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Investigation of Split Ring Resonator Based Rectangular Micro-Strip Patch Antenna for Radar Communication

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ABSTRACT

The advent of antenna technology has greatly influenced the field of wireless communication. In this paper, a novel rectangular microstrip patch antenna with split ring resonators is presented. It is intended for use in the X-band, which normally operates between 8 and 12 GHz. Split ring resonators are incorporated into the radiating patch to increase gain and frequency bandwidth. Based on Rogers TMM 10TM, a dielectric material with a relative permittivity of 9.8, the antenna is made to operate at 10.4 GHz in the X-band. Several factors, such as S-parameters, radiation pattern, Voltage Standing Wave Ratio (VSWR), gain, and directivity are used to assess the performance of the proposed antenna. The design and simulation of the antenna need the usage of High-Frequency Structure Simulator (HFSS) software. The findings imply that the suggested antenna configuration has an efficiency of 93.5% and is proved to be an excellent candidate for Radar Communication because of its wide frequency bandwidth and other performances.

1. Introduction

The researches in the field of antennas are achieving new dimensions. Mainly the researchers spotlight on the performance enhancement of antenna structure which should be enduring and compact. Antennas are the vital circuits used in communication system for transmission and reception of information. Radar communication is getting emphasized constantly especially with the inevitable role in the areas like air traffic control, speed detection, military applications principally in electronic warfare [1]. Micro strip patch antennas and Printed antennas are common candidates for radar communication and for mobile and satellite equipment [2]. Most commonly used antenna type in wireless communication is the low profile micro strip patch antennas due to its idiosyncratic

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behavior. The micro strip antennas consist of a substrate with radiating patch and ground plane on top and bottom sides respectively [3]. The antenna should be designed with same material having conducting properties for both patch layer and ground layer. The substrate of the antenna which is a dielectric should be selected according to the performance requirements of the structure [4]. Based on the operational needs of the antenna the design parameters are selected. The alluring details of MPA like low profile, featherweight, low cost, easy implementation etc make it widely acceptable across the globe. With the help of proper optimization the drawbacks like low gain and narrow band width can be beaten up [5,6]. In order to substantiate the innovation of the designed structure the various parameters such as S11, antenna gain, VSWR and bandwidth are interpreted. For ensuring better efficiency, larger bandwidth and better radiation which are highly required in application like radar communication, a thick dielectric substrate of dielectric constant less than 10 is desirable [7,8]. One of the main focuses is to reduce the size of the structure by proper miniaturization techniques [9]. The proposed antenna is designed to resonate at 10.4GHz with enhanced bandwidth. The proposed antenna has a relative gain of 1.9124dB at 10.4GHz. Radar has ample of X- band applications at 8-12 GHz [10]. Radars which are operating in this range are speed camera radar which are generally used in police detector and are exceptional in military, navigation and in weather forecasting [11,12]. The proposed antenna operating at 10.4GHz is generally used as traffic light crossing detectors and can be used for amateur radio operations.

2. Antenna Design

In this section, the design constraints of the proposed structure, properties and the design equations are discussed. The major role of substrate in MPA is to provide mechanical strength to the antenna. The two parameters that define the characteristics of a substrate are its dielectric permittivity and loss tangent. The substrate used in this research is Rogers TMM 10(tm) which is a thermoset microwave material. The properties of the substrate are clearly depicted in Table 1. All the units mentioned here are in mm and frequency is represented in GHz. The finalized structure of proposed antenna after undergoing the process of optimization is shown in Figure 1.

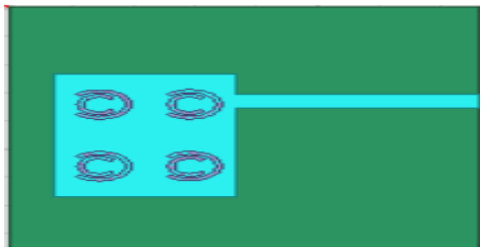

Fig. 1. Illustration of the Structure of the proposed Antenna with resonating elements

2.1 Properties of Rogers Substrate

The substrate used in this design is Rogers TMM 10(tm) material. This thermoset microwave material is a ceramic thermoset polymer composite designed for micro-strip applications. This substrate has benefits of both Poly Tetra Flouro Ethylene and ceramic based substrates. Due to its low dielectric loss, stable dielectric constant, tight electrical tolerances, high thermal stability, low moisture absorption, durability, compatibility with high-frequency and microwave applications, and good mechanical properties, Rogers TMM is a specialized substrate material used in antenna design and high-frequency applications. These materials' low dielectric loss tangent enables effective signal transmission and consistent performance under various operating circumstances. In addition, they are renowned for having great thermal stability, low moisture absorption, and durability, which makes them perfect for microwave and high-frequency applications. Rogers provides TMM materials in a variety of grades, enabling designers to select the optimal grade for their application needs. This substrate exhibits excellent electrical and mechanical properties and is a very good candidate for radar communication. Table 1 shows the substrate properties.

Table 1
Substrate properties

Parameters	Values
Relative permittivity	9.8
Dielectric Constant	267v/mil
Loss Tangent	0.002
Thermal conductivity	0.76W/m/K
Thermal expansion	20
Coefficient of Dk	-38

2.1.1 Design equations

The values of different parameters such as length and width of patch, length and width of substrate and height of substrate are calculated using the design equations. The design equations are vital as it decides the dimension of the structure. The designed parameters are optimized to obtain the required antenna performances suitable for aforementioned applications. Antenna is a major part of wireless communication and so proper design of antenna is very important. Any discrepancies in antenna design bring range issues. Optimizing the antenna design is the suitable method to overcome the poor range and to improve the overall system performance. Length and width of the structure is calculated by choosing appropriate parameters as depicted in Eq. (1) and Eq. (2). The parameter selection is purely based on the choice of substrate. Substrate selection is done so as to meet the requirements for the proposed application. The major parameter for consideration is effective relative permittivity, ε_{reff}. The Eq. (3) and Eq. (4) show how ε_{reff} is related with other parameters like relative permittivity and substrate dimensions. Length and width are calculated for both patch and substrate and the values are optimized to obtain desired antenna performances at desired frequency. The related equations are shown in Eq. (5), Eq. (6) and Eq. (7).

$$W = \frac{c}{2fo\sqrt{\frac{\varepsilon r+1}{2}}} \tag{1}$$

$$L = \frac{c}{2fo\sqrt{\varepsilon r}} - 2\Delta L \tag{2}$$

Where the effective dielectric constant can be obtained from the equation below equation

$$\varepsilon reff = \frac{\varepsilon r+1}{2} + \frac{\varepsilon r-1}{2\sqrt{1+12\frac{h}{w}}} \tag{3}$$

$$\frac{\Delta L}{h} = 0.412\frac{(\varepsilon reff+0.3)(\frac{w}{h+0.264)})}{(\varepsilon reff-0.258)(\frac{w}{h}+0.8)} \tag{4}$$

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

$$L_s = L_n + 6h \quad (6)$$

$$W_s = W_n + 6h \quad (7)$$

Where the above parameters are as follows c=speed of light which is approximately $3*10^8$m/s, f_r is the resonant frequency, ε_r defines the dielectric constant or relative permittivity similarly ε_{reff} is the effective dielectric constant. L_{eff}=effective Length and the L_p or L denotes the Length of the patch, W_p or W defines the Width of the patch Finally L_s and W_s represents Length and the width of the substrate respectively.

2.2 Antenna Design Parameters

The dimensions of the design parameters for the proposed antenna obtained from the design equations are mentioned in Table 2 below.

Table 2
Representation of various design parameters of the antenna

Parameters	Dimensions(mm)
Substrate	Rogers TMM 10(tm)
Patch length & width	3.9947 and 4.7067
Substrate length & width	Substrate length & width
Substrate height	1.58
Ground length & width	14.1867and 6.1
Feed length & width	3.74 and 1
Outer circle width and radius	0.2 and 0.93
Inner circle width and Radius	0.2 and 0.68

The fabricated structure shown in Figure 2 was tested and the below session shows the results and discussion where the simulation and test results are compared. The various antenna parameters have been tested and discussed in the below session.

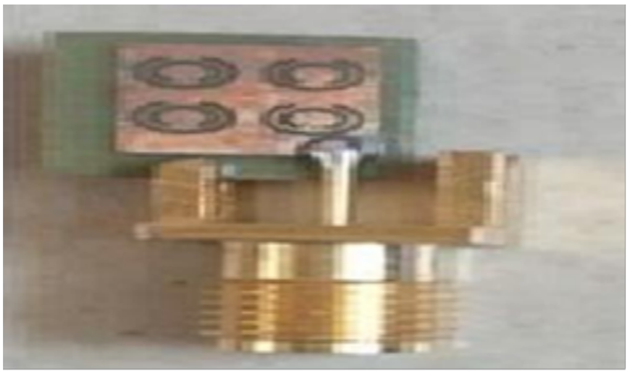

Fig. 2. Fabricated Structure

3. Results and Analysis

Figure 3 depicts both simulation and experimental results obtained for the return loss measurement of micro strip patch antenna. The return loss (S11) values of the proposed antenna with SRR at 10.4GHz is -15.11dB during simulation and -14.5 dB during physical test. Generally, the return loss is the ratio of incident power to the reflected power and it denotes the reconfigurable antenna performance [13,14]. The return loss has to be below -10 dB to obtain good mode of radiation [15]. From Figure 3 the proposed antenna's bandwidth can be determined. It offers a wider bandwidth of 3.9333GHz at the resonant frequency of 10.4GHz. The antenna is operable at the entire X band as a result of the adoption of SRR technique.

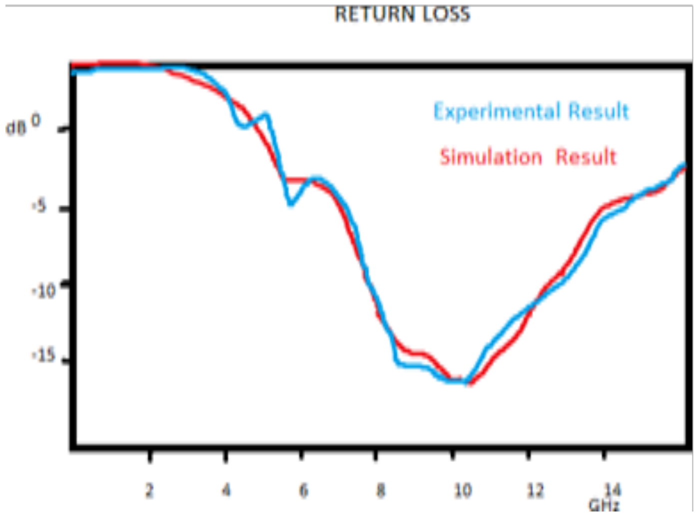

Fig. 3. The comparative analysis between simulated and Fabricated results

Figure 4 depicts the VSWR of proposed antenna at the resonant frequency of 10.4GHz. The VSWR of value between 1 and 2 could be considered a good reference value to ensure acceptable impedance matching by using the concepts of edge feed [8]. The VSWR of proposed antenna with circular SRR is 1.4259 at10.4GHz.

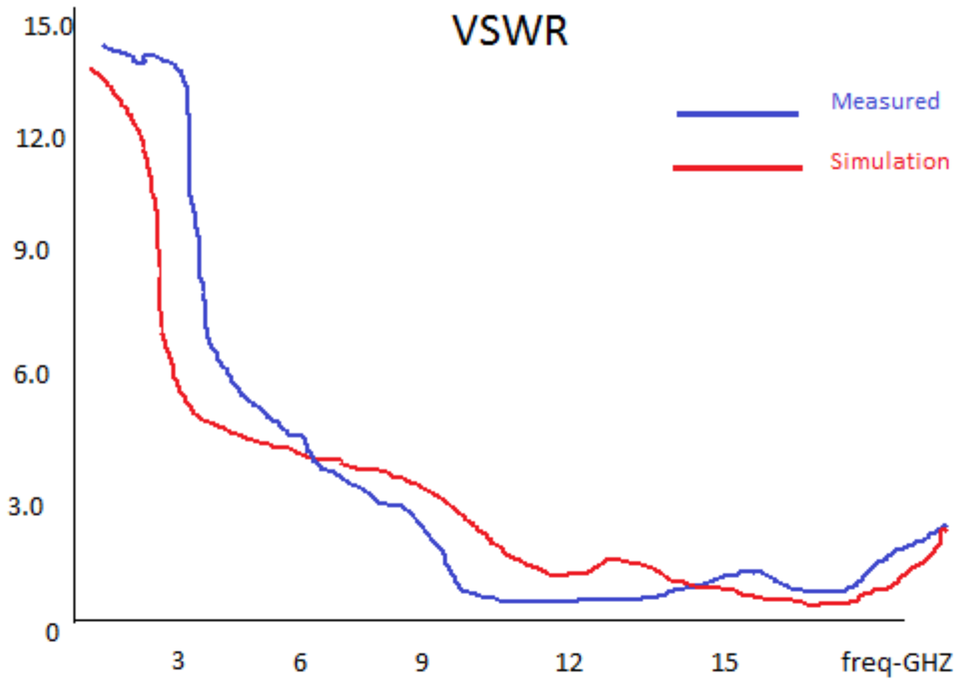

Fig. 4. VSWR of the proposed Antenna

The Figure 5 depicts the simulated radiation pattern of proposed antenna at the operating frequency of 10.4GHz. In the diagram two plots are described –one is E plane pattern and the other is H Plane pattern. The Figure 6 and Figure 7 indicate the test result of the E plane and H plane patterns. Both the simulation and experimental results have good proximity. The Figure 9 shows the directivity of proposed antenna. The directivity is 2.0093dB at resonant frequency of 10.4GHz. Therefore, the efficiency of antenna is 93.5%. The Figure 8 depicts relatively good gain of proposed antenna of 1.9124dB. Generally, when gain is relatively equal to directivity then the antenna works more efficiently as gain is directly proportional to directivity. Table 3 depicts various simulation and measured results of proposed micro strip patch antenna. This gives an evident information on how efficiently the designed antenna works.

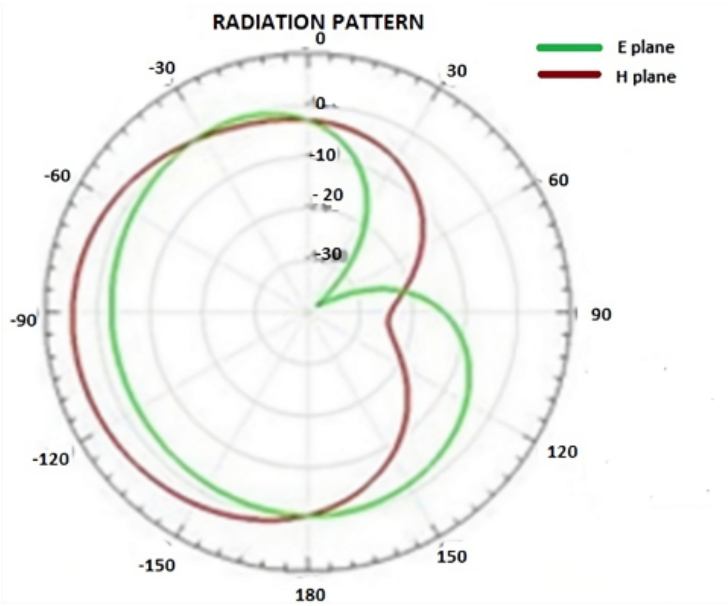

Fig. 5. Radiation Pattern of the Antenna

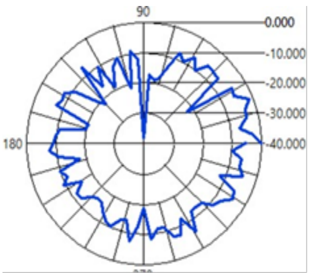

Fig. 6. H plane pattern (Experimental result)

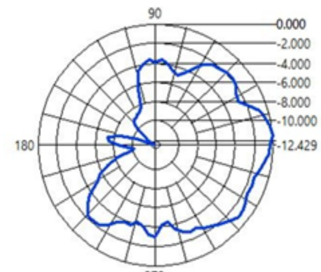

Fig. 7. E plane pattern (Experimental result)

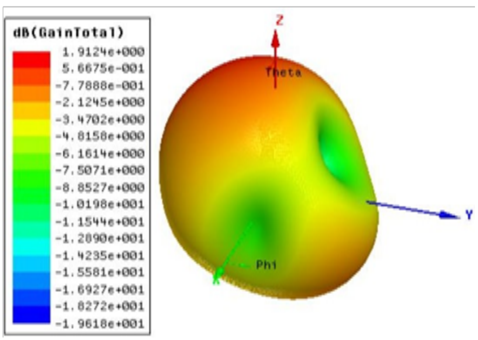

Fig. 8. Gain of proposed antenna

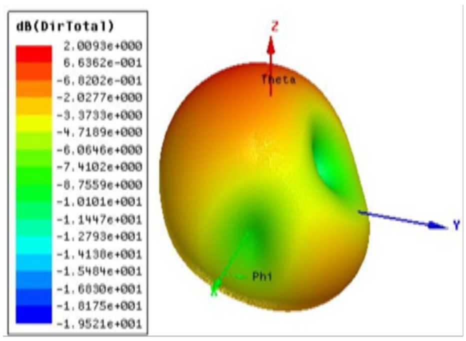

Fig. 9. Directivity of proposed antenna

Table 3
The output Parameters of the Antenna with a comparative analysis

Characteristics of antenna	Results	
	Simulation	Measured
Resonant frequency	10.4GHz	10.4GHz
Return loss	-15.11dB	-14.5dB
Bandwidth	3.933GHz	3.9GHz
Antenna gain	1.9124dB	2dB
Antenna directivity	2.0093dB	2dB
Antenna efficiency	95%	93%

4. Conclusion

A detailed performance analysis is being carried out in this work along with the design and simulation of proposed antenna with circular split ring resonators is obtained using HFSS software. Investigation was done on various functional characteristics of proposed antenna. This designed structure is resonating at 10.4 GHz frequency with the return loss of around -15dB and the VSWR of 1.4. As the VSWR of proposed antenna nearly equals to 1 and less than 2, it can be considered as a good reference for acceptable impedance matching. As the gain and directivity of antenna are similarly equal, this antenna works more efficiently with 93.5%. The dimensions of antenna are 13.4747x14.1867mm. The size of proposed antenna is small and meets the requirements for X-band applications and gives wide frequency bandwidth. Hence it can be incorporated for radar communication. Considering the future enhancements, this proposed structure can be modified and implemented with a wearable substrate and can be used with conformal clothing. As a future extension the proposed structure can be modified as an antenna and can be effectively used as a RF energy harvester [16]. This will be an appropriate device for the soldiers when they are at war-front.

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