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Independently tunable quad band patch antenna using CSRR for C and X-band applications

B. Nancharaiah *, T. Poorna Sridevi, Ch. Vasantha Kumar and A. Sai Karthik

Department of Electronics and Communication Engineering, Usha Rama College of Engineering and Technology, Telaprolu, Andhra Pradesh -521109, India.

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Abstract

The suggested antenna is based on a patch including complementary split-ring resonators in the ground plane and a truncated corner slot. The antenna displays four operational bands in this manner, and its resonant frequencies can be individually adjusted by adjusting the ground plane resonator structures and the patch slot's dimensions. Furthermore, the antenna displays a notch-band feature at 10.7 GHz as a result of the complementary split-ring resonator structures' anti-resonant behavior. Four X-band operating bands are displayed by the suggested antenna, together with their respective absolute and relative bandwidths. 7.0–7.2 GHz (200 MHz, 7.8–8.0 GHz (200 MHz),8.3–8.4 GHz (100 MHz) and 8.7-8.9 GHz(200MHz) s. The antenna is simulated in order to achieve desired gain, omnidirectional radiation patterns, and return loss characteristics.

Keywords: Complementary split-ring resonators; Perfect electric conductor; Perfect magnetic conductor

1. Introduction

It is desirable to build a patch antenna that covers two or three nearby frequency bands in certain wireless communications applications. For example, a base station antenna may be required to simultaneously provide wireless access services for both WCDMA (1.92 2.17 GHz) and WiMAX (2.50 2.69 GHz), while rejecting most of the frequencies between the two bands [1-3]. In this case, the center frequency ratio is 1.27. A three-band antenna is preferred if the WiMAX middle band (3.3–3.7 GHz) is also to be covered by the antenna. In this second case, the frequency ratios are 1.27 and 1.71. For dual-band patch antennas with small frequency ratios, an effective design is that of stacked patches, first reported by Long and Walton [1]. A dual band antenna with frequency ratios ranging from 1.11 to 1.18 was demonstrated by varying the relative diameters of the top and lower circular discs. The linear polarization of the radiation at the two bands is the same, and the patterns are comparable. You can extend the stacked patch design to include more than two bands. In [4-6], a five-band patch antenna was demonstrated using five stacked patches. The following bands' frequency ratios were 1.113, 1.195, 1.280, and 1.4 in relation to the first band. Recently, a new approach to designing dual and triple band patch antenna with small frequency ratios was introduced [7], [8]. First, a broadband antenna is used in the process. The introduction of a band notch at a frequency inside the original broadband occurs when a properly positioned U-slot of the right proportions is cut in the patch. Antennas for two bands are created by converting broadband ones. One can introduce two band notches and create a triple-band antenna by cutting a second U-slot in the patch. In [9-11], this new method was applied to the cases when the original broadband antennas were (1) a L-probe fed patch; (2) a M-probe fed patch; (3) coax-fed stacked patches; and (4) aperture coupled stacked patches. All these cases involve either relatively complicated feeds or more than one layer or more than one patch [12]. In this communication, we apply the method to the case when the original broadband antenna is a coax-fed U-slot patch. One layer and one patch, along with the feed's simplicity, are the benefits of this design.

* Corresponding author: B. Nancharaiah

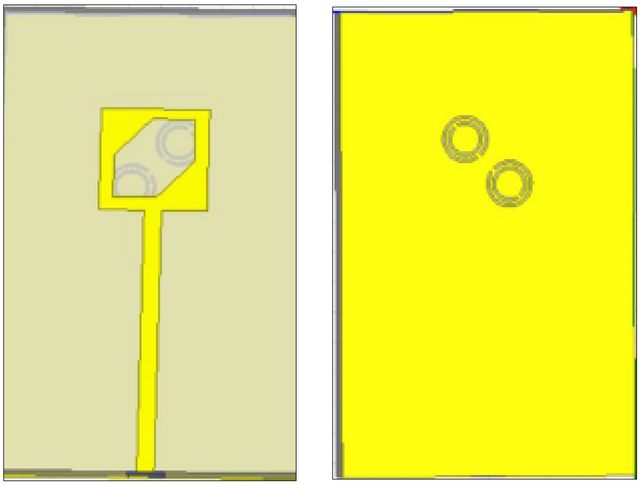
2. Design of antenna

In order to achieve multiresonant frequency and notched-band features, the suggested antenna is developed using a patch antenna with a number of top and bottom layer changes. In the square radiating patch, a truncated corner square slot is inserted as the top layer, as seen in Figure 1 (Figure 1(a)).

As seen in Figure 1(b), the two complementary split-ring resonators (CSRRs) lack the bottom layer, which serves as a ground plane. A dielectric layer of FR-4 (εr = 4.4, tanδ = 0.2) separates the copper radiating patch and ground plane. Parametric studies that examine the behavior of the antenna with varying slot and CSRR structure dimensions and placements will be provided in the next section.

Table 1 Design Parameters

S. No	Parameter	Value
1	Frequency of operation	7GHz to 9GHz
2	Patch Length	7mm
3	Patch Width	5mm
4	Dielectric Material	FR-4
5	Substrate height	1.6mm
6	Dielectric Constant	4.4
7	Dielectric Loss Tangent	0.02



(a) (b)

Figure 1 (a) Top view and (b) Bottom view of the proposed antenna

3. Simulation results

Figure 1 shows the proposed antenna's gradual development from a traditional square patch with a 7.94 GHz fundamental resonance. An extra resonance at 8.44 GHz is created by adding a truncated corner slot to the radiating patch, while the existing resonance moves from 8.39 GHz to 8.49 GHz. This is caused by the degenerate rectangular patch modes' mode splitting, which distributes their currents now perpendicular to the main axis of the slot. The slotted antenna's ground plane is then expanded to accommodate two CSRR structures as the following stage. The two lower resonances are dramatically downshifted, whereas the slotted antenna filled with CSRR structures generates a greater resonance at 8.83GHz. Additionally, a notch in the frequency band is created, with its center at about 8.44 GHz. The resonant and anti resonant frequency properties of the CSRR structure, which are described and shown in the next subsection, are the basis for the formation of both the band notch and the higher antenna resonance.

In this part, the impact of the slot on the resonant frequencies of the antenna is examined by a parametric study of the slot. The resonant characteristic of the antenna with various orientations is the first thing we look into. In this part, the impact of the slot on the resonant frequencies of the antenna is examined by a parametric study of the slot. The resonant characteristic of the antenna is first examined using various slot orientations. positioned beneath the slot patch radiator. The left and right faces of the waveguide have the perfect electric conductor (PEC) boundary condition set up, while the front and back faces of the waveguide have the perfect magnetic conductor (PMC) boundary condition set up.

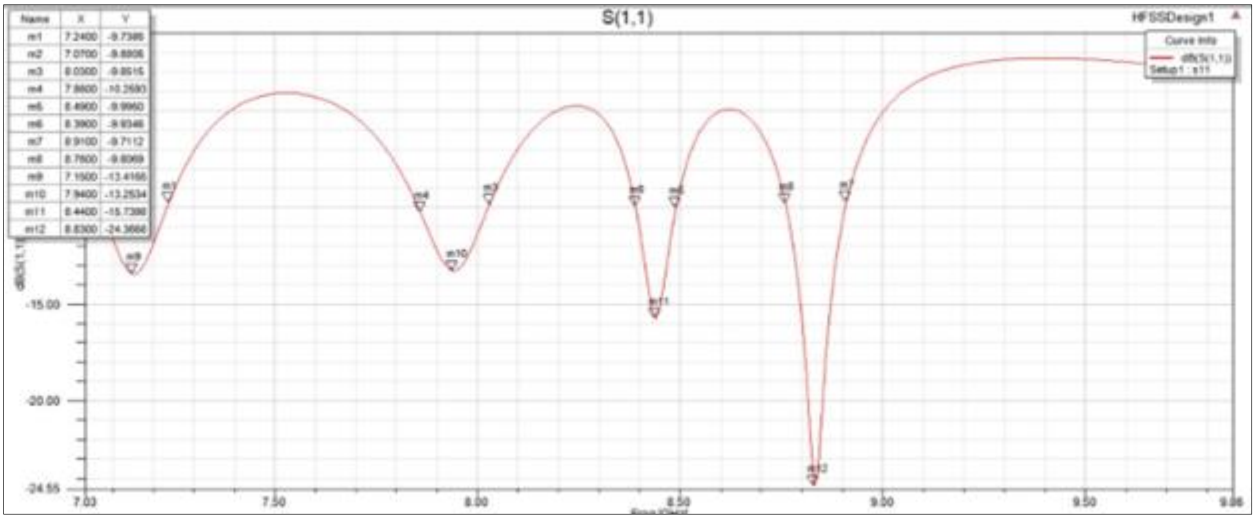


Figure 2 Refection coefficient S(1,1) of the simulated antenna

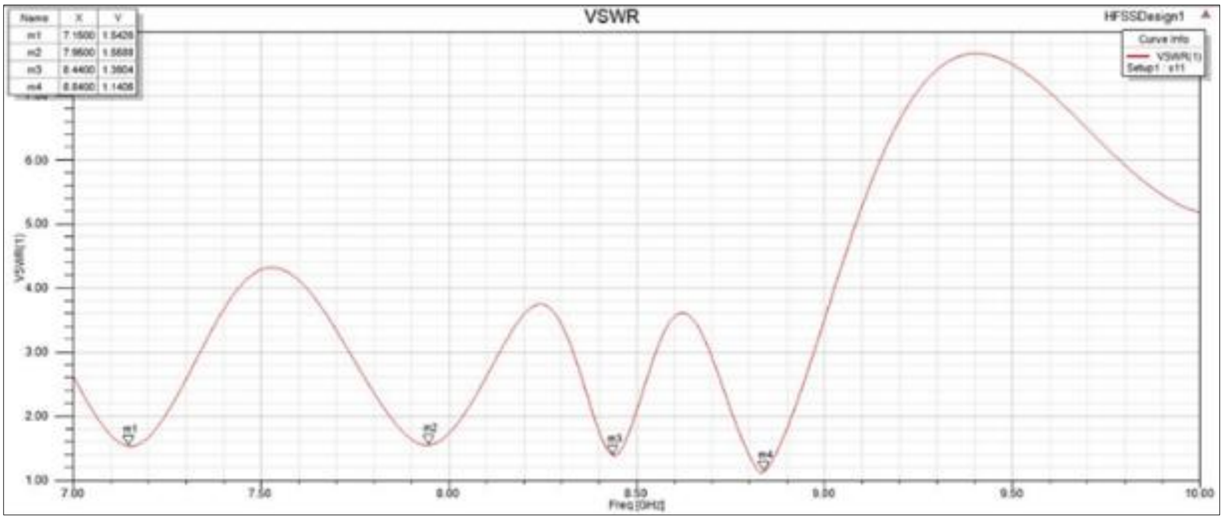


Figure 3 VSWR of the simulated antenna

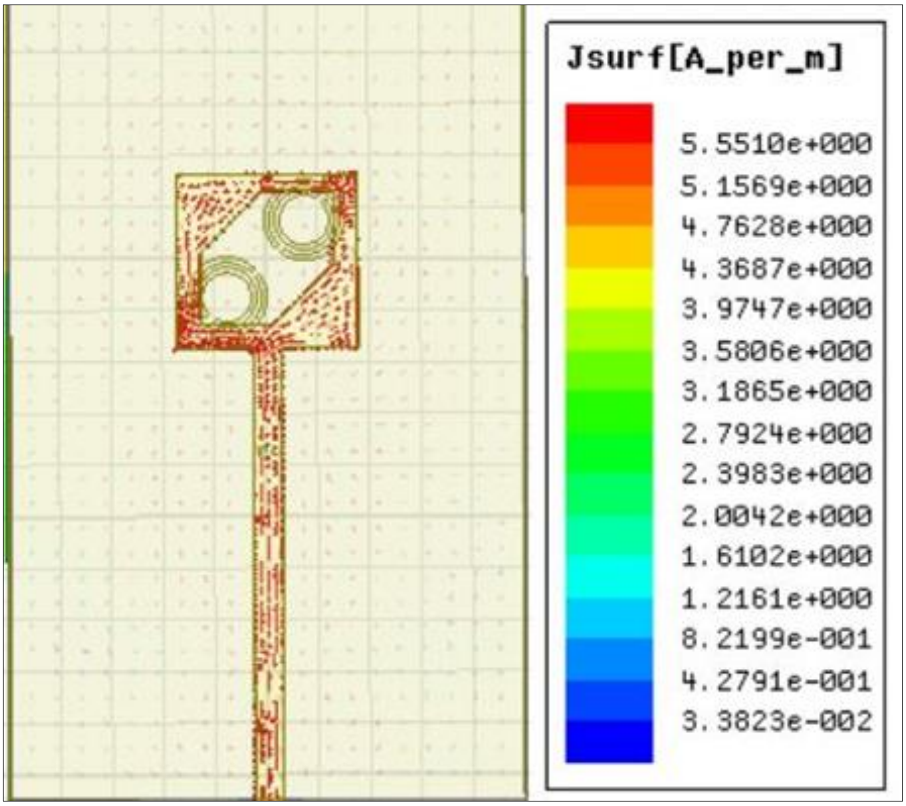


Figure 4 Current distributions on the top and bottom layers of the proposed antenna

Figure 2 represents the S11 of the proposed antenna. Antenna shows Quad band performance ranging from 7.0–7.2 GHz (200 MHz), 7.8–8.0 GHz (200 MHz),8.3–8.4 GHz (100 MHz) and 8.7-8.9 GHz(200MHz) s. S11 of the proposed antennas operating frequencies is shown in Figure 2. VSWR being 1.54,1.55,1.39 and 1.14 at 7.15 GHz,7.94,8.44 and 8.83 GHz respectively. Also, the VSWR values at different frequencies is shown in Figure 3 displays the current distributions on the upper and lower layers of the suggested antenna (4). The 3D polar graphs in Fig. 5 can be used to understand the antennas' gain of 2.7dB. The Figure 6 illustrates the radiation patterns in the E- and H-planes of the microstrip patch antenna that were investigated using modeling at 7-9 GHz.

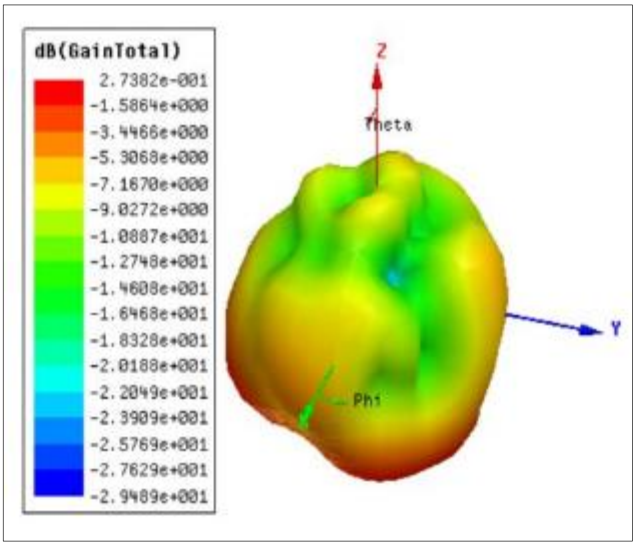
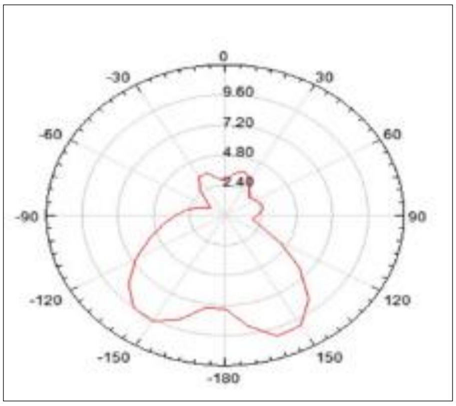
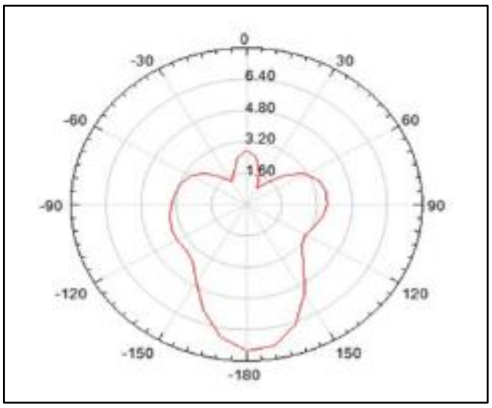


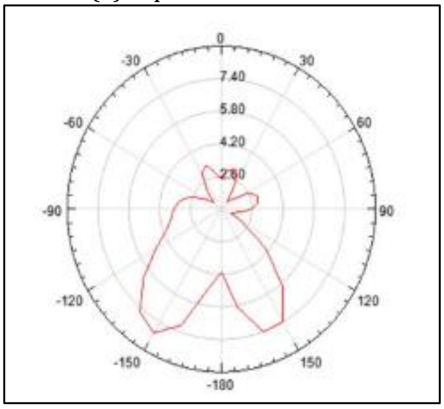
Figure 5 3D polar plot of the simulated antenna



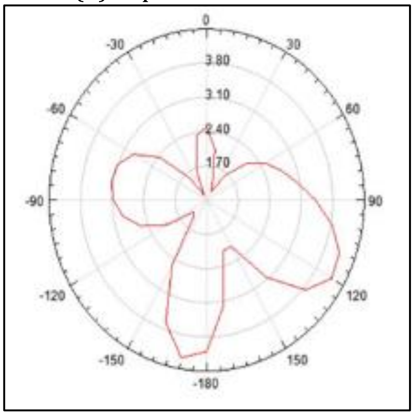
(a) E-plane at 7.15 GHz



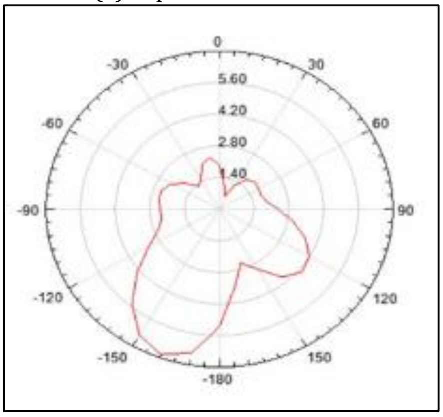
(b) H-plane at 7.15 GHz



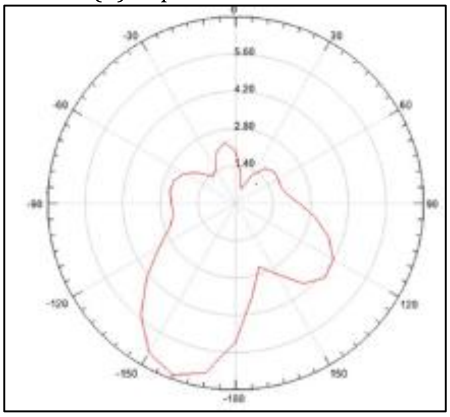
(c) E-plane at 7.95GHz



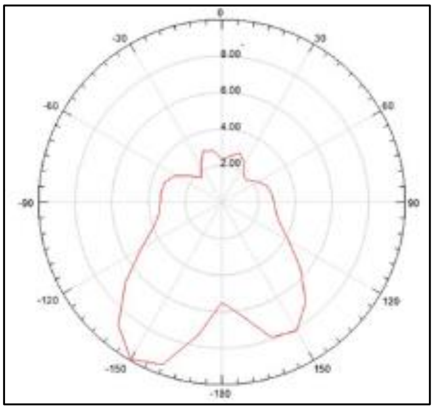
(d) H-plane at 7.95 GHz



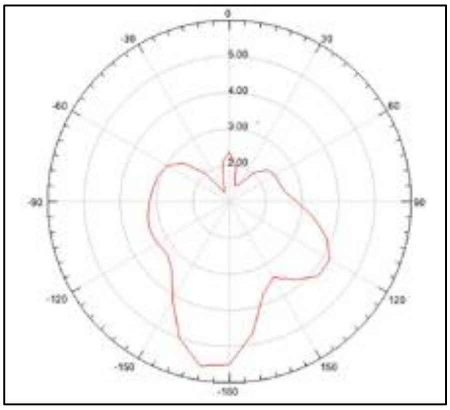
(e) E-plane at 8.44 GHz



(f) H-plane at 8.44GHz



(g) E-plane at 8.8 GHz

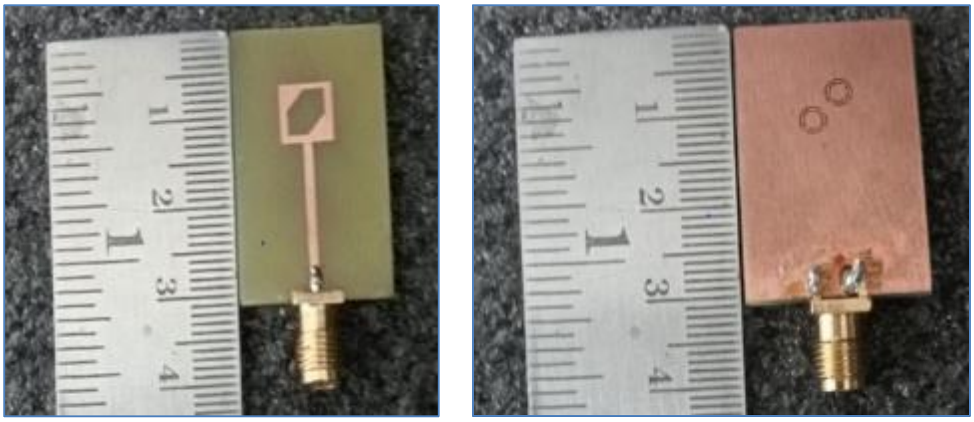


(h) H-plane at 8.8 GHz

Figure 6 Simulated radiation patterns at the Quad band operating frequencies of the proposed antenna

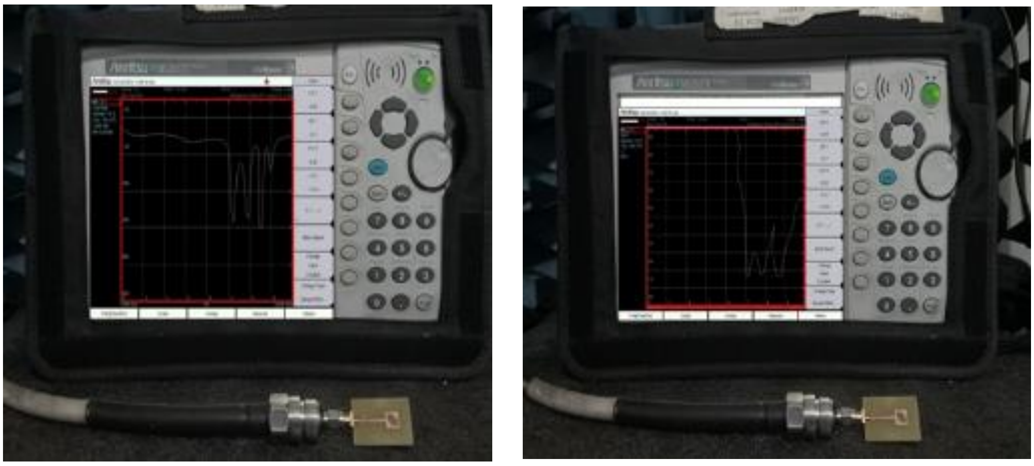
4. Experimental results

In order to validate the simulation results, the suggested antenna was built and measured. The measured reflection coefficient (S11) is depicted in Figure and, with the exception of a small downward frequency shift at the highest resonance and notch band, is comparable with the calculations. The VSWR of the proposed antenna is the acceptable range of 1-2. The resonance frequencies of the antenna are 7.2,7.9 and 8.5GHz. The antenna has a return loss of -13.7, -13.2 and -15.4 dB (S11). According to the S11 plot, the bandwidth was 200,200 and 100 MHz as well. At the operational frequency of 7 to 9 GHz, it was discovered that the VSWR was 1.3,1.5 and 1.4. The comparison of all the parameters studied through simulation and experimentation for the antennas are presented in Table 2.



(a) (b)

Figure 7 (a) Top view of antenna, (b) bottom view of antenna



(a) (b)

Figure 8 (a)(b) VNA set up for measuring various antenna parameters

Table 2 Comparison of Parameters

	Frequency (GHz)	S11 (dB)	Band Width (MHz)	VSWR
Simulation	7.15	-13.4	200	1.54
	7.95	-13.26	200	1.55
	8.44	-15.7	100	1.39
	8.85	-24.36	200	1.14
Measured	7.2	-13.7	200	1.3
	7.9	-13.2	200	1.5
	8.5	-15.4	100	1.4

5. Conclusion

This paper presented quad-band antenna with integrated notch-band characteristics while maintaining design simplicity. The proposed antenna is a patch loaded with a slot and two CSRR structures in the ground plane, allowing it to operate at four frequency bands and exhibit a band-notch behavior within the C and X-band. Most importantly, the resonant frequencies of the antenna can be controlled independently by varying the dimensions of the slot and CSRR structures. The measurement results validated this antenna operating in fo bands in the C-band including (with absolute and relative bandwidths) 7.1–7.3 GHz (200 MHz), 7.7–7.9 GHz(200MHz),8.4–8.5GHz(100MHz)and8.7-8.9 GHz(200MHz).Considering sensing and radar applications in the C and X band, the suggested antenna is a viable option. the suggested a multiband antenna with several notch bands will be more preferred than an antenna with just one. In order to create a multi-notch band antenna, the CSRR structures with various dimensions had to be integrated in additional work.

Compliance with ethical standards

Disclosure of conflict of interest

No conflict of interest to be disclosed.

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