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Design and Construction of a Circular Microstrip Patch Antenna for Bluetooth Band Applications

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Abstract: This paper presents a design of low profile inset feed microstrip circular patch antenna working at 2.4GHz. The design is achieved by using substrate (ε_r=4.3), with substrate height (1.5mm) and tangent less 0.025. The dimensions and performances of the designed antenna are optimized by using (CST) software. The designed antenna is fabricated on the available FR-4 epoxy as substrate material and then such antenna is tested by using network analyser to measure the return loss. The measured results shown that the return loss of (-29.323 dB), and the impedance bandwidth is BW=100 MHz at resonate frequency 2.4056 GHz. While the simulated results the patch antenna resonate at 2.4 GHz with a return loss of (-29.8 dB), and impedance bandwidth is BW=78 MHz.
Keyword: return loss, directivity, bandwidth, circular patch

1. INTRODUCTION

Due to its unique characteristics, including itstiny size, light weight, low profile, affordable manufacture, and adaptability to various shapes, consumption ofa tiny size, simple integration with printed circuit boards, and simple manufacturing, andThe microstrip patch antenna has an efficient directional radiation pattern and can be applied to many different situations. [1,2,3]. The name of a microstrip patch antennais based on the radiating patch's style. The forms of radiating patches include square, rectangle, circle, ellipse, triangle, circular ring, and ring sector. Microstrip patch antennas that are square, rectangular, and circular are simple to design and assess all of the antenna's properties. These qualities increase their prevalence [4]. The proposed microstrip shown in Fig(1), consists of circular conducting patch with thickness ($t << \lambda_o$) with radius (a) placed on one side of dielectric substrate with thickness (h) within the range ($0.003\lambda_o \leq h \leq 0.05\lambda_o$) while the ground placed on the other side of the substrate with thickness where is the operating wave length. There are various substrates that can be used for the design of microstrip patch antenna and their e dielectric constants are usually in the range $2 \leq \varepsilon_r \leq 12$ [5]. Due to the fact that a circular microstrip patch antenna only has one degree of freedom to manage (radius) as opposed to a rectangular microstrip patch antenna's two (length and width), the circular microstrip patch antenna is easier to build and its radiation is more controllable [6]. Additionally, at the same design frequency, the physical dimension of the circular patch antenna is 16 present smaller than that of the rectangular microstrip antenna [7].

The proposed circular antenna was chosen to operate at 2.4GHz to support many applications especially in wireless communication such as Wi-Fi, Bluetooth and medical area [12].

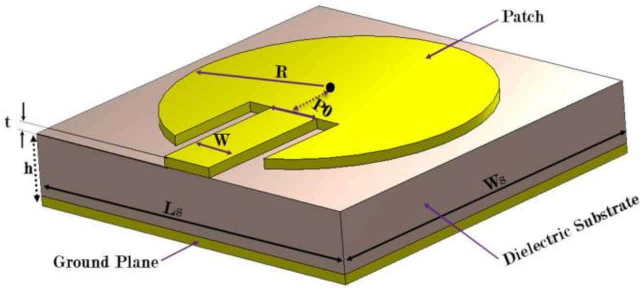

Figure 1: Geometry of microstrip circular patch antenna

Its dimensions and performances of the designed antenna are optimized by using Computer Simulation Technology (CST). Also the designed an antenna is made from the available FR-4 epoxy substrate with dielectric constants of 4.3 with thickness of 1.5 mm

2. THE DESIGN OF THE CIRCULAR PATCH ANTENNA

The inset feed circular patch antenna shown in Fig. 2. The patch and ground planes for the proposed antennas are assumed to be printed on the FR-4 dielectric substrate which has dielectric constant ε_r=4.3. The dimensions of antenna structural parameters such as patch radius, feeding point location P_o the width W_f and length L_f of inset feed microstrip transmission line shown in Fig. 2 should be calculated. To achieve the calculation of the previous patch dimensions three important parameters must be available are (the frequency of operation f, the dielectric constant of the substrate $\varepsilon_r$and the thickness of the dielectric substrateh) as in the following subsections [13].

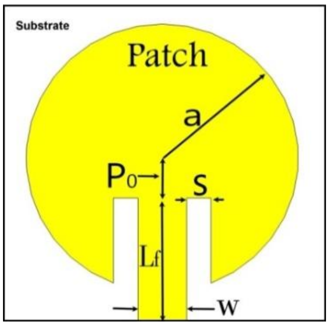

Figure 2:Proposed inset feed microstrip circular patch antenna

2-1 The circular patch's radius

The circular patch's radius is determined using equation. Since the patch's size is regarded as a circular loop, and the patch's real radius is determined by [4]:

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

Where, $F = \frac{8.791\times10^9}{f_r\sqrt{\epsilon_r}}$, calculated is the circular patch's effective radius a_e by the eq.(2)[8];

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

The width calculation of feed microstrip line W_f when the chartacterstic impedance (Z_o=50Ω), [4].

$$Z_O = \begin{cases} \dfrac{120\pi}{\sqrt{\epsilon_{reff}}\left[\frac{w_f}{h}+1.393+0.667\ \ln\left(\frac{w_f}{h}+1.444\right)\right]} \ for \dfrac{w_f}{h} > 1 \\ \\ \dfrac{60}{\sqrt{\epsilon_{reff}}} Ln\left(\dfrac{8\,h}{w_f}+\dfrac{w_f}{4\,h}\right) for \dfrac{w_f}{h} < 1 \end{cases} \quad (3)$$

The length L_f of inset feed line shown in Fig. 2 is given as, [9];

$$L_f = \frac{C}{4f\sqrt{\epsilon_r}} \quad , \quad (4)$$

where the inset cut is given by, [10];

$$S = \frac{v_o}{\sqrt{2\epsilon_{reff}}}\frac{4.65\times10^{-12}}{f_{GHz}} \quad (5)$$

where $v_O = 3\times10^8 m/sec.$

2-2 Resonant input resistance:

The circular patch's input impedance is an actual at resonance. Taking the reference of the feed point at $\acute{\rho}$ = a_e then the input resistance is given by [14];

$$\text{Rin}(\acute{\rho} = a_e) = \frac{1}{G_{rad}} \quad (6)$$

where G_{rad} is the conductance due to the radiated power across the gap between the patch and ground plane is given as, [4].

$$G_{rad} = \frac{(Ka_e)^2}{480}\int_0^{\pi/2}\left[J_{02}'^2 + \cos\theta^2 J_{02}^2\right]\sin\theta d\theta \quad (7)$$

2-3 The inset feeding point location

In this work inset feed line has been used as shown in Fig. 2. The feeding point must be located at$\acute{\rho} = P_o < a_e$ from the centre of the circular patch so that the input resistance of circular patch given by eq. (6) will reduce to a value that that the impedance must match that of the characteristic Z_o of the inset feed microstrip line. Then the input resistance of circular patch with inset feed at any radial distance $\acute{\rho} = P_o$ is given by, [4].

$$\mathrm{Rin}(\acute{\rho} = P_o) = \mathrm{Rin}(\acute{\rho} = ae)\frac{j_1^2(KP_o)}{j_1^2(Ka_e)} \quad (8)$$

Here, $Rin(\acute{\rho} = ae)$ is given by eq (6), $P_o$is thethe separation between the inset feeding point and the centre of circular patch as in Fig. 2, and k is the phase constant given by ;

$$k = \frac{2\pi}{\lambda} = \frac{2\pi f}{c} \quad (9)$$

3. CALCULATION OF THE PHYSICAL DIMENSION

With the help of the previous formulae and using MATLAB code all the physical dimensions that are required to design the proposed circular patch antenna are obtained and summarized asdepicted in table. 1

Table 1: The proposed antenna's physical specifications for ϵ_r=4.3, h=1.5mm, at f =2.4GHz

Parameter	*value*
Dielectric constant ϵ_r	4.3
Radius of patch a (mm)	17
Effective radius of patch a_e(mm)	17.68
Feeding point location P_o (mm)	4.55
Feedlinewidthw_f(mm)	2.94
thefeedline'slengthL_f (mm)	17
Width of inset cut S (mm)	0.2

3.1 The circular antenna's directivity and radiation efficiency

The directivity (maximum directive gain) of circular microstrip patch antenna is given by, [4].

$$D_o(\epsilon_r) = \frac{(ka_e(\epsilon_r))^2}{120\ G_{rad}} \quad (10)$$

G_{rad} , is the radiation conductance of the patch given by eq. (7). Using MATLAB program the directivity has been plotted as a function of dielectric constant ϵ_r with thickness h =1.5 mm and operating frequency f =2.4 GHz amount that the directivity D_o=6.139 dB for dielectric constant ϵ_r= 4.3.

The power radiated by an antenna (P_{rad}) in comparison to the electrical input power is what is known as its radiation efficiency P_{in} given by [11];

$$\eta = \frac{P_{rad}\ (watt)}{P_{in}\ (watt)} \quad (11)$$

The total dielectric loss and conduction loss in dB of circular microstrip patch shown with radius (a) is given by the following eq. (11):

$$\alpha_{dtot} = \alpha_d\ .2a \quad (12)$$

$$\alpha_{ctot} = \alpha_d\ .2a \quad (13)$$

Then according to (12) the efficiency becomes

$$\eta = \frac{0.001 * 10^{0,1 P_{rad\ dBm}}}{P_{in}\ (watt)} \quad (14)$$

where,

$P_{rad}\,(dBm)$ = $P_{in}\,(dBm) - \alpha_{dtot}$ (dB) $- \alpha_{ctot}$ (dB) (15)

With the help of the previous formulae and by using MATLAB code the radiation efficiency of the designed amount that the efficiency η = 0.8998 when tangent loss tan δ= 0.025.

3.2.. Designed patch's radiation pattern

The circular patch antenna's normalized radiation pattern in E- plane ($\emptyset$ =0°) is given by,[4].

$$F_E(\theta) = j'_{02} \quad (16)$$

while in H- plane($\emptyset$ =90°) is given by;

$$F_H(\theta) = j_{02}\cos(\theta) \quad (17)$$

where J_{02}, and J'_{02} are given by:

$$j_{02} = j_o(ka_e\sin\theta) + j_2(ka_e\sin\theta) \quad (18)$$

$$j'_{02} = j_o(ka_e\sin\theta) - j_2(ka_e\sin\theta) \quad (19)$$

The radiation patterns given by (16) and (17) in E and in H-planes has been plotted in a polar form for frequency f =2.4 GHz as in Fig. 3. The HPBW θ_E, θ_H in E- and H- planes are93.5^o, 80^o respectively.

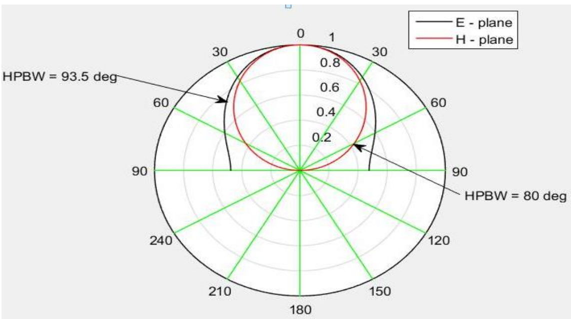

Figure 3: 2D-Radiation patterns of E and H planes of single circular patch antenna

The calculated performances of the circular patch was created is summarized in table. 2.

Table 2: Calculated performances of the designed circular patch antenna at 2.4 GHz

Parameter	*Calculated performance*
3D–directivity (dB)	6.139
2D-HPBW in H-plane (deg)	80
2D-HPBW in E-plane (deg)	93.5
Radiation efficiency	0.8998

4. SIMULATION RESULS

To optimize the dimensions and performances ofdesign of the inset feed microstrip circular patch antenna shown in Fig.2, the CST program has been used to simulate such an antenna by using the calculated physical dimensions shown in table1. The simulation results of patch dimensions are shown in table 3. The simulation result of the return loss S_{11}whic is given by [15] or (S11= 20log k_r) in dB is shown in Fig4, where k_r is the voltage reflection coefficient, 3D, and 2D directivity are shown in Fig. 5.

Table 3: The simulated physical dimensions of the proposed antenna for (ϵ_r=4.3, h=1.5, and at f =2.4 GHz)

Parameter	*value*
Dielectric constant ϵ_r	4.3
Radius of patch a (mm)	17.78
Effective radius of patch a_e(mm)	17.68
Feeding point location P_o (mm)	5.85
Feed line width w_f (mm)	2.94
$\mathrm{thefeedline'slength} L_f$ (mm)	15
Width of inset cut S (mm)	1.47

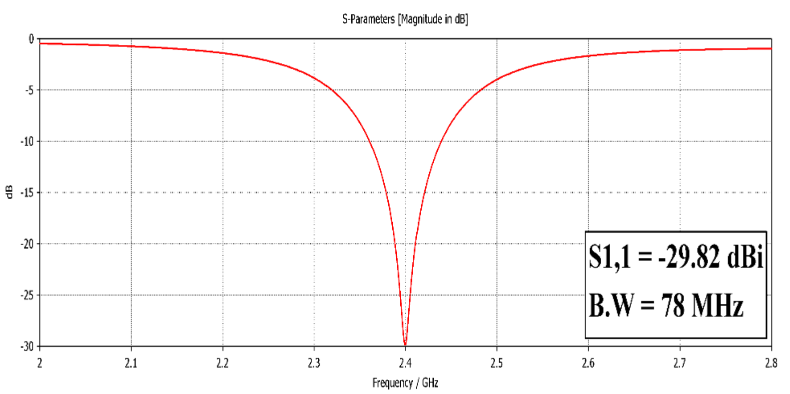

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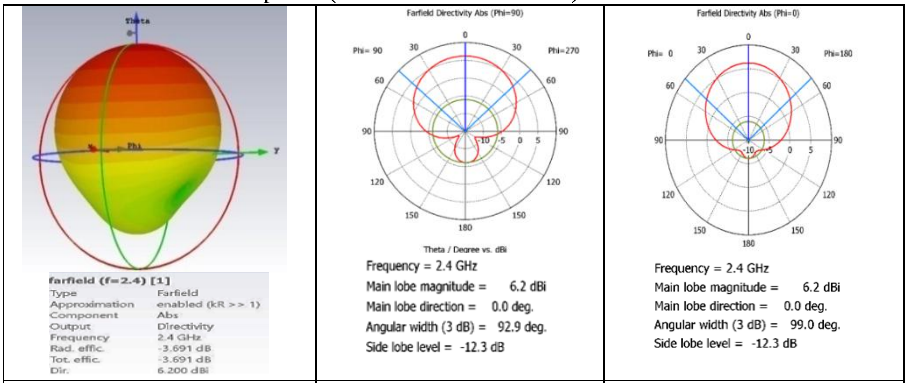
Figure 4:The simulation results of response return loss S11, for the designed and circular patch (εr=4.3 and h=1.5mm).



(a) (b) (c)

Figure 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 simulated results for the circular patch antenna were listed in the table 4.

Table 4: The summary of the performance simulated results for the designed circular patch.

Parameter	*Value*
Return loss S1,1 (dB)	-29.82
Impedance bandwidth (MHz)	78
3D- directivity D_o (dB)	6.2
Radiation efficiency	0.976
2D- HPBW in H- plane (deg)	92.9
2D- HPBW in E- plane (deg)	99

5. FABRICATION OF THE DESIGNED ANTENNA

The designedmicrostrip circular patch antennahas been fabricated on the only available FR–4 Epoxy substrate with thickness h=1.5 mm and dielectric constant $\epsilon_r = 4.3$, after the etching process the (top view) patch of the fabricated antenna is shown in Fig.6. Fabricated antenna's dimensions are those obtained by using the CST program. Such dimensions are the patch radius a=17,78 mm, feeding point location P_o =5.85mm, feeder line width w_{50} =2.94 mm, and inset cut S=1.47 mm.

6. RESULTS AND DISCUSSION

The network analyzer has been used to test such fabricated antenna,which gives us measured practical return loss $\mathbf{S_{11}}$ results as shown in Fig. 7.

Figure 6:The top view of the fabricated microstrip circular patch antenna fixed with SMA connector

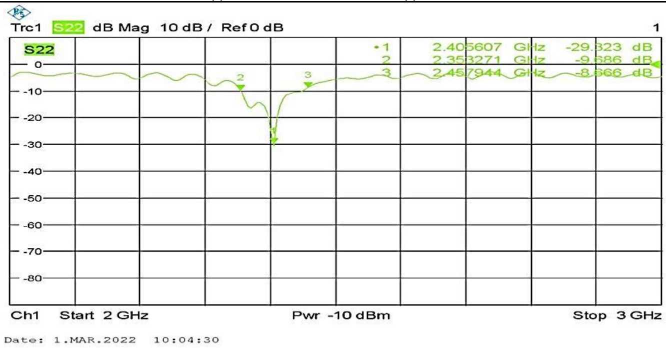


Figure 7: Measured results of return loss for the designed circular microstrip antenna with dielectric constant ϵ_r = 4.3 and substrate thickness h=1.5 mm

The theoretical calculation of the directivity for the designed circular patch antenna decreases as the substrate dielectric constant increases while the efficiency decreases as the tangent loss increases and the efficiency increases as the substrate thickness increase at the same value of the dielectric constant. Table 5 shows the comparison performances of the designed circular patch antenna.

Table 5: Comparison of performances of the designed circular antenna at 2.4 GHz

Parameter	*Calculated results*	*Simulated results*
Return loss S1,1 (dB)	……	-29.82
Impedance bandwidth (MHz)	……	78
3D – directivity Do (dB)	6.139	6.2
Radiation efficiency	0.8998	0.976
2D – HPBW in H – plane (deg)	80	92.9
2D – HPBW in E – plane (deg)	93.5	99

The practical measured of return loss shown in Fig. 7 and the simulated results shown in Fig.4 of the designed microstrip circular antenna are plotted as in Fig. 8.

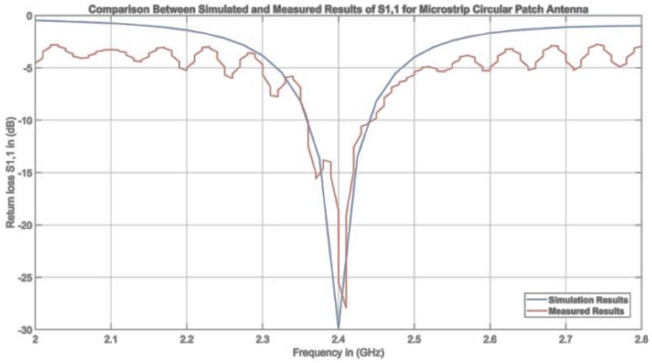


Figure 8: Comparison of Simulated and measured results of return-loss S11 for circular patch antenna

From measured results, it is found that the patch antenna resonates at 2.4056 GHz with a return loss of -29.323 dB, and the impedance bandwidth is BW=100 MHz, while from the simulated results the patch antenna resonates at 2.4 GHz with a return loss of -29.8 dB, and impedance bandwidth is BW=78 MHz. The comparison between the simulated and practical measured performance results of the designed microstrip circular patch antenna which obtained from Fig. 8 are shown in table 6.

Table 6: Comparison between the simulated and practical measured performance results of the designed microstrip circular antenna

Parameter	*Optimized results*	*Measured results*
Reasonance frequency	2.4	2.4056
Return loss (dB)	-29.8	- 29
Impedance banwidth(MHz)	78	100

From Fig. 8 and table 6, the measured result of return loss S_{11} in dB and impedance bandwidth BW have values very close to the simulated values and with measured return loss is S11=-29 dB i.e. with reflection coefficient is less or equal to 0.001 and this will lead to good patch antenna performances due to very small reflected power, also the measured and simulated resonance frequencies are very close. This design is suitable for scientific, industrial applications, medical sectors, Bluetooth and wireless communication

7. CONCLUSION

This paper details the design process for a 2.4 GHz inset fed microstrip circular patch antenna for Bluetooth use. Important factors including return loss (S11), bandwidth, and radiation patterns have been investigated and agree with the outcomes of measurements. The entire frequency band between 2.4 and 2.4056 GHz is fully utilized by this antenna, which can be used for Bluetooth applications. The suggested antenna's resonance occurs at a frequency of 2.4 GHz.

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