ISSN 2320 2599
Volume 4, No.1, January - February 2015
International Journal of Microwaves Applications
Available Online at http://warse.org/pdfs/2015/ijma02412015.pdf

Circular-Rectangular Microstrip Antenna for Wireless Applications

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ABSTRACT

Generally the WLAN standard defines two frequency ranges one for the Lower (2.4-2.48GHz) and the other for the Upper (4.9- 6 GHz). In Wi-Fi, the coverage for lower and upper is specified as 2.4-2.48 GHz and 5.15-5.8GHz respectively. Commercially for Wireless LAN two separate Ethernet port adapters are currently utilized in many places– one for the 2.4 GHz band and for the 5.5 GHz band. These adapters use two different antennas for their operations. In this paper, a modified slotted microstrip antenna resonating at 2.4GHz, 5GHz and 5.5 GHz is proposed. This antenna is found to provide improved performance in terms of lower return loss and higher gain when compared to the conventional one. The antenna has been designed and simulated using ANSOFT HFSS EM simulator. It makes use of FR4 as substrate with dimensions 50mm x 40mm x 1.6mm and the antenna pattern is printed on it using copper. The outer radius of the circular microstrip antenna is 17mm. The circular antenna resonates at 2.4GHz and the rectangular antenna kept inside this circular antenna resonates at 5.5GHz. Additionally the circular-rectangular combination results in the resonance possibility with a third frequency at 5GHz also. This modified single patch antenna is analyzed in terms of resonance, bandwidth, VSWR, radiation pattern, gain and directivity.

Key words : Gain, microstrip patch antenna, pattern, radiation, return loss, Wireless LAN

1. INTRODUCTION

Circular-rectangular patch has been developed for the triple band antennas in the wireless communication systems [1]. Microstrip antenna has wide range of application in the field of mobile and satellite communication, RFID (radio frequency identification), GPS (global positioning system) and in radar applications. It is widely used because of its low profile and lightweight. There was a recent development in wireless communication in order to convert IEEE WLAN (wireless local area network) standards in 2.4GHz and 5-6 GHz. Hence this paper introduces an antenna that can satisfy operations in all these frequency ranges. This triple-band antenna [4, 6] resonates at 2.4GHz, 5GHz and 5.5GHz.

The Wireless LAN IEEE 802.11b/g radios utilize the 2.4 GHz frequency band (2.412 – 2.472GHz) and the IEEE 802.11a radio utilizes the 5.5 GHz frequency band (5.180 – 5.825GHz). However, IEEE 802.11n radios provide the possibility of operation in either frequency band. Till now, the use of the 5.5GHz band in industrial applications has been more or less limited to wireless applications such as smaller access points when compared to 2.4GHz band. As of now, more overlapping wireless channels exist in 2.4GHz band leading to interferences. However when the 5.5GHz band is used, there are some limitations [7] mainly with range covered. Particularly, the proposed antenna resonates in 5.5GHz with increased gain and hence it can cover longer range. Hence it can accommodate more non-overlapping channels when used for smaller access point applications. Therefore this antenna is recommended for applications in various short range wireless devices.

The Figure.1 shows the basic microstrip antenna structure. This antenna consists of radiating patch, dielectric substrate and a ground plane. The length and width of the patch is represented as L and W, h is the height of the substrate. The radiating patch is placed above the substrate and ground plane on the other side [2]. The patch and ground are made of copper. There are different methods for feeding the antenna such as microstrip line feed, coaxial probe feed, aperture coupled feed and proximity coupled feed. For the improvement of the performance slots [3, 5] on the patch on the antenna structure can be made.

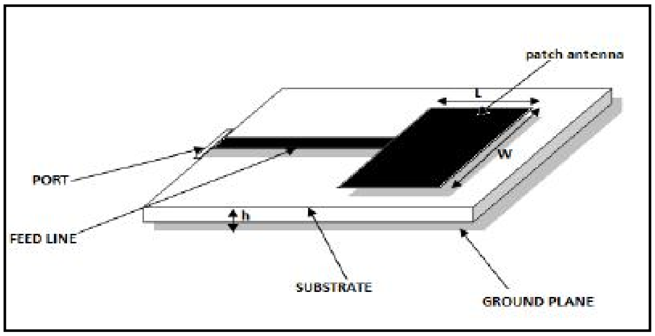


Figure 1: Basic Structure of Microstrip Antenna

2. ANTENNA DESIGN

This paper proposed triple-band printed circular-rectangular patch antenna. Initially circular patch antenna is designed for 2.4GHz and rectangular patch for 5.5 GHz. Then these two antennas are kept one inside the other and connected using small conducting strips called bridges. These bridges have a great impact in tuning the antenna to the required frequency band. The required resonance frequencies are obtained by parameter variation such as changing the bridge width or position [2].The rectangular patch antenna can be designed [5] using the equations as shown in Equations (1)-(5).

$$\varepsilon_{eff} = \frac{\varepsilon_r+1}{2} + \frac{\varepsilon_r-1}{2}\left(1 + 12\frac{W}{h}\right)^{0.5} \quad (1)$$

$$\Delta L = 0.412h\frac{(\varepsilon_{eff}+0.3)(\frac{W}{h}+0.264)}{(\varepsilon_{eff}-0.258)(\frac{W}{h}+0.8)} \quad (2)$$

$$L_{eff} = L + 2\Delta L \quad (3)$$

$$L_{eff} = \frac{c}{2f_r\sqrt{\varepsilon_{eff}}} \quad (4)$$

$$W = \frac{c}{2f_r\sqrt{\frac{\varepsilon_r+1}{2}}} \quad (5)$$

The dimensions of the circular patch [4] antenna can be determined using the Equations (6) - (7).

$$f_r = \frac{1.8412c}{2\pi a_e\sqrt{\varepsilon_r}} \quad (6)$$

$$a_e = a(\sqrt{1 + \frac{2h}{\pi a\varepsilon_r} ln[\frac{\pi a}{2h} + 1.7726]}) \quad (7)$$

The following are the details of notations used in all the above Equations (1) - (7).

f_r - resonant frequency(GHz)
c - speed of light(m/sec)
a_e - effective radius(mm)
ε_r - relative permittivity
ε_{eff} - effective permittivity
h - thickness of the substrate(mm)
a - radius of patch (mm)
W - Width of the patch (mm)
ΔL - extension of the length (mm)
L_{eff} - effective length of the patch(mm)

The calculated dimensions of these two antennas are listed in the Table I.

Table I: Design Parameters

Antenna	**Parameters**	**Dimensions**
	Resonant Frequency	2.4GHz, 5.5 GHz
	Dielectric Constant	4.4
Rectangular Patch	Length of the patch	12.4mm
	Width of the patch	16.59mm
Circular Patch	Radius of the patch	17mm
Connecting Strip	Length of horizontal strip	6.5mm
	Length of vertical strip	3.25mm
Feed	Length of the strip	15mm
	Width of the strip	2mm
Ground/Substrate plane	Length of the plane	40mm
	Width of the plane	50mm

3. SIMULATION TOOL

The antenna has been designed and simulated using ANSOFT HFSS (High Frequency Structure Simulator) EM (Electro Magnetic) simulator, with a sweep range between 1-6GHz.This software supports 3-D structures.

4. RESULTS AND DISCUSSIONS

The Figure 2 shows the structure of the initially proposed circular-rectangular patch antenna. Four connecting bridges are used to link the circular and rectangular antennas. The length of the connecting strip is maintained to be λ/4. However, the width of the strip is treated as a variable. The four strips are placed symmetrically at four points. Microstrip feeding techniques is preferred in this design. The length of the feed is again considered to be multiples of λ/4 for proper impedance matching at the end. The patch antenna shape is etched from the double side printed dielectric substrate FR4-Epoxy with dielectric constant (ε_r) of 4.4. The backside of the substrate is used as the ground portion. The dimensions are determined based on selected resonant frequencies 2.4 and 5.5 GHz.

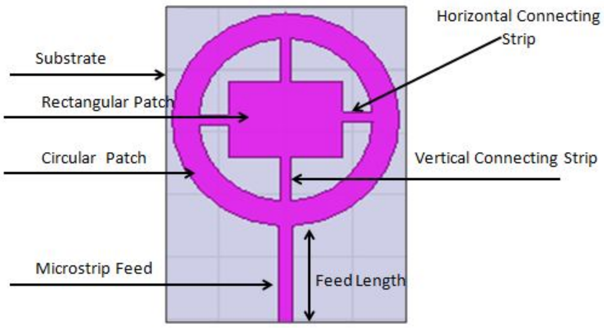
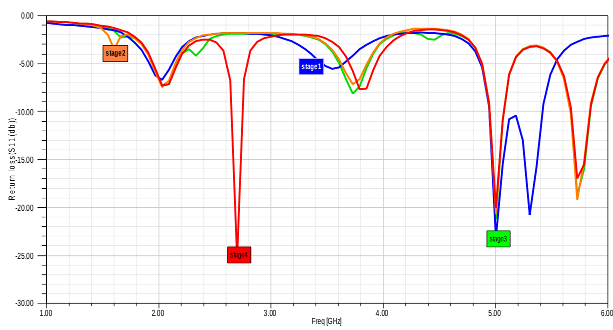


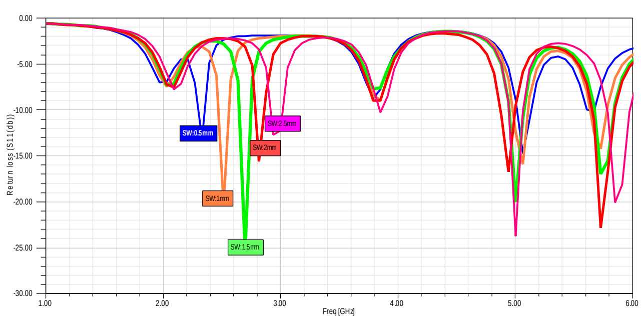
Figure 2: Structure of Initially Proposed Circular-Rectangular Antenna

The detailed parametric study of the design has been discussed in this section. This plays a vital role in obtaining the desired frequency with lower return loss and higher gain [5]. FR4-Epoxy was originally chosen as the substrate as it has a low loss tangent which will not reduce the antenna efficiency, and has a relatively low dielectric constant. Thick dielectric substrate with low dielectric constant provides better efficiency, larger bandwidth and better radiation, but it is against the low profile concept. However thickness variation is also considered in the optimization, in this paper. The simulation results of proposed antenna is discussed in the following sections.

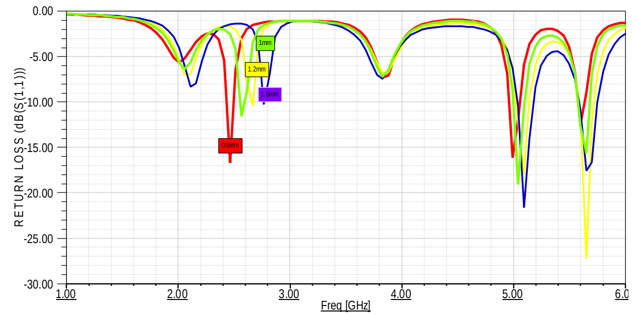
4.1 Parametric Analysis



(a)



(b)



(c)

Figure 3: Simulation of Parametric Analysis. (a) Resonance Characteristics with Increase in Number of Bridge (b). Resonance Characteristics when Width is Varied (c). Resonance Characteristics when Substrate Thickness Varied

The proposed antenna can be optimized in different stages to obtain the better performance. Mainly parametric analyses are considered in this design which are variation in number of bridges (strips), width of the bridge and substrate height.
The analyses were carried out one by one.

A. Increased Number of Connecting Strips

In this stage circular patch and the rectangular patch are connected by using conducting strips called bridges. Initially one bridge was connected and the performance of antenna was analyzed [5, 6]. Similarly in consecutive steps, two, three and four strips were added. From this analyzes it is noted that when four bridges were used, the antenna exhibited better performance. Hence four such bridges were added at equal places at the inner part of the circular patch antenna so that the rectangular patch is fed through the same for connecting circular and rectangular patches. In the Figure 3(a), a comparison of the performance of antenna when number of connecting bridges were added in consecutive steps is shown. With single connecting strip, the resonance frequency is 5GHz with a return loss value of -24dB. Then for two strips, the f_r is 5.8 GHz with a return loss of -19dB. When three connecting strips were added, the return loss becomes- 22dB and the resonant frequency is 5GHz.The red colored line in the graph indicates that the antenna performance when four conducting strips were used. The return loss provided by this structure is very less when compared to the other structures with one, two and three connecting strips. It resonate at frequency of 2.6GHz and 5GHz with return loss of -25dB and -20dB.From the analysis, it is found that the structure performs well when four connecting strips are added. Hence the structure is retained for rest of the parametric analysis.

B. Variation in the width of the connecting strips

From here onwards the structure with four connecting strips is used for further analysis. In this section the width of the bridge is varied so as to determine the better resonance [8]. Variation of the bridge width from 0.5mm to 2.5mm was carried out in steps of 0.5mm. The simulation results are shown in Figure 3(b).

From the return loss graph it is clear that when the bridges width is 1.5mm, it give reduced return loss and hence better performance. So we fixed the width of the bridges with 1.5mm.

C) Variation in the thickness of the substrate

The next parametric analysis deals with varying the thickness of the substrate [7]. To obtain better performance we will check the antenna with different substrate heights. The substrate height that was selected is 0.8mm, 1mm, 1.2mm and 1.6mm.

When substrate height is 0.8mm, the circular-rectangular antenna resonates for the designed resonate frequency. That is at frequency of 2.4 GHz and 5.5 GHz the antenna has a return loss of -16.8 dB and -16 dB. So for circular-rectangular antenna the height is fixed with 0.8mm.

4. 2 Optimized Antenna

Based upon the variations in the elected parameters and the comparison and final results obtained the final optimized antenna is decided. Hence the antenna with four connecting bridges and each strip of width of 1.5mm and for the substrate thickness of 0.8mm provides better performance.

Literature [7] says that introduction of slots improve the antenna performance in terms of reduced return loss and lowered resonant frequency. Hence, this concept is introduced by etching two arcs like slots and one circular slot on the antenna.

The Figure 4 shows the final optimized design for circular-rectangular microstrip antenna. In this design the feed, patch and the ground plane is assigned copper material. The antenna performance is discussed in the below section.

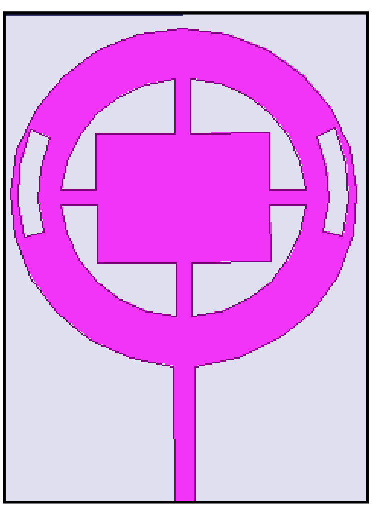
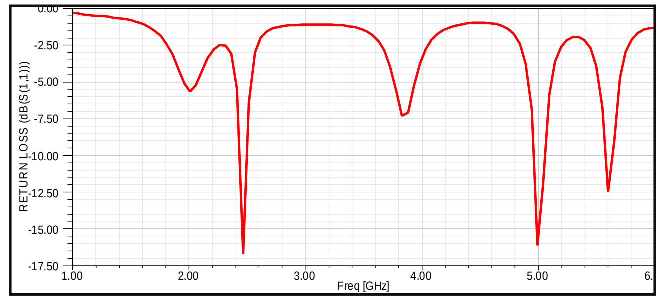
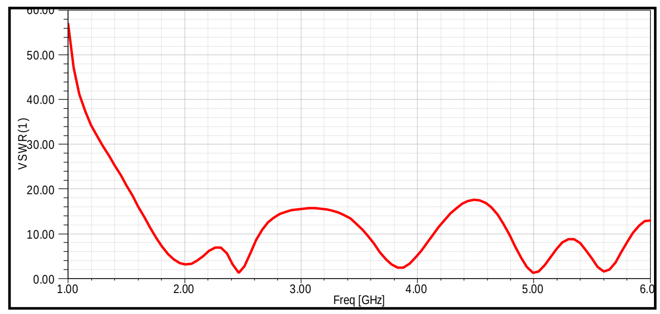


Figure 4: The structure of circular-rectangular patch Antenna



(a)



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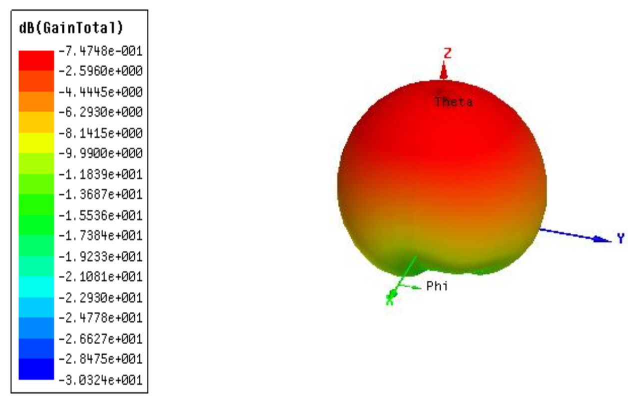
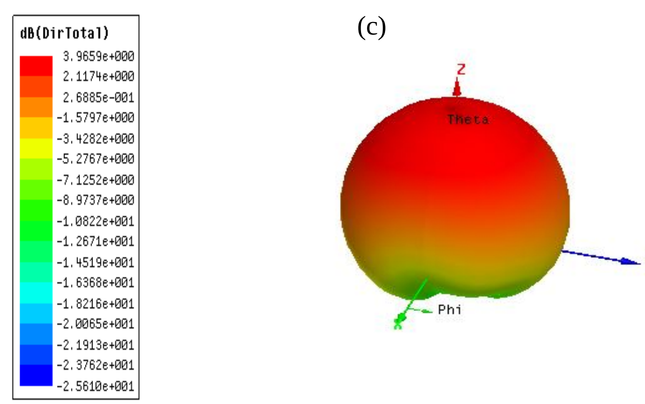


(c)



(d)

Figure 5: Characteristics. (a) Return Loss (b) VSWR (C) Gain (d) Directivity

A) Return Loss Characteristics

When there is a mismatch with the load, the power is not fully delivered to the load some amount of power will be returner back. The loss of power in reflected signal due to the mismatch in the load impedance is measure as return loss. When the return loss graph crosses -10 dB, it indicates the input impedance matched with the load impedance, so that the antenna radiates with high power. The simulation result for the designed graph is shown in figure 5(a).
At the resonate frequency of 2.4 GHz and 5.5GHz, the antenna has a return loss of -16.8 dB and -12.5 dB. And an additional band of frequency at 5 GHZ with return loss of -16 dB is obtained due to the connecting strips.

B) VSWR Characteristics

The VSWR is an important characteristic of communication devices. It gives the measurement of how well an antenna is matched with it feed impedances where the reflection coefficient will be 0. The simulation result for VSWR is shown in Figure 5 (b).
At 2.4 GHz and 5.5GHz the VSWR value is between 1 and 2. Hence, the antenna radiate efficiently

C) Gain Characteristics

The performance of the antenna is described in terms of gain. It gives overall performance of the antenna .gain refers to the direction of maximum radiation. The figure 5(b) shows the gain of the designed antenna.

D) Directivity

The fundamental parameter of an antenna is its directivity. It tells us how directional an antenna radiates. An antenna that radiate equally in all direction will have zero directionality. The figure 5.4 shows the directivity of triple band antenna.

E) Radiation Pattern

The 3D polar plots of gain and directivity are shown in Fig. 5 and Fig. 6.It is found that the radiation is unidirectional in the Ө (0^0 to 180^0) and Φ (0^0 to 360^0) directions. There is no radiation in the backside because of the ground plane.

6. CONCLUSION

This proposed antenna offers better performance in terms of return loss and gain while providing triple band resonances. Hence it is recommended for many wireless applications in the frequency range of 2.4GHz, 5GHz and 5.5GHz. The gain of the antenna can be further increased by introducing slots on the patch. The future plan is to fabricate the antenna and verify the results using network analyzer.

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