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Design and Analysis of Rectangular and Circular Microstrip Patch Antenna

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Abstract: Recently, the popularity of microstrip patch antennas has increased due to their favourable radiation characteristics, ease of fabrication and analysis, low cost, and lightweight design. Patch antennas have many benefits, but they also have certain disadvantages, like poor gain, narrow bandwidth, and the possibility of radiation pattern distortion and reduction. A design, modelling, and study of circular and rectangular microstrips patch antenna are presented in this study. It talks about the performance of antennas based on front-to-back ratio, bandwidth, 3D radiation pattern, reflection loss, and Reflection factor coefficient at the inlet.

The design of the antennas has to resonate and are built on a FR-4 substrate with a thickness of 0.71 mm and a Permittivity ratio (εr) of 10, supplied by a 50 Ω microstrip feed line.

The bandwidth of the rectangular patch antenna was 0.17GHz with a 6.37dBi gain. The circle patch antenna simultaneously displays a bandwidth of 6.53dBi and 0.16GHz. The rectangular antenna outperforms the circular antenna in terms of bandwidth, according to a comparison of their respective performances. Although circulars have better gains than rectangulars, circulars are superior at achieving good matching. Consequently, the antennas can be an excellent fit for applications requiring fixed end-to-end links.

Keywords: Rectangle, circle, microstrip antenna, reflection loss, amplification, emission direction.

I. INTRODUCTION

Utilizing antennas possessing high bandwidth and minimal loss is crucial for enhancing connectivity in today's wireless and mobile communication landscape (Alam et al., 2015).

The notion of microstrip patch antenna radiators dates back to 1953; nonetheless, it garnered noteworthy recognition in the 1970s with the availability of appropriate substrates (Kumar & Srivastava, 2010; Free & Aitcheson, 2022). Because of their benefits—such as being lightweight, affordable, and simple to fabricate using existing circuit technology—microstrip patch antennas have become a popular option (Nasidi & Bello, 2022). Narrow bandwidth, poor gain, and non-directional emission pattern are problems with microstrip patch antennas, though (Schantz, 2004). There have been several documented ways to increase the gain of microstrip patch antennas in the literary works. For example, a triple-band circular patch antenna operating at 5.8 GHz, 2.4 GHz, and 1.8 GHz was designed by Parveen T. et al. in 2019. Our target frequency, 1.8GHz, had a gain of 5.5dBi thanks to the patch antenna's slot creation. A circular microstrip patch antenna with three rings situated on the patch and a finite ground plane was created by (Sharma et al., 2022). The antenna's meagre 1.3dBi gain was attained. Umayah and Srivastava (2020) constructed a planar antenna by utilising a surrounding cylindrical patch antenna. A gain of 3.74dBi was attained by the design. The author of (Ramya & Gupta, 2022) compares a sector patch antenna that is circularly polarised and has a fractal defective ground structure. The system runs at 1.8 GHz. It offers a gain between 3.39 and 3.75 dBi. Additionally, (AL-Amoudi, 2021) created antennas with a variety of patch forms, including elliptical, circular, and rectangular ones. With a gain/directivity of 5dBi, the antenna is fashioned like a rectangular patch. A further way to enhance antenna performance is to maximise the size of the microstrip feedline. Suganthis et al. (2014) demonstrated enhanced antenna performance, namely a gain of 6.37dBi and a return loss of -29.2133, using this method. The circular patch antenna simultaneously displays a bandwidth of 6.53dBi and 0.16GHz. The rectangular antenna outperforms the circular antenna in terms of bandwidth, according to a comparison of their respective performances. Although circulars have better gains than rectangulars, circulars are superior at achieving good matching. Supratha and Robinson devised a square spiral antenna in order to increase the bandwidth of a microstrip antenna. At 2.4GHz, the intricate architecture could only muster a meagre 593MHz bandwidth conventional shape, albeit at high frequencies—were also used to characterise the performance of microstrip patch antennas. The performance of these approaches is compromised in that Low gain tends to correspond with high loss, and conversely.

When bandwidth is increased. This study presents the structure and examination of a Microstrips patch Antennas using both circular and rectangular patches. Complete antennas characteristics are studies that consist of front-to-back ratio, gain, radiation pattern, bandwidth, and Voltage Standing Wave Ratio (VSWR). The antenna performs admirably in every area that is being studied. Applications involving point-to-point links may find use for it.

II. METHODOLOGIES

In this work, the antennas are designed and analysed using computer-simulated software, or CST. Thick substrates with low dielectric constants are recommended for wider bandwidth and more effective antenna performance. Thus, a FR4 substrate that is readily available in the market is selected, with a width of 0.71 mm and a permittivity ratio (εr) of 10. The substrate's rear side acts as a grounded surface, while the patches are patterned on its front side. It is intended for the ground plane to be endless. A microstrip feedline that has a low insertion and matching impedance is used to feed the antenna patch. So, an impedance with a characteristic of 50Ω is employed. The Thickness Wf and Length Lf of the microstrip feedline were estimated by the formulas in the source cited (Balanis, 2005)

The design seeks to produce good radiation characteristics and Resonance occurring at a frequency of 1.8GHz with a greater add on. Because they have an impact on both the resonant frequency and performance, the antenna dimensions thus become quite important. The dimensions of rectangular and circular's antenna can be calculated using the equation of the transmission line model (Balanis, 2005), as will be covered in the sections that follow.

III. MICROSTRIP PATCH ANTENNA WITH A RECTANGULAR SHAPE

The suggested rectangular shaped patch antenna is shown on Fig. 1. Using the intended resonant frequency f, the equation provided by Free & Aitcheson in (2022) are used to determine the patch's initial dimensions (length L and width W).

1) Step-1 involves determining the width 'W' using the following formula.

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

2) Step 2 entails computing the effective dielectric constant using the formula provided below, where 'εr' denotes the relative dielectric constant of the material, 'h' signifies the substrate's height, and 'W' represents the width of the patch calculated in the initial step.

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

3) Step 3 involves determining ΔL using the following formula.

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

4) Step-4: Calculate the length of the patch using the formula below, where 'v0' represents the speed of the light in free space.

$$L = \frac{\upsilon_o}{2 f_r \sqrt{\varepsilon_{reff}}} - 2\Delta L$$

In this case, V = 1.8GHz, x = 3x 109 m s, and λo = f c. Table 1 displays the optimised characteristics of the suggested rectangular patch antenna.

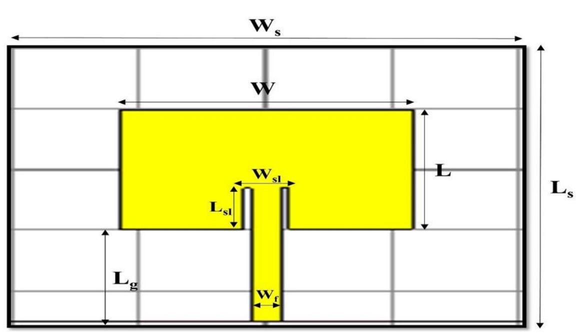

Figure1 depicts the design of the rectangular shaped patch antenna being proposed in this study

IV. CIRCULAR MICROSTRIP PATCH ANTENNA

1) Step-1 Calculation of the Width(W):

W = C / 2fr (2 / (r + 1))

2) Step-2 Calculation of the Effective Dielectric Constant (reff):

The following mathematical statement predicts it:

$$\in_{reff} = \frac{\in r + 1}{2} + \frac{\in r - 1}{2}[1 + 12\frac{h}{w}]^{-1/2}$$

3) Step-3 How to Calculate Patch Effective Length (Leff):

The following formula is used to estimate the patch effective length:

$$Leff = \frac{c}{2fr\sqrt{\in reff}}$$

4) Step-4 Computation of Patch Length Extension (ΔL):

$$\Delta L = 0.412h\frac{(\in reff + 0.3)(\frac{W}{h} + 0.264)}{(\in reff - 0.258)(\frac{W}{h} + 0.8)}$$

5) Step-5 Calculation of the Real Patch Length (L):

L = Leff - 2ΔL

6) Step-6 Ground Dimension Calculation (Wg, Lg):

Wg = 6h + W, Lg = 6h + L.

Here, h stands for the dielectric surface's crest
W for the patch's diameter, and L for the patch's.

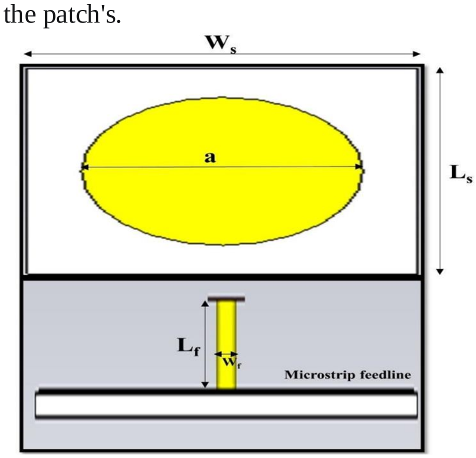

Figure 2 depicts the design of the circular shaped patch antenna being proposed in this study.

V. BANDWIDTH

The bandwidth is calculated with a reflection coefficient of -10dB (S11 <-10 dB) to guarantee impedance matching. The range of frequencies that an antenna can properly function over is referred to as its bandwidth. The term fractional bandwidth (FBW), which is defined as follows:

FH represents the highest frequency, FL denotes the lower frequency, and FC indicates the centre frequency, which are utilized to characterize the antenna's bandwidth.

$$Fractional\ Bandwidth\ (FBW) = \frac{f_H - f_L}{f_c} \times 100\ \%$$

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The return loss (reflection coefficient) of a rectangular patch antenna depicted in Figure 3(a). Resonance is observed at 1.8GHz that shows a good matching exhibiting an extremely low reflection coefficient of -13.712 dB. The bandwidth of the rectangular patch antenna is 0.17GHz with a -10dB reflection coefficient. The FBW is 9.4% with FH=1.84GHz, FL=1.67GHz, and Fc=1.84GHz.
The circular patch antenna's reflection coefficient is displayed in Figure 3(b). It also succeeded in reaching the intended frequency response at 1.84GHz, as is evident. The reflection coefficient is approximately -14db, indicating a very less value. At 0.16GHz, the circular patch antenna offers a bandwidth with a -10db level. The FBW is 8.8% with FH=1.87GHz, FL=1.71GHz, and Fc=1.81GHz.
The findings suggest that, for almost equal reflection coefficient or return loss, the rectangular patch antenna offers a broader bandwidth compared to the circular one.

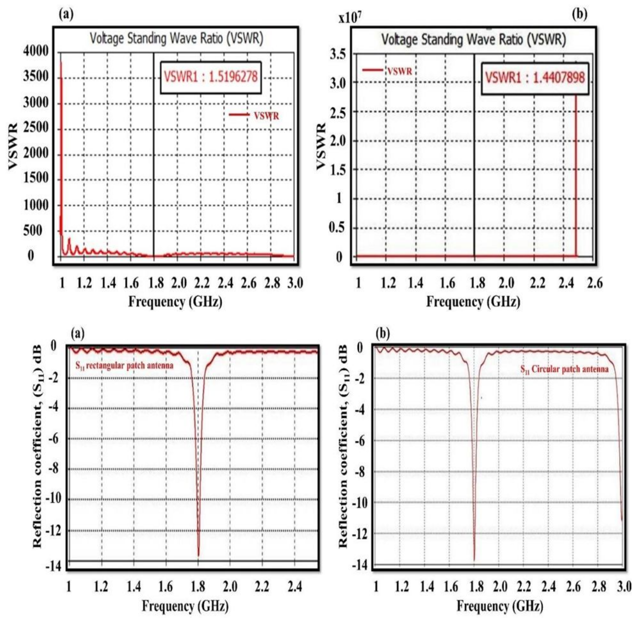

Figure 3 illustrates the reflection coefficients at 1.8 GHz for (a) rectangular shaped patch and (b) circular shaped patch

VI. PERFORMANCE COMPARISON

A comparison of the suggested circular shaped patch antenna and rectangular shaped patch antenna performance is shown in table 1. According to the results, the rectangular patch antenna outperforms the circular patch antenna with respect to bandwidth, VSWR, and return loss. On the other hand, the circular antenna offers superior front-to-back ratio and gain/directivity. As a result, compared to the rectangular patch antenna. The circular patch antenna exhibits greater unidirectional strength, while a rectangular patch antenna is recommended for applications that require essential bandwidth.
Circular patch antennas are suitable for applications where a low front-to-back ratio and strong gain/directivity are required in order to minimise interference. It might be noticed that by employing a circular patch antenna, our suggested design provides a larger gain.

Performance Parameter	Return Loss (dB)	Bandwidth (GHz)	VSWR
Rectangular	14	0.17	1.5195
Circular	13.712	0.15	1.4406

Table 1 shows the performance comparison

VII. CONCLUSION

The structure, modelling, and examination of circular shaped and rectangular shaped microstrip patch antennas supplied by microstrip transmission lines are presented in this study. The 1.8 GHz resonance of the antennas was intended. As it is designed to for use with low to medium capacity requirements, this band was selected. The rectangular shaped patch antenna exhibits a gain or diversity of 6.37dbi with a bandwidth of 0.17GHz.

The circular patch antenna has a gain or directivity of 6.52dbi and a bandwidth of 0.16GHz. Since both antennas' VSWR is almost perfect, they show good impedance matching. The rectangular patch antenna performs better in other metrics. On the other hand, the circular shaped patch antenna demonstrates superior performance in terms of gain or diversity and ratio to front to rear. In contrast, the rectangle shaped patch antenna outperforms in other performance metrics. The suggested antennas' high gain could be utilised in applications involving fixed wireless point-to-point communications.

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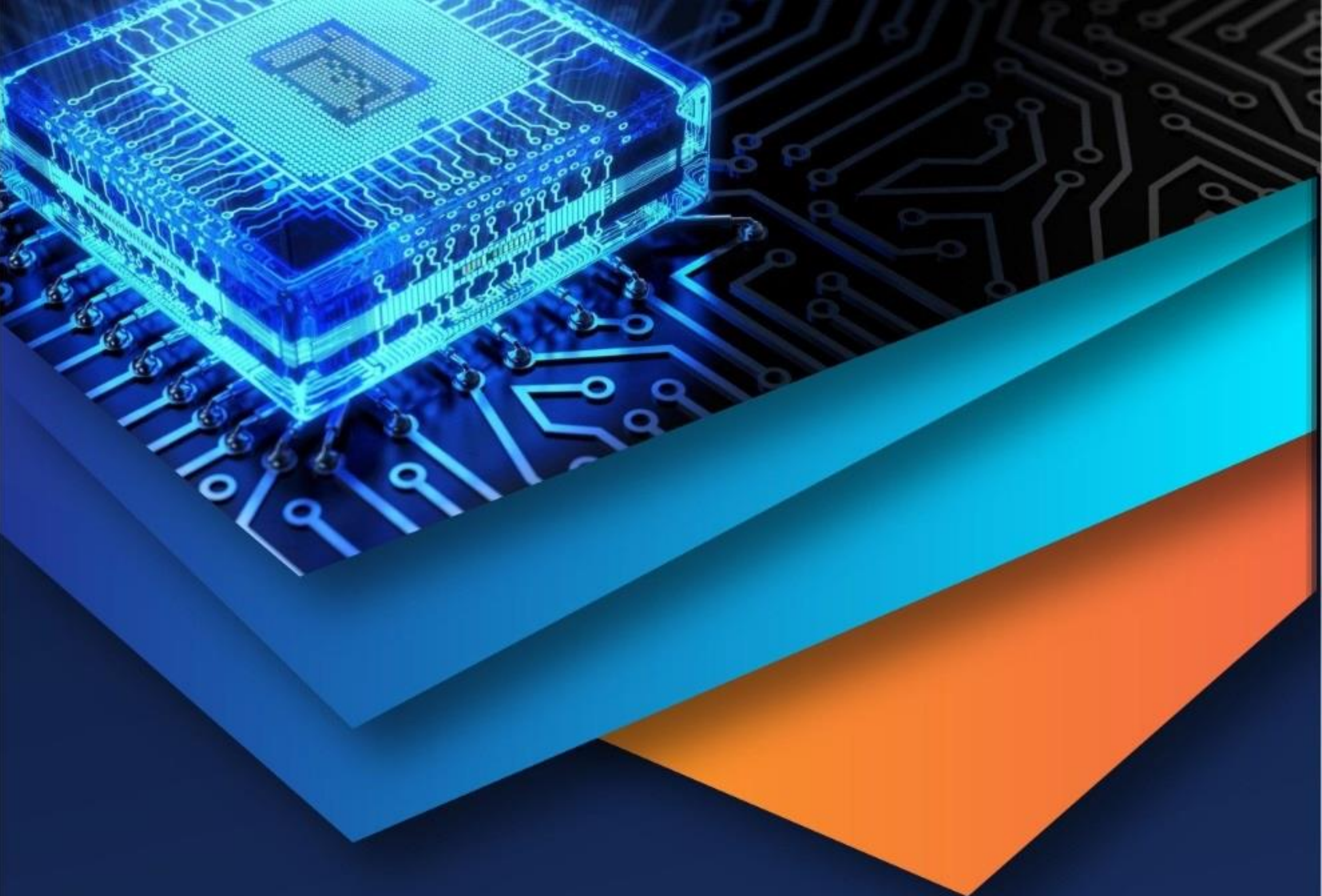

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