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Research paper

Circularly Polarized Rectangular Microstrip Patch Antenna with Diagonal Asymmetric Slits

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Abstract

In this paper, the circularly polarized rectangular microstrip patch antenna with asymmetric slits was proposed for Radio Frequency Identification (RFID) applications. The investigation was done over the whole S-band frequency (2-4 GHz) and found favor with the operating frequency of 2.4GHz which is very much suitable for RFID applications. Circular polarization was acquired by presenting four asymmetric slits along the diagonal corners of the microstrip patch with appropriate angles. An additional parasitic element was also introduced opposite to feed face to improve bandwidth and impedance matching. The performance of the proposed antenna was analyzed and compared for three different substrates namely Rogers (ε_r =2.2), RT-DUROID (ε_r =2.33), and FR4 (ε_r =4.4). All the designs were simulated using CADFEKO 7. Detailed analysis carried out on all the three substrates to obtain circular polarization (axial ratio = 1) with desired parameters of return loss (>-10 dB), VSWR (<2), and gain (>2 dB). The experimental results conclude that the FR4 is the optimum choice and it proficiently meets the desired specifications.

Keywords: *Asymmetric slits, Substrates, Circular polarization, Return loss, Radiation pattern*

1. Introduction

Currently, circularly polarized microstrip antennas are an essential part in RFID field [1-3]. Due to its low planar profile, ease of fabrication and compatible with the integrated circuit technology, they were predominantly utilized as a part of various applications such as wireless, mobile, satellite [4] and RFID [2]. Exclusively for RFID applications, the circular polarization is very essential characteristic over linear polarization in terms of less polarization loss, overcome multipath inference and Faraday rotation effects. Therefore, an interest emerges to perform circularly polarized microstrip patch for RFID.

RFID works under different frequencies, especially the microwave bands (2.45 and 5.8 GHz) were focused, because of its fast reading capability [5-7]. RFID is designed as tag, reader and antennas (For both transmitting and receiving purposes). Therefore, the point is to outline the RFID antenna with the circular polarization. Circular polarization had been achieved by different means; one among them was by introducing integrated metallic wall structure like substrate with half wavelength [8]. Nevertheless, this method prompts a larger antenna size. Another one method was feeding strips connected to four probes on the patch antenna. However, the complexity of the feeding network is very high [9]. Consequently, some perturbation methods were suggested to achieve circular polarization by introducing slits [10-11], slots [12-19], stubs and corner truncation [19-22]. Furthermore, this method provides reduction in the size of the antenna. It is also revealed that the return loss, axial ratio and gain do not depend on the shape and the area of the slits. Henceforth, to accomplish the circular polarization, four uneven slits in the corners of the patch are presented. Since the slits are with different areas and corners of diagonals, it is known as an asymmetric patch. Symmetric slits can also be used but it gives poor response when compared to asymmetric slits [23] which inspires to use asymmetric slits in the proposed paper. The first goal of the proposed work is to perform circular polarization by introducing asymmetric slits on the four diagonals of the rectangular patch.

The second goal is to analyze the proposed antenna with three dielectric substrates [24-27] (Roger, RT-DUROID and FR4) at 2-4 GHz. Additionally, the desired parameters such as gain, reflection coefficient, VSWR and axial ratio were considered for the designed antenna. Workflow was presented in four sections. In section-I, introduction to RFID is depicted, in section-II, the design of the proposed antenna is exhibited. Section-III deals with the results and discussions, Section-IV narrates the comparison and finally, the conclusion is presented in Section-V.

2. Antenna Design

The dimensions of the proposed antenna with asymmetric slits for three different dielectrics (Roger, RT-DUROID, and FR4) are analyzed. In this, a rectangular patch is etched on a square substrate along with a parasitic element whose length is longer than that of the patch.

a) Width and Length calculation:

Considering 2.4GHz as operating frequency, the length (L) and the width (W) of the patch with different substrates are calculated [27] manually using the formulas

$$W = \frac{vo}{2fr} \times \frac{\sqrt{2}}{\sqrt{\varepsilon r+1}} \quad (1)$$

Where vo the free space velocity of light is, fr is the resonant frequency and εr is the dielectric constant of the substrates

$$L = \frac{\lambda}{2} + 2\Delta L \qquad (2)$$

Here λ is the wavelength and ΔL is the incremental length of patch which can be calculated using equation 3

$$\Delta L = h \times (0.412) \times \left(\frac{\varepsilon r,eff+0.3}{\varepsilon r,eff-0.258}\right) \times \left(\frac{\frac{W}{h}+0.264}{\frac{W}{h}+0.8}\right) \qquad (3)$$

In this $\varepsilon r,eff$ is the effective dielectric constant which is expressed in equation 4

$$\varepsilon_{r,eff} = \left(\frac{\varepsilon r+1}{2}\right) + \left(\frac{\varepsilon r-1}{2}\right) \times \frac{1}{\sqrt{\left(1+12\times\left(\frac{h}{W}\right)\right)}} \qquad (4)$$

The permittivity of the substrates is known to be 2.2, 2.33, and 4.4 for Rogers, RT-DUROID, and FR4 respectively. The width and length were calculated using the equations 1, 2, 3 and 4 are tabulated in table 1. The geometry of proposed FR4 substrate antenna was shown in Fig.1. The designed antennas of different substrate were shown in Fig.2 and the current distribution in Fig.3.

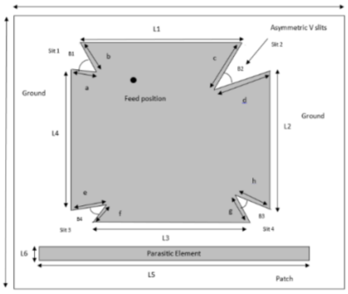
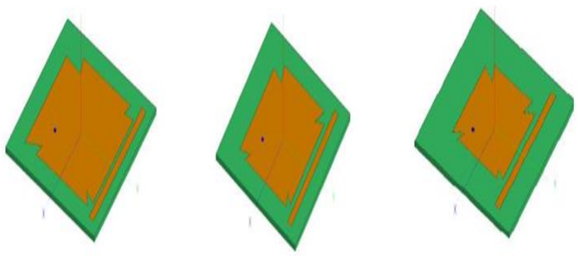


Fig.1: Geometry of Proposed antenna (FR4 Substrate)



a). ROGER b). RT-DUROID c). FR4
Fig 2: Proposed antenna designs for different substrate

2.3. MPFA

b) Slits and Angles in the patch:

In general, the length S= {a, b, c, d, e, f, g, h} and the angle A= {B1, B2, B3, B4} of the 4 asymmetric slits were used to design the antennas for three substrates. The slit 1 found in the top left corner has the values of 0.618 cm x 1.285 cm, which meets at a point forming an angle of 38.48° . The angle of the asymmetrical slits along the diagonal directions for the designs is tabulated in table 1. The length of the asymmetrical slits along the diagonal directions for the designs is tabulated in table 2.

c) Parasitic Element:

The parasitic element with dimension (L5xL6) is placed below the patch. It is introduced opposite to feed face to improve bandwidth and impedance matching. Furthermore, by constructing the length of it greater than the radiating side length, it was made to function as a reflector.

3. Results And Discussions

The comparative analysis of three substrate materials on the circularly polarized microstrip antenna is performed. The simulation is carried out for S-band. The attributes of different dielectric substrate materials have been prepared on the basis of Return loss |S11<-10dB|, VSWR (<2), the Axial ratio (0 to 1) and gain (<2dBi). These parameters make an antenna to work in the well-defined fields. Out of these three substrates, the one which has an effective solution is chosen for the RFID applications.

a) Return Loss:

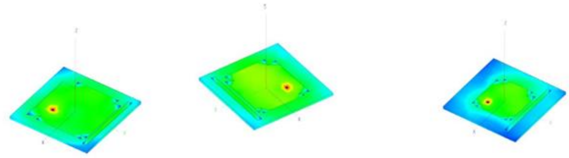
The measured reflection coefficient versus frequency for the above three designs is shown in Fig 4**.** The center frequency of the design is 2.4GHz. The reflection coefficient for the 3 substrates is -33dB at 2.42GHz (Rogers), -18dB at 2.6GHz (RT-DUROID) and -13dB at 2.34GHz (FR4). Normally the reflection coefficient <-10 dB achieves good performance. Among the three substrates, Roger has the highest reflection coefficient of -33 dB. RT-DUROID has moderate return loss-18dB but goes beyond 2.4 GHz, while FR4 gives only -13dB of return loss at 2.34GHz. Even though, FR4 possesses the least reflection coefficient compared to the other two substrates, it is well suitable for RFID, since return <-10 dB is a sufficient one.

Table1: The design parameters (W, L) and the angles of the asymmetrical slits along the diagonal directions.

Substrate - Permittivity (εr)	Parameters		Angles			
	Width- W (cm)	Length- L (cm)	B1 (Degree)	B2 (Degree)	B3 (Degree)	B4 (Degree)
ROGERS (2.2)	5.189	4.530	38.48	45.57	42.87	45.69
RT-DUROID (2.33)	5.080	4.298	49.39	64.44	33.53	60.25
FR4 (4.4)	3.995	3.190	37.87	55.61	31.32	40.23

Table2: The length of the asymmetrical slits along the diagonal directions

Design: Substrate	Slit 1		Slit 2		Slit 3		Slit 4	
	a(cm)	b(cm)	c(cm)	d(cm)	e(cm)	f(cm)	g(cm)	h(cm)
Design 1: ROG-	0.618	1.285	1.369	0.857	0.781	0. 790	0.764	0.632
Design 2: RT-	0.540	0.948	0.936	0.895	0.700	0.625	0.782	0.924
Design 3: FR4	0.587	0.816	0.866	0.807	0.480	0.559	0.800	0.777



a). ROGER b). RT-DUROID c). FR4
Fig.3. Current distribution

b) Gain:

The antenna gain is another important parameter in antenna design. By introducing slots and slits, the gain can be further increased. The peak gain of Roger, RT-DUROID, and FR4 is 3.2 dBi, 5 dBi, and 2.7 dBi respectively which is revealed in Fig 5 a. Similarly, the beam width is 60.80° for Rogers and 65.94° for RT-DUROID, and 67.90° for FR4. From the analysis, RT-DUROID shows the higher gain and FR4 shows the lower gain but the beam width essential for Circular Polarization is higher for FR4 only. Thus, FR4 deserves good performance.

c) Axial Ratio:

To obtain circular polarization the axial ratio has to be closer to 1 (0dB) and it mostly depends on the area of the slits. Fig 5 b compares the Axial Ratio (dB) variation with frequency (GHz) for the 3 designs with asymmetric slits. The axial ratio range of 4.098 dB, 0.4104 dB, and 1.978 dB is obtained for Roger, RT-DUROID, and FR4. The Minimum value of 0.4dB is obtained for RT- DUROID but its frequency range is not within the RFID filed. So, the next minimum axial ratio of 1.978 dB for FR4 is taken into consideration. Thus, the circular polarization is achieved due to introducing asymmetric slits along the diagonal corners.

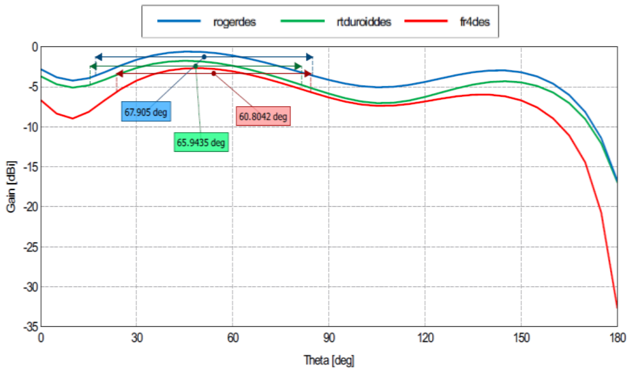
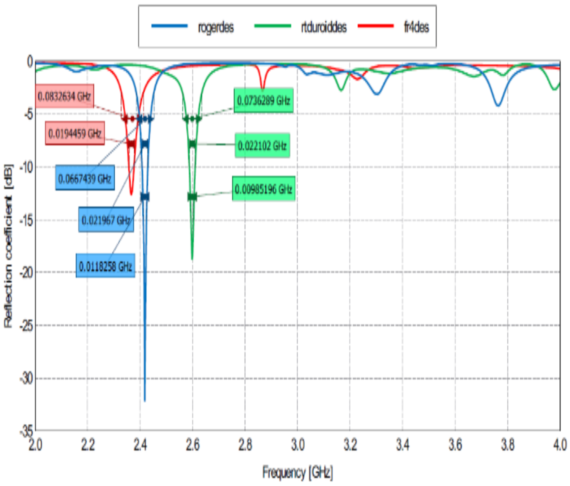
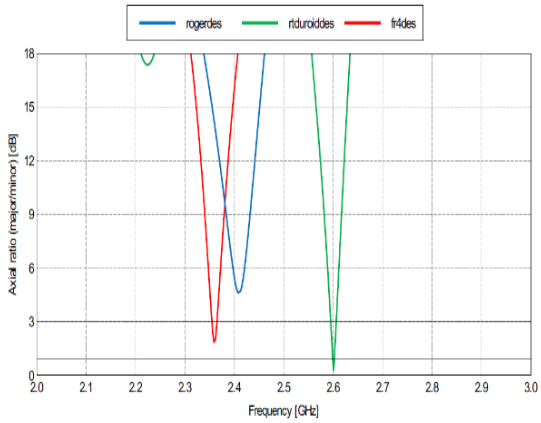


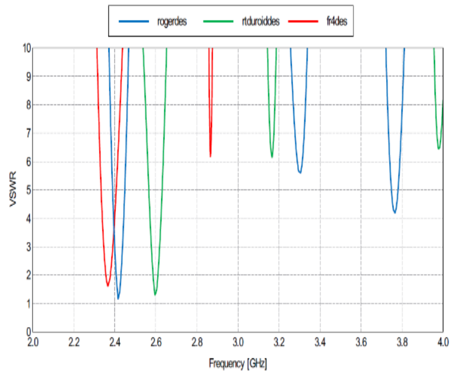
Fig.4: Return Loss



a)



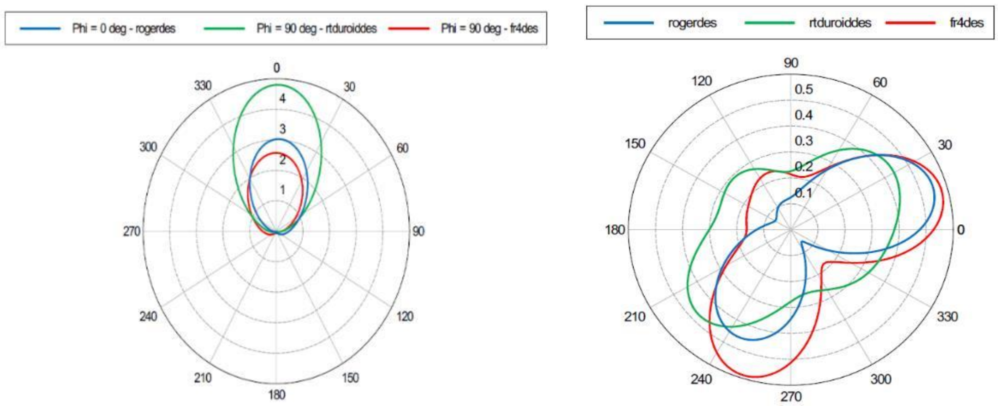
b)



c)

Fig 5. a) Gain, b) Axial ratio and c) VSWR of the proposed antennas **d) VSWR:**

The parameter VSWR is a measure that numerically describes how well the antenna is impedance matched to the radio or transmission line. The VSWR response is depicted in Fig 5 c. Usually the response of VSWR expected to be less than 2. Roger shows 1.2, RT-DUROID shows 1.4 and FR4 shows 1.7 at frequencies of 2.42, 2.6 and 2.34 GHz. It is concluded that both FR4 and Roger exhibits a good VSWR response near the RFID application. Additionally, the horizontal and vertical cut of far field radiation and the 3-d radiation pattern of the proposed antennas are also plotted and shown in Fig.6 and 7**.**



a) **b)**

Fig 6: 2-D Far field radiation a) Horizontal cut and b) Vertical cut

The figure 6 shows the 2-D Far field radiation pattern of horizontal and vertical cut for the proposed antenna to understand the orientation of the wave which is coming out from the antenna. The horizontal cut represents the azimuth pattern and vertical cut represents the elevation pattern. From both these plots the gain of the antenna can be found.

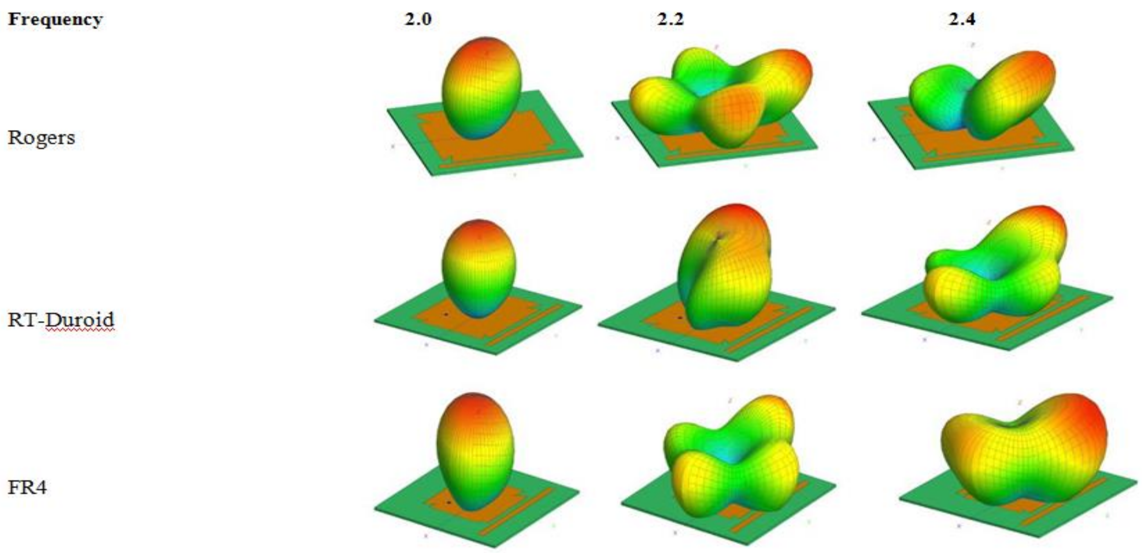


Fig 7: Three-dimensional Far-Field Radiation pattern

Table 3: Comparative analysis of the proposed antenna designs

Substrate	Reflection Coefficient	VSWR	Axial Ratio	Gain	Beam width	Bandwidth (GHz)		
	dB	dB	dB	dBi	degree	-3db	-10db	-15db
ROGERS	-33	1.2	4.098	3.2	60.80	0.067	0.0210	0.0118
RT-DUROID	-18	1.4	0.410	5	65.94	0.073	0.0221	0.0098
FR4	-13	1.7	1.978	2.7	67.90	0.083	0.0195	-

4. Comparative Analysis

Table 3 illustrations the comparative parametric analysis of the proposed antenna with three different dielectrics Roger, RT-DUROID, and FR4. From the analysis, it is found that the FR4 substrate satisfies the requirements of the RFID applications when compared to the other two substrates. Because RT-DUROID covers 2.6 GHz, which is not in the range of RFID. Roger meets the same expectations; however, it is too costly when compared to FR4. Hence the antenna is designed with the FR4 substrate were considered for the extended work for attaining circular polarization with symmetric and asymmetric slits.

5. Conclusion

The following observations were made from the analysis,

- The axial ratio for Rogers is 88.8% lower than that of RT-DUROID, hence it cannot radiate pure circularly polarized waves.
- RT-DUROID radiates pure circularly polarized waves with a moderate beam width of 65.94° at 2.6 GHz, which is beyond the operating frequency (2.4GHz).
- FR4 has relatively better circular polarization than Rogers and better beam width and nearest to the design frequency.
- The efficiency of Rogers, RT-DUROID, and FR4 is 90%, 98%, and 97% respectively. Moreover, FR4 is the cheapest and nearly hardest material that can be found. Therefore, it is concluded that FR4 substrate is the best optimum substrate.

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