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DESIGN AND ANALYSIS OF RECTANGULAR AND CIRCULAR MICROSTRIP PATCH ANTENNAS AT 1.8 GHZ FOR FIXED POINT-TO-POINT LINKS APPLICATIONS

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ABSTRACT

Microstrip patch antenna has become more popular recently because of its easy analysis, fabrication, low cost, lightweight, and attractive radiation characteristics. Although a patch antenna has numerous advantages, it also has some drawbacks such as narrow bandwidth, low gain, and a potential decrease and distortion in the radiation pattern. This paper presents the design, simulation, and analysis of rectangular and circular microstrip patch antennas. It discusses antennas' performances based on return loss, reflection coefficient at the input port, bandwidth, 3D radiation pattern, and front-to-back ratio. Designed on an FR-4 substrate of thickness 0.7 mm and relative permittivity (ε_r) of 10, and fed by a 50 Ω microstrip feed line, the antennas are designed to resonate at 1.8GHz. The rectangular patch antenna achieved a bandwidth of 0.17GHz and a gain of 6.37dBi. At the same time, the circular patch antenna exhibits a bandwidth of 0.16GHz and again of 6.53dBi. A comparison of the antenna performances indicates that the rectangular antenna has more bandwidth than the circular antenna. While circular has better gain than rectangular; thus, good matching is better achieved in the circular. Therefore, the antennas can be a good candidate for fixed Point-to-Point link applications.

Keywords: rectangular, circular, microstrip patch antenna, return loss, gain, radiation pattern

INTRODUCTION

Efficient systems are imperative for better connectivity in today's world of wireless and mobile communication. To achieve this, the use of an antenna with high bandwidth and low loss is crucial (Alam et al., 2015). The concept of microstrip patch antenna radiators has been around since 1953, but it gained significant attention in the 1970s when suitable substrates became available (Kumar & Srivastava, 2010), (Free & Aitcheson, 2022). Microstrip patch antenna have emerged as a popular choice due to their advantages like lightweight, cost-effectiveness and ease of fabrication using current circuit technology (Nasidi & Bello, 2022). However, microstrip patch antenna has issues of narrow bandwidth, low gain and non-directional radiation pattern (Schantz, 2004).

Several methods to improve the gain of microstrip patch antennas have been reported in the literature. For instance, (Parveen T., et al., 2019) designed a triple-band circular patch antenna for operation at 5.8 GHz, 2.4 GHz and 1.8 GHz. The 1.8GHz, which is our frequency of interest, achieved a gain of 5.5dBi by creating a slot in the patch antenna. (Sharma et al., 2022) designed a circular microstrip patch antenna with three rings located on the patch and finite ground plane. The antenna achieved a low gain of only 1.3dBi. Using a surrounding cylindrical patch antenna, a planar antenna was designed by (Umayah & Srivastava, 2020). The design achieved a gain of 3.74dBi. In (Ramya & Gupta, 2022), the author presents a comparative analysis of a circularly polarized sector patch antenna with fractal defected ground structure. The design operates at 1.8 GHz and provides a gain in the range 3.39-3.75dBi. Moreover, (AL-Amoudi, 2021) designed antennas with various patch shapes such as rectangular, circular, elliptical and so on. The rectangular patch-shaped antenna exhibits a gain/directivity of 5dBi. Another method of improving antenna performance is by optimizing the microstrip feedline dimensions. Using this approach, (Suganthis et al., 2014) reported an improved antenna performance specifically the return loss (-29.2133 dB). To improve the bandwidth of a microstrip antenna, a square spiral-shaped antenna was designed by (Supratha & Robinson). However, the complex design achieved a bandwidth of only 593MHz at 2.4GHz.

Furthermore, microstrip patch antenna performance was characterized using different patch shapes such as hexagonal shape (Maneesh & Satyendra, 2017), slit shape (Tomar & Tripathi, 2022), metallic (copper or gold) shaped patch (Kumar& Srivastava, 2010), alumina and paper substrate (Akila et. al, 2018) and conventional shapes but at high frequency as reported by (Srivastava & Tiwara, 2019). These methods have a compromise in performance, that is, if bandwidth is widened, gain tends to be low and vice versa.

In this paper, a microstrip patch antenna with rectangular and circular patches is designed and analyzed. Full antenna properties are investigations which include bandwidth, voltage standing wave ratio (VSWR), gain, radiation pattern, and front-to-back ratio. The antenna offers an appreciable performance in all aspects under investigation. It could find applications in point-to-point links applications.

METHODOLOGY

In this work, Computer Simulated Software (CST) is used to design and analyse the antennas. For larger bandwidth and efficient antenna performance, a thick substrate with a low dielectric constant should be used. Hence, a commercially available FR4 substrate with a relative permittivity (ε_r) of 10 and 0.7mm thickness is chosen. The patches are designed on the front side of the substrate and the back side serves as a ground plane. The ground plane is designed to be infinite. The antenna patch is fed with a microstrip feedline which is required to have low insertion and matching impedance. Hence, a 50Ω characteristic impedance is used. The microstrip feedline's dimensions (width W_f and length L_f) were determined based on the expressions in the reference (Balanis, 2005).

The design aims to achieve resonance at 1.8GHz with higher gain and good radiation characteristics. Therefore, the antenna dimensions become crucial as they affect the resonant frequency and performance. Using transmission line model equations (Balanis, 2005), the antenna's rectangular and circular dimensions can be computed as described in subsequent sections.

Rectangular microstrip patch antenna

Fig. 1 depicts the proposed rectangular patch antenna. To calculate the initial dimensions of the patch (length *L*, and width *W*), the following equations are used (Free& Aitcheson, 2022) using the desired resonant frequency *f*.

Step 1: Calculation of Width (W), the width of the Patch

$$W = \frac{c}{2f\sqrt{\frac{E_r+1}{2}}} \quad (1)$$

Step 2: Calculation of Effective dielectric constant (E_{eff})

$$E_{eff} = \frac{\varepsilon_r+1}{2} + \frac{\varepsilon_r-1}{2}\left[\frac{1}{\sqrt{1+\frac{12h}{W}}}\right] \quad (2)$$

Step 3: Calculation of Effective Length (L_{eff})

$$L_{eff} = \frac{c}{2f\sqrt{E_{eff}}} \quad (3)$$

Step 4: Calculation of the Length Extension

$$\Delta L = 0.412h\frac{E_{eff}+0.3}{E_{eff}-0.258} * \frac{\frac{w}{h}+0.268}{\frac{w}{h}+0.8} \quad (4)$$

Step 5: Calculation of actual Length of the Patch (L)

$$L = L_{eff} - 2\Delta L \quad (5)$$

Step 6: Calculation of the Length of the microstrip transmission line (L_f):

$$L_f = \frac{\lambda}{4} = \frac{\lambda_O}{4\sqrt{E_r}} \quad (6)$$

Where $\lambda_o = \frac{c}{f}, c = 3x10^9\frac{m}{s}, f = 1.8GHz$. The optimized parameters of the proposed rectangular patch antenna are presented in Table 1.

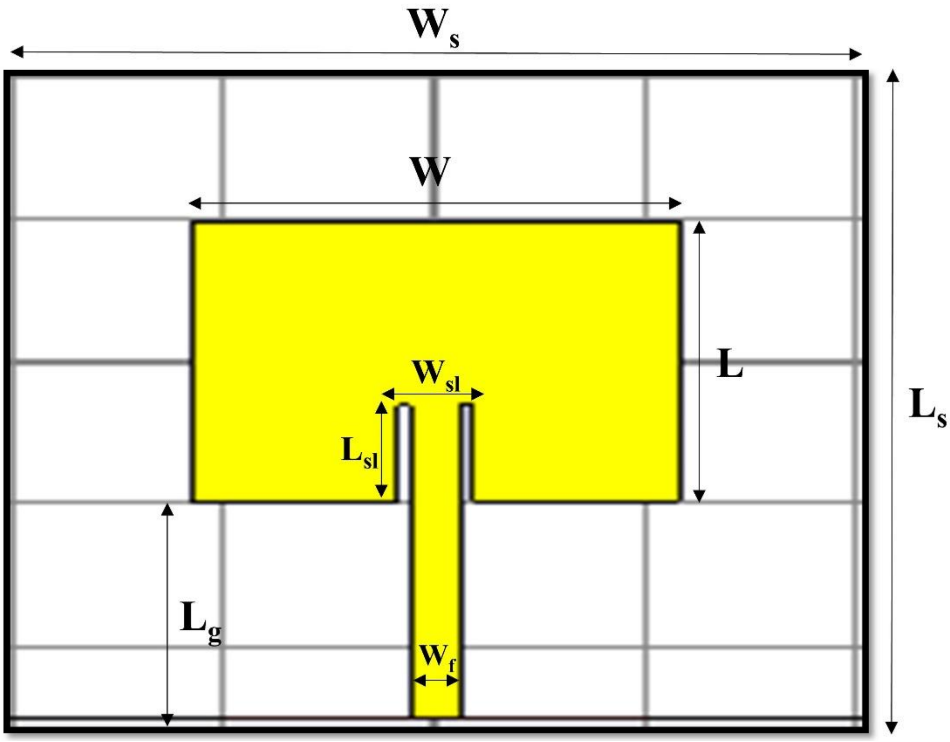


Figure 1: The geometry of the proposed rectangular patch antenna.

Circular patch antenna

A circular patch antenna is mainly made of a circle and a feedline, as shown in Figure 2. The radius of the circle can be obtained using the following expressions:

$$a = \frac{F}{\left\{1+\frac{2h}{\pi\varepsilon_r F}\left[ln\left(\frac{\pi F}{2h}\right)+1.7726\right]\right\}^{1/2}} \quad (7)$$

$$F = \frac{8.791 \ X \ 10^9}{f\sqrt{E_r}} \quad (8)$$

Where a is the radius of the circular patch, f is the resonant frequency, E_r is the relative dielectric constant of the substrate and h denotes the height of the dielectric substrate (Sharma, R., et al.,2022).

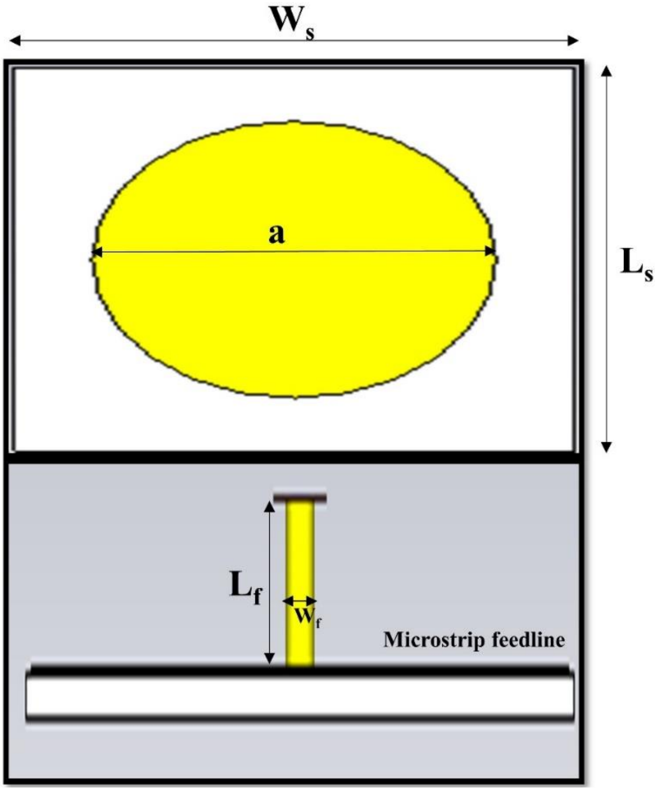


Figure 2: The geometry of the circular patch antenna with a microstrip feedline.

Using the equations above, the optimized radius of the circular patch (a) calculated was obtained.

Table 1: Rectangular patch and circular patch antenna specifications.

Antenna parameters	L_s (mm)	L_g (mm)	W_s (mm)	a (mm)	W (mm)	L (mm)	W_f (mm)	L_f (mm)	L_{sl} (mm)	W_{sl} (mm)
Rectangular patch	80	80	80	-	35.65	26.35	0.605	7.2	3	1
Circular patch	80	80	80	2.3	-	-	0.59	7.2	-	-

L_s is the substrate length, L_g is the ground plane length, W_s is the Substrate Width, W_f is the feedline Width, L_{sl} is the slot length, W_{ls} is the slot width and L_f is the feedline length.

RESULTS AND DISCUSSIONS

Having obtained the necessary dimensions, the antennas are designed and simulated on CST software.

Bandwidth

A -10dB reflection coefficient (S_{11} <-10 dB) is used to calculate the bandwidth to ensure impedance matching. The bandwidth of an antenna refers to the range of frequencies over which the antenna can operate correctly. Fractional bandwidth (FBW) is used to describe how wideband the antenna is and is expressed as:

$$\text{FBW} = 100 \text{ x } \frac{F_H - F_L}{F_C} \quad (9)$$

Where F_H = Highest frequency, F_L = Lower frequency and F_C = is the centre frequency.

Figure 3(a) presents the return loss (reflection coefficient) rectangular patch antenna. A resonance at 1.8GHz with a very low reflection coefficient of -13.711dB can be observed, indicating a good matching. For a -10dB reflection coefficient, the rectangular patch antenna exhibits a bandwidth of 0.17GHz. With F_H=1.85GHz, F_L=1.68GHz and F_c=1.8GHz, the FBW=9.4%.

Figure 3(b) shows the reflection coefficient of the circular patch antenna. As can be seen, it also achieved a resonance at 1.8GHz, as desired. It as well exhibits a very low reflection coefficient of about -14dB. The circular patch antenna offers a -10db bandwidth of 0.16GHz. With F_H=1.88GHz, F_L=1.72GHz and F_c=1.8GHz, the FBW=8.8%.

From the results, it can be inferred that the rectangular patch antenna offers better bandwidth than the circular with almost similar reflection coefficient or return loss.

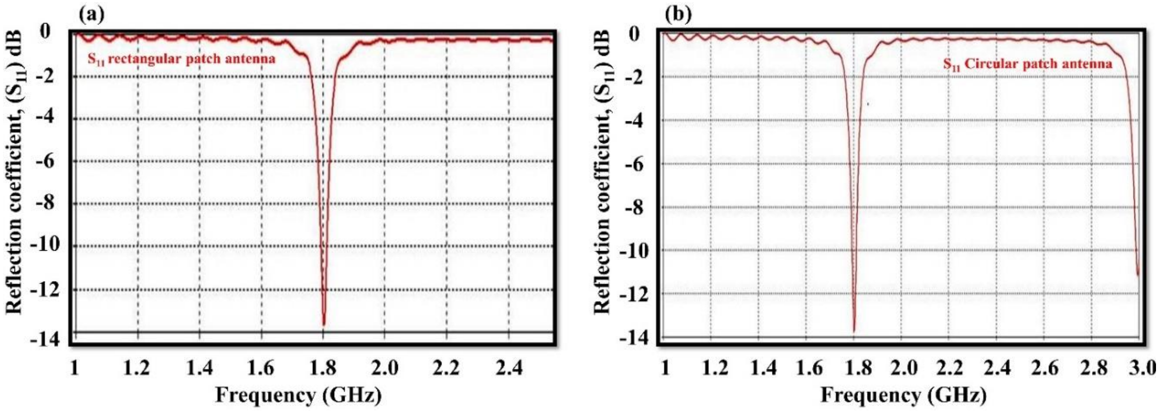


Figure 3: Reflection coefficient at 1.8 GHz for (a) a rectangular patch and (b) a circular patch.

Voltage Standing Wave Ratio

To describe how the rectangular and circular patch antennas are matched to the feedline, the voltage standing wave ratio (VSWR) is utilized. A well-matched antenna transmits or receives power efficiently. An antenna with a VSWR of one (1) is known as an ideal antenna.

Figure 4 presents the VSWR for the rectangular and circular patch antennas. It can be observed the rectangular and circular patch antennas have a VSWR of 1.5196 (see fig.4(a)) and 1.4407 (see fig.4(b)), respectively, at 1.8 GHz resonant frequency. Therefore, with a VSWR < 2, which is a value close to the ideal, both antennas can be said to have good impedance matching. The VSWR is also related to the reflection coefficient. The reflection coefficient defines the power reflected from an antenna. The VSWR and reflection coefficient (Γ) are related by:

$$VSWR = \frac{1+\Gamma}{1-\Gamma} \quad (10)$$

$$\Gamma = \frac{VSWR-1}{VSWR+1} \quad (11)$$

For rectangular patch antenna with VSWR = 1.5196 and using equation 11, $\Gamma = 0.206$. For circular patch antenna with VSWR = 1.4407 and using equation 11, $\Gamma = 0.1805$.

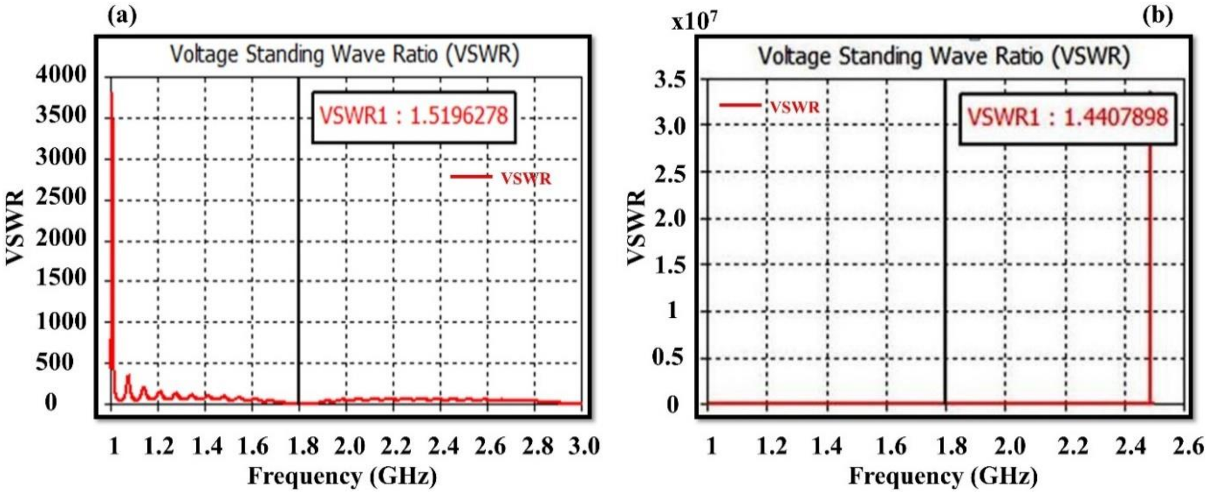


Figure 4: VSWR for the antenna with (a) rectangular patch and (b) circular patch.

Radiation pattern

The radiation pattern describes the relative strength of the radiated field in various directions from the antenna, at a constant distance. Fig. 5 shows the 3D radiation pattern of the proposed antennas. The rectangular patch antenna exhibits a directivity of 6.371dBi, while the circular patch antenna shows a 6.53dBi. Both antennas can be said to have strong radiation intensity in a specific direction. However, the circular patch antenna has a more unidirectional pattern than the rectangular.

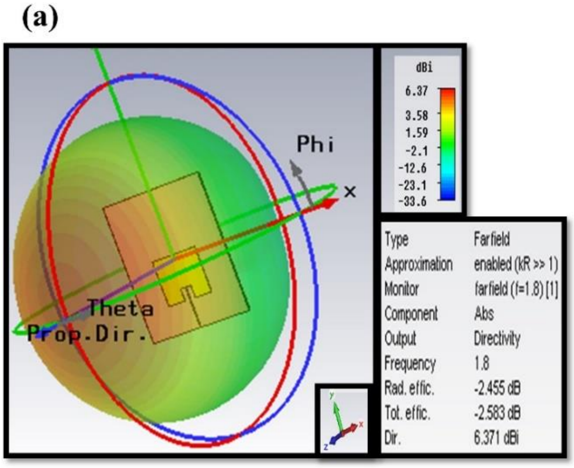


Figure 5: The 3D radiation pattern of the antenna with (a) rectangular patch and (b) circular patch.

Front-to-back ratio

The front-to-back ratio of an antenna is the proportion of energy radiated in the principal direction of radiation to the energy radiated in the opposite direction. A high front-to-back ratio is desirable because a minimum amount of energy is radiated in the undesired direction. This ratio signifies the extent of backward antenna radiation and is usually expressed in dB.

$$front - to - back\ ratio\ (dB) = main\ lobe\ gain - side\ lobe\ gain \quad (12)$$

Alternatively,

$$front - to - back\ ratio\ (dB) = \frac{forward\ power}{backward\ power} \quad (13)$$

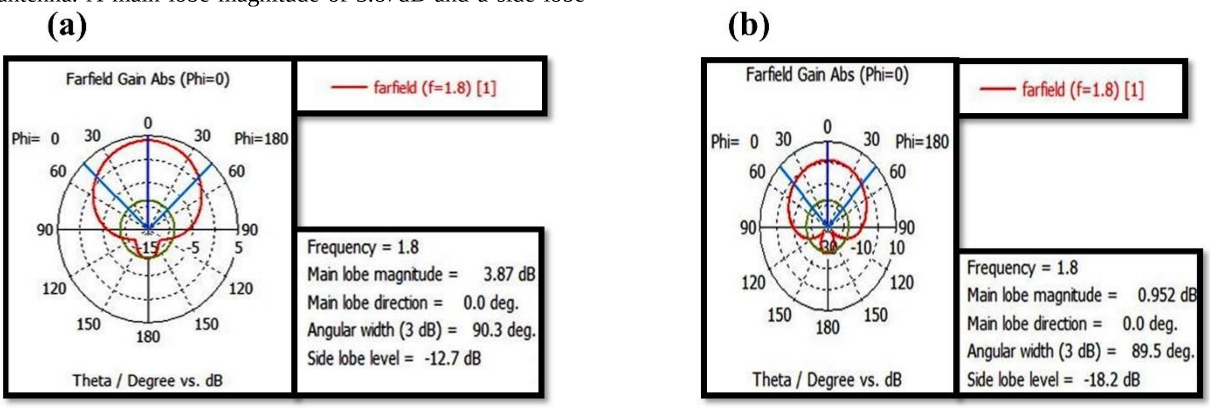
To compute the front-to-back ratio of an antenna, two-dimensional polar plots (2D) radiation pattern is needed. Fig. 6 shows the 2D radiation pattern for rectangular patch and circular patch antennas in the electric plane (E-plane) and the magnetic plane (H-plane). It can be observed that the radiation patterns have two lobes, that is the main lobe and side lobe, which are shown as a function of radiation intensity and angle relative to the broadside direction.

Figure 6(a) shows the E-plane of the rectangular patch antenna. A main lobe magnitude of 3.87dB and a side lobe magnitude of -12.7 dB. The front-to-back ratio can be determined using equation 12 as follows:

$$front - to - back\ ratio\ (dB) = 3.87 - (-12.7) = 16.57dB.$$

Figure 6(b) shows the E-plane of the circular patch antenna. The main lobe magnitude and side lobe magnitude are 0.952dB and -18.2dB, respectively. Hence, using equation 12, the front-to-back ratio is $front - to - back\ ratio\ (dB) = 0.952 - (-18.2) = 19.152dB$.

Figure 6(c & d) depicts the radiation pattern of the rectangular patch and circular patch antennas in the H-plane. It can be observed that the radiation magnitude is almost the same as that of the E-plane. Hence, one front-to-back ratio calculation will suffice. Moreover, the H-plane radiation pattern also has a single lobe centered on the axis of the antennas. The circular results have a symmetric radiation pattern compared to the rectangular because it has no side lobe radiation pattern. Finally, a Long-range and great directional antenna will exhibit a minimum front-to-back ratio (gain) of 15dB, thus all the proposed antennas displayed the utmost strength of the signal will little back radiation.



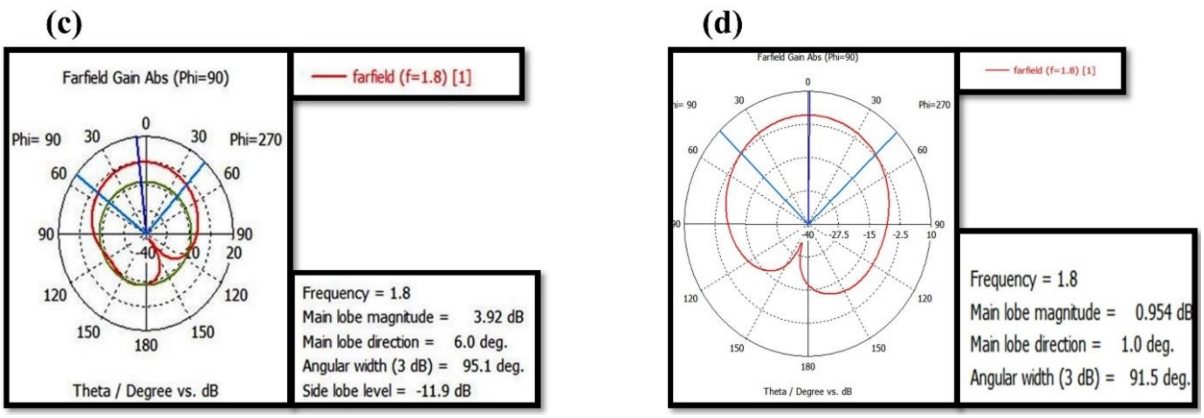


Figure 6: The 2D radiation pattern of the antennas in (a) E-plane for the rectangular antenna (b) E-plane for the circular patch (c) H-plane for the rectangular antenna (d) H-plane for the circular patch.

Performance comparison

In Table 2, a performance summary and comparison between the proposed rectangular patch antenna and circular patch antenna is presented. The results obtained show that the rectangular patch antenna has more bandwidth, VSWR, and improved return loss compared to the circular patch antenna. However, the circular antenna has better gain/directivity, and front-to-back ratio. Therefore, the circular patch antenna has more unidirectional strength than the rectangular patch antenna. In applications where bandwidth is the utmost requirement, a rectangular patch antenna is recommended. In applications where less interference is needed, an antenna with strong gain/directivity and less front-to-back ratio is necessary, hence, a circular patch antenna is recommended.

A comparison of our gain with that of previously reported antennas is shown in Table 3. It can be observed that our proposed design offers a higher gain using a circular patch antenna.

Table 2: Performance comparison between the proposed antennas

Performance Parameters	Return Loss (dB)	Bandwidth (GHz)	VSWR	Gain /directivity (dBi)	Reflection coefficient	Front-to-back ratio (dB)
Rectangular Patch	14	0.17	1.5196	6.37	0.206	16.5
Circular Patch	13.711	0.16	1.4407	6.53	0.1805	19.152

Table 3: Comparison of gain between the proposed antennas with previously reported antennas

S/N	**Antenna**	**Gain (dBi)**
1	Our rectangular patch	6.37
2	Our circular patch	6.53
3	Parveen et. al, 2019	5.5
4	Sharma et. al, 2022	1.3
5	Umayah & Srivastava, 2020	3.74
6	Ramya & Gupta, 2022	3.39 - 3.75
7	Al-amoudi, 2021	Rectangular patch = 5 Circular patch = 8.5
8	Akila P., et al, (2018)	Alumina = 4.79 Paper = 3.8

CONCLUSION

This paper presents the design, simulation and analysis of rectangular and circular microstrip patch antenna fed with microstrip lines. The antennas were designed to exhibit a resonance at 1.8 GHz. This band is chosen because it is designated for use by low-medium capacity. The rectangular patch antenna offers a bandwidth of 0.17GHz and a gain/directivity of 6.37dBi. The circular patch antenna gives a bandwidth 0.16GHz and a gain/directivity of 6.53 dBi. Both antennas exhibit good impedance matching because their VSWR is close to ideal. In terms of the gain/directivity and front-to-back ratio, the circular patch antenna performs better while the rectangular has better performance in other parameters. while the rectangular has better performance in other performance parameters. With high gain, the proposed antennas could be used in wireless fixed point-to-point links applications.

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