$

The actual circular patch radius is given by [2]

$$a = \frac{F}{\left\{1+\frac{2h}{\pi\epsilon_r F}\left[\ln\left(\frac{\pi F}{2h}\right)+1.77726\right]\right\}^{\frac{1}{2}}} \qquad (5)$$

Where $F = \frac{8.791\times10^9}{f_r\sqrt{\epsilon_r}}$, and the effective radius a_e of patch is given by, [12].

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

The line characteristic impedance of microstrip is given as following, [13].

$$Z_O = \begin{cases} \frac{120\pi}{\sqrt{\epsilon_{reff}}\left[\frac{w_f}{h}+1.393+0.667\,ln\left(\frac{w_f}{h}+1.444\right)\right]} & \frac{w_f}{h} > 1 \\ \frac{60}{\sqrt{\epsilon_{reff}}}\,Ln\left(\frac{8\,h}{w_f}+\frac{w_f}{4\,h}\right) & for\ \frac{w_f}{h} < 1 \end{cases} \qquad (7)$$

where w_f is feed line width, it is difficult to find the width w_f in terms of characteristic impedance Z_o, then a MATLAB Program has been used to plot or Z_o as a function of the width w_f for different dielectric constant $\varepsilon_r = 4.3$ and each with different substrate thickness h=1.5mm, then width w_f is determined at Z_o=50Ω for each case. The length L_f of inset feed line shown in Fig 2 (a,b) is given by, [14].

$$L_f = \frac{c}{4f\sqrt{\epsilon_{reff}}} \qquad (8)$$

The inset feed (s) is given by, [15];

$$S = \frac{v_o}{\sqrt{2\epsilon_{reff}}}\ \frac{4.65\times10^{-12}}{f_{GHz}} \qquad (9)$$

Where $v_o = 3 \times 10^8$. The inset feed point location γ_o

In this design inset feed line has been used as shown in Fig2 (a and b). The feeding point must be located at γ_o from the edge of the rectangular and circular patch so that the edge input resistance of the patch γ_o=0 will reduce to a value that must the characteristic impedance Z_o of the inset feed microstrip line. The inset feed at any distance γ_o as a function of the characteristic impedance of the inset feed line is given by, [13].

$$y_o = \frac{L}{\pi}\cos^{-1}\sqrt{\frac{Z_o}{R_{in}}} \quad (10)$$

2.1. The calculation results of the physical dimension of the designed antenna

All physical dimensions required to design the proposed rectangular and circular patch antenna were obtained using the previous formulas with MATLAB code and listed in table 1.

Table 1: List of design physical parameters (for $\varepsilon_r = 4.3$, h=1.5 mm, and at f= 2.4GHz)

Parameter	Rectangular	Circular
Patch size	Width w-38.39mm Length L=29.87mm	Radius= 17mm Effective= radius=1.768mm
Feeding point location y_o	9.862mm	4.55mm
Width of feed line W_f	2.94mm	2.94mm
Length of the feed line L_f	15mm	17mm
Width of inset cut S	1.142mm	0.2mm

3. Simulation Results

To optimize the dimensions and performances of the designed inset feed microstrip rectangular and circular patch antenna, CST software has been used to simulate such antenna by using the physical calculated dimensions shown in table 1. The simulation results of the patch dimensions are shown in table 2.The simulation results such as the return loss S11 (20 Log Kr) in dB is shown in Fig. (3), where K_r is the voltage reflection coefficient, 3D and 2D directivity are shown as in Fig (4) and Fig (5).

Table 2: The simulated dimensions of the both proposed antennas (For; $\varepsilon_r = 4.3$, h=1.5mm, and f= 2.4 GHz).

Parameter	Rectangular	Circular
patch size	Width W=38.39mm Length L=29.39mm	radius= 17.78mm effective radius=17.68mm
feeding point location y_o	7.4mm	5.85mm
width of feed line W_f	2.94mm	2.9mm
length of the feed line L_f	13mm	15mm
width of inset cut S	1.47mm	1.47mm

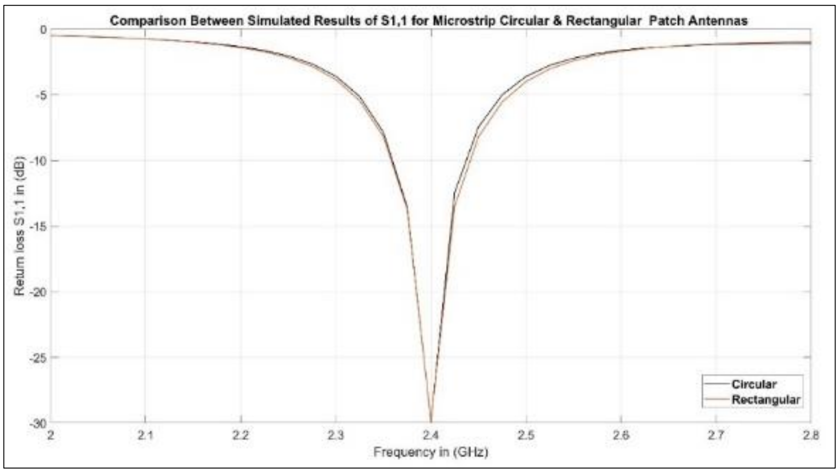
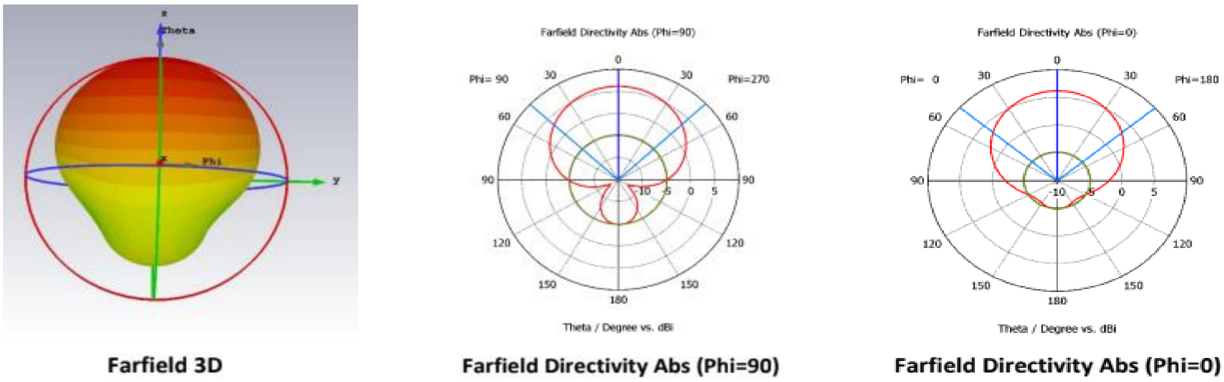


Fig 3: The simulation results of response return loss S11, for the designed rectangular and circular patch ($\varepsilon_r = 4.3$ and h=1.5mm).

Fig.3, show that at the resonant frequency the minimum return loss value of the rectangular is -29.8 dB, whereas for the circular patch antenna the return loss has a minimum value of -29.84 dB at the resonant frequency *i.e.* that an approximate at the value. In the case of (-10 dB) impedance bandwidth, the rectangular patch antenna shows a bandwidth of 79 MHz whereas the circular patch antenna shows a bandwidth of 72 MHz so; the rectangular patch antenna gives better performance in this regard.



(a) (b) (c)

Fig 4: The simulation radiation pattern for the rectangular patch at f=2.4GHz, (a) 3D-directivity, (b) 2D-HPBW in H-plane, (c) 2D-HPBW in E-plane

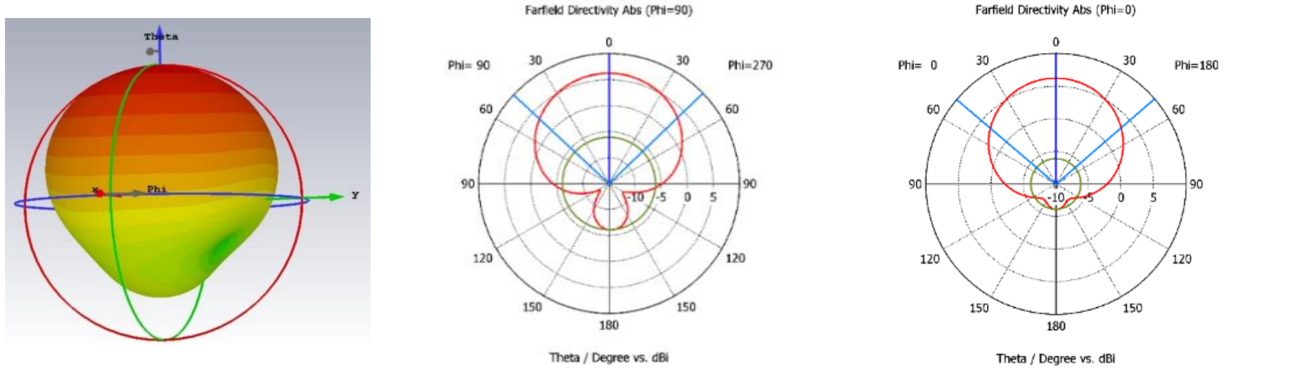


Fig 5: The simulation radiation pattern for the circular patch at f= 2.4 GHz, (a) 3D-directivity, (b) 2D-HPBW in H-plane (c) 2D-HPBW in E-plane

The 3D radiation pattern, (Fig. 4 and Fig. 5), it is shown that both antennas have a directive radiation pattern and an approximately same value for both rectangular and circular antenna (6.13 dB and 6.2 dB) respectively. While the both antenna having a wide half power beamwidth (HPBW) at (3dB). The overall performance parameters of both rectangular and circular patch antennas were summarized in table 3.

Table 3: The simulated performances of the rectangular and circular antennas

Parameter	Rectangular	Circular
Return loss S1,1 (dB)	-29.8	-29.84
Impedance bandwidth (MHz)	79	72
3D – directivity D_o (dB)	6.13	6.2
2D – HPBW in H – plane (deg)	93.6	92.9
2D – HPBW in E – plane (deg)	97.8	99
Radiation efficiency	0.48	0.428

4. Conclusion

A comparison between rectangular and circular patch antennas has been carried out using the simulation results obtained from CST at the resonance frequency 2.4 GHz, and the substrate with dielectric constant of 4.3. The return loss and the efficiency of E-plane HPBW and H-plane HPBW in the circular patch antenna was very close to the rectangular patch antenna. The impedance bandwidth of the rectangular patch and circular patch were 79 MHz, and 72 MHz respectively. The directivity appears almost equal for both antennas. However, both the antennas with this work design exhibit the same radiation efficiency and total radiation efficiency and nearly the same directivity which make them compatible for similar applications.

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