Progress In Electromagnetics Research C, Vol. 80, 13–20, 2018

Complimentary Split Ring Resonator Inspired Meandered CPW-Fed Monopole Antenna for Multiband Operation

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Abstract—A novel design of Meandered Coplanar waveguide (CPW) fed CSRR loaded multiband antenna is presented in this paper. A compact triple-band antenna is designed by etching CSRR slots on the radiating element. The proposed antenna shows good performance at all resonant frequencies. The simulation results are discussed and compared with the measured ones. The effects of CSRR loading on the radiating element are explained. Parametric studies are carried out and explained in detail. The proposed antenna is fabricated and measured, and the results are compared with the simulated ones. CSRR permittivity characteristics are explained to validate the results. The proposed antenna can be used for C-band, Wireless Local Area Network (WLAN) and International Telecommunications Union (ITU) applications.

1. INTRODUCTION

Due to the ever growing wireless communication applications, there is a demand for the design of multiband antennas. Various techniques have been discussed in the literature. A multiband antenna is an antenna designed to operate in several bands of frequencies. Metamaterial inspired elements were excellent candidate for the design of compact multiband antennas [1–5]. Metamaterials are not a natural material but an artificial structure designed to exhibit unusual material properties [6]. Metamaterials derive their properties from their structures and not from the constituent materials. Double negative metamaterials have simultaneously negative values of permeability and permittivity [7]. Split ring resonator and complementary split ring resonator are two popular metamaterial inspired structures. Artificial metamaterial inspired structures such as SRR and CSRR can be designed on any kind of planar transmission lines [8].

Metamaterial inspired SRR and CSRR embedded antennas were studied for performance improvement and multiband operation. Miniature antenna was designed using metamaterial substrate instead of conventional dielectric substrate [9]. SRR backed substrate was designed for good impedance matching and bandwidth improvement without altering the basic shape of the CPW-fed antenna [10]. Gain was improved by using artificial metamaterial superstrate instead of nonmagnetic superstrate [11]. Gain and bandwidth enhancements were simultaneously achieved by CSRR loaded ground plane [12]. Compact radiating element was designed using metamaterial inspired sub-wavelength resonant element SRR [13].

Multiband operation was achieved by embedding an open complementary split ring resonator on the rectangle radiating patch without altering the shape and dimensions of the basic antenna [14]. Multiband antenna was designed by introducing OCSRRs at an appropriate position of the monopole antenna [15]. Rectangular shape CSRR was tailored on the conductor backed CPW-fed antenna for multiband operation [16].

Received 14 October 2017, Accepted 17 October 2017, Scheduled 1 December 2017
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The objective of the work is to introduce CSRR with three slots on the circular monopole for obtaining multiband operation and study the performance of the antenna. SRR and CSRR are dual elements. Duality principle says that the dual elements are represented by the same mathematical expression and solution. SRR consists of concentric metallic rings with split at opposite sides. The resonant frequency of CSRR with three slots is the same as SRR with three rings for the same dimensions. Metamaterial inspired structures are electrically small elements. Due to the small size of metamaterial inspired structures, impedance matching is a tedious task. Hence, CSRR embedded circular monopole is fed by meandered CPW feed.

2. ANTENNA DESIGN AND SIMULATED RESULTS

The design starts with a conventional CPW-fed circular monopole, which produces resonance around 5.8 GHz. In the second step, a CSRR with three slots is introduced in the monopole. A CSRR with three slots is used to generate three resonance frequencies of 4.28 GHz, 5.66 GHz and 7.37 GHz with return losses of −16.97 dB, −16.84 dB, −30.73 dB, respectively. In order to further improve the return loss, CPW feed line is meandered in the third step. Good return loss is observed for all three bands by changing conventional feed to meandered feed. The meandered CPW-fed CSRR loaded monopole resonates at 4.3 GHz, 5.2 GHz, 7.0 GHz with return losses of −43 dB, −41 dB, −25 dB, respectively. Meandered feed is used to improve the return loss and also used to reduce the resonance frequency of second and third bands. The evolution steps of the proposed antenna are shown in Figure 1. The simulation of the antenna is carried out using Ansoft HFSS Electromagnetic Simulation Software. The simulated return loss characteristics at different stages of the design are shown in Figure 2. The proposed antenna is printed on a low cost FR4 substrate with relative permittivity 4.4 and thickness 1.6 mm. The proposed antenna has a CSRR embedded circular monopole, meandered CPW feed and symmetrical ground plane.

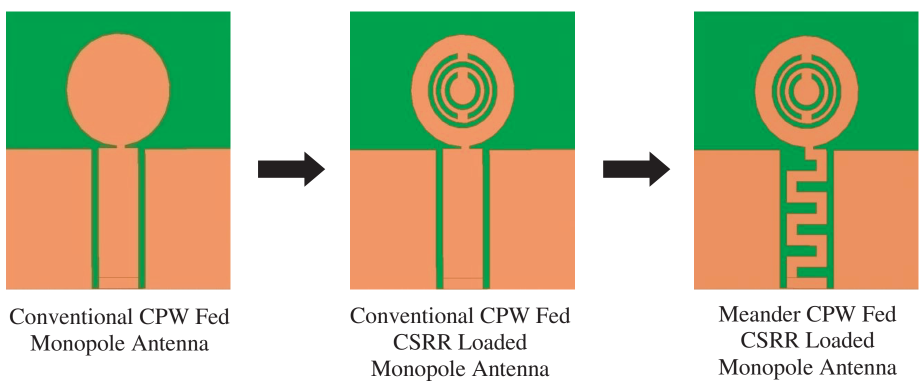

Figure 1. Evolution of antenna.

The detailed geometry of the proposed antenna is shown in Figure 3. The antenna has a compact size of $26\times23\times1.6\,\text{mm}^3$. Size miniaturization is obtained by using CSRR and meandered CPW feed. The dimensions are as follows: $L_s = 26$ mm, $W_s = 23$ mm, $L_g = 13$ mm, $W_g = 8.8$ mm, $g_1 = g_2 = 0.7$ mm, $L_1 = 3$ mm, $W_1 = 4$ mm, $R_M = 5.2$ mm, $r_1 = 3.5$ mm, $r_2 = 2.7$ mm, $r_3 = 1.8$ mm, $S = 1.4$ mm, $R_w = 0.34$ mm, $W_f = 4$ mm.

3. PARAMETRIC STUDY AND CSRR CHARACTERISTICS EXTRACTION

Parametric study is done on various parameters of CSRR. The proposed CSRR consists of three slots and three slits. Parametric study is done for the effect of number of slots (N) on resonant frequency and return loss. Simulated return loss characteristics of a CSRR loaded monopole antenna with one slot, two slots and three slots are shown in Figure 4. As shown in Figure 4, the CSRR with $N = 1$ slot produces two resonant frequencies of 4.6 GHz and 5.6 GHz with return losses of −33 dB and −16.45 dB,

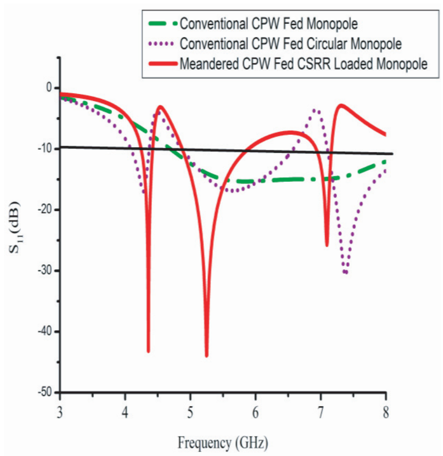

Figure 2. Simulated S_{11} (dB) of evolution of antenna.

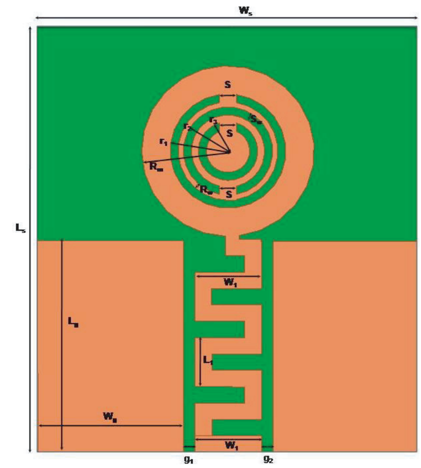

Figure 3. Geometry of proposed antenna.

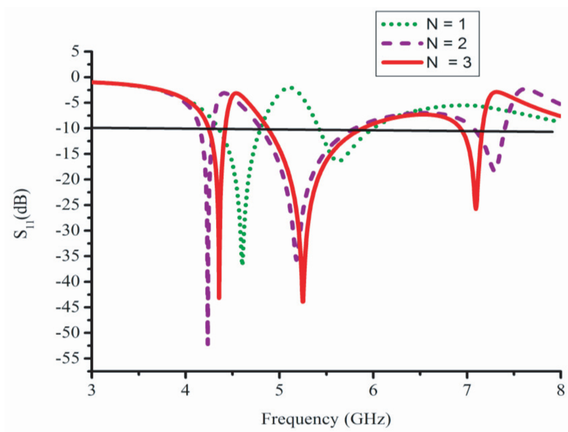

Figure 4. Simulated S_{11} (dB) of antenna for different slots.

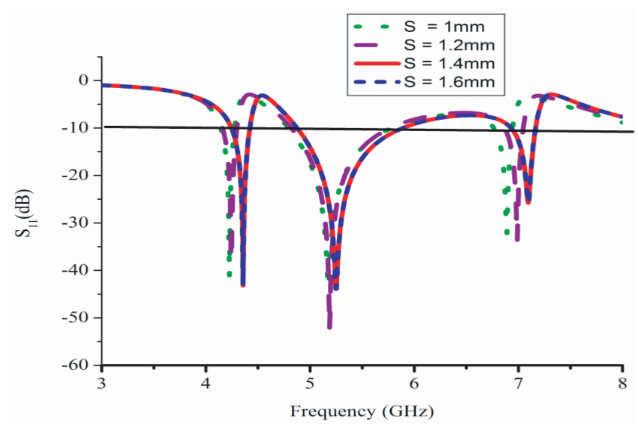

Figure 5. Simulated S_{11} (dB) of antenna for different slit width.

respectively. The CSRR with $N = 2$ slots produces three bands with resonant frequencies of 4.2 GHz, 5.1 dB and 7.29 GHz. Return losses of -52 dB, -35 dB, -18 dB are observed for the lower, middle and upper bands, respectively. Return loss is further enhanced by increasing the number of slots. Three frequency bands with resonance frequencies of 4.35 GHz, 5.25 GHz and 7.09 GHz with return losses of -43 dB, -41 dB, -25 dB are observed respectively for the CSRRs with three numbers of slots. Return loss is improved by increasing the slots for the second and third bands.

Next, parametric studies are concentrated on CSRR parameters such as slit width (S), slot width (S_w), ring width (R_w) between the slots. Simulated return losses for various slit widths, ring widths and slot widths are shown in Figures 5, 6 and 7. The split width is varied from 1 mm to 1.6 mm with incremental step of 0.2 mm. As the slit width (S) decreases, return loss is improved. Same characteristics are obtained for $S = 1.4$ mm and 1.6 mm. The optimum dimension of $S = 1.4$ mm is assigned for the final design. Hence optimum slit width of $S = 1.4$ mm is assigned for the proposed antenna. The metal ring width (R_w) between the slots is changed from 0.24 mm to 0.44 mm with the step of 0.1 mm. The slot width (S_w) is varied from 0.2 mm to 0.6 mm. Simulated results show that the return loss is good for $R_w = 0.34$ mm and $S_w = 0.5$ mm.

The surface current distribution is obtained at resonant frequencies 4.27 GHz, 5.50 GHz and 7.20 GHz. The simulated surface current distribution is shown in Figure 8 at resonant frequencies 4.27 GHz, 5.50 GHz and 7.20 GHz. Surface current distribution is good between the first and second

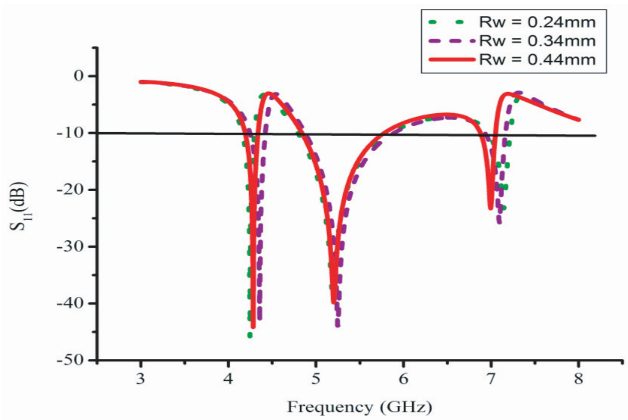

Figure 6. Return loss of antenna for various ring width.

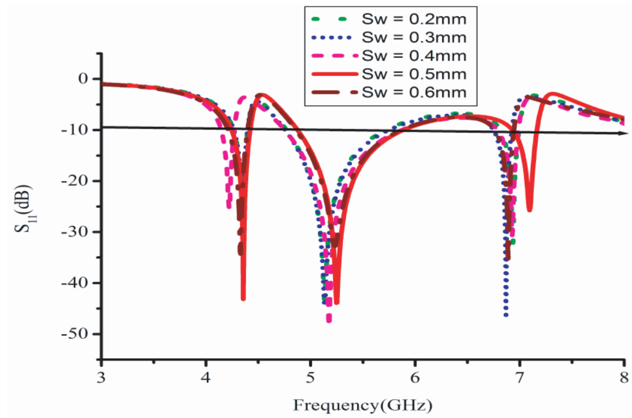

Figure 7. Return loss of antenna for various slot width.

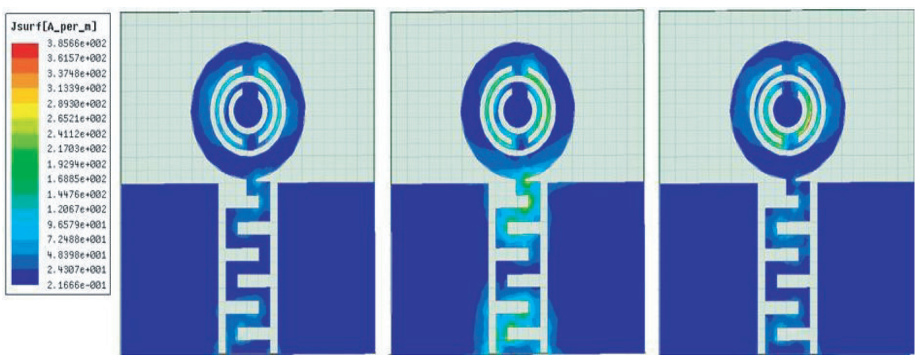

Figure 8. Surface current distribution at 4.27 GHz, 5.50 GHz and 7.20 GHz.

slots at 4.27 GHz. Good surface current distribution is observed in meandered feed and between the first and second slots at 5.50 GHz. At 7.20 GHz, current distribution is good between the second and third slots.

CSRR is an epsilon negative metamaterial inspired structure. Negative permittivity characteristics of CSRR are extracted using classical waveguide setup shown in Figure 9. The boundary conditions and excitations are assigned as shown in Figure 9. Waveguide setup is used to extract the reflection (S_{11}) and transmission (S_{21}) coefficients of CSRR. The negative permittivity of CSRR is calculated using Nicolson-Ross-Weir (NRW) approach [17].

$$\varepsilon_r = \frac{2}{jk_0 d} * \frac{1-V_1}{1+V_1} \tag{1}$$

$$\mu_r = \frac{2}{jk_0 d} * \frac{1-V_2}{1+V_2} \tag{2}$$

where $V_1 = S_{21} - S_{11}$, $V_2 = S_{21} + S_{11}$, k_0 = wave number of free space, d = substrate thickness.

The permittivity characteristic of CSRR is shown in Figure 10. CSRR is the complementary element of SRR. The permeability is negative for SRR. The real part of permeability is negative at the resonance frequency and imaginary part also negative at the resonance frequency for SRR. So, for dual element of SRR (i.e.) CSRR, permeability becomes permittivity. The permittivity characteristic of CSRR is similar to SRR's permeability characteristic. The permittivity characteristic given in Figure 10 is for CSRR alone. The equivalent circuit of CSRR consists of LC elements. The introduction of CSRR will alter the resonant characteristics of antenna and leads to new resonance.

From Figure 10, it is clear that negative permittivity is observed around the frequencies 4.3 GHz, 5.2 GHz, 7.5 GHz. Hence, it is validated that the proposed CSRR can be used to generate three resonance frequencies. When CSRR is combined with CPW-fed monopole, a slight shift in resonance frequency is observed. The proposed antenna is compared with the already reported antenna, and the comparison is given in Table 1. The size of the antenna is very small compared with the antenna listed in the references.

Table 1. Comparison of the proposed antenna and already reported antenna.

Reference	Year	Patch details	Dimensions ($L \times W$) mm^2	Frequency (GHz)
[19]	2011	Circular ring	38×25	2.5, 3.5, 5.5
[16]	2016	Rectangle	26.27×31	3.4, 5.16, 9.15
[18]	2014	Rectangle slot	34×28	2.5, 3.5, 5.5
[14]	2015	Rectangle	40×30	2.6, 3.4, 5
proposed		Circular patch	26×23	4.27, 5.5, 7.20

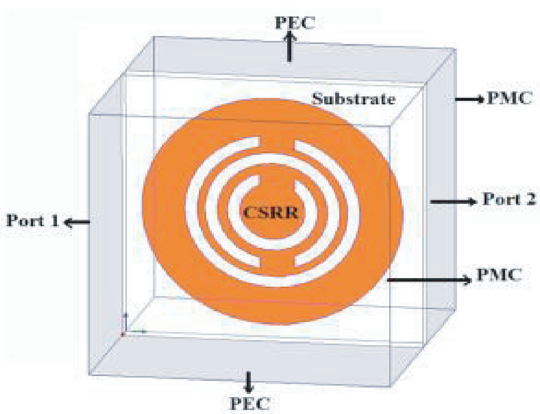

Figure 9. Waveguide setup to determine CSRR characteristics.

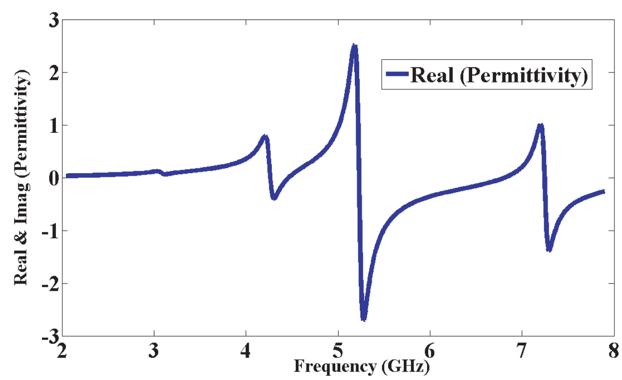

Figure 10. Permittivity characteristics of proposed CSRR.

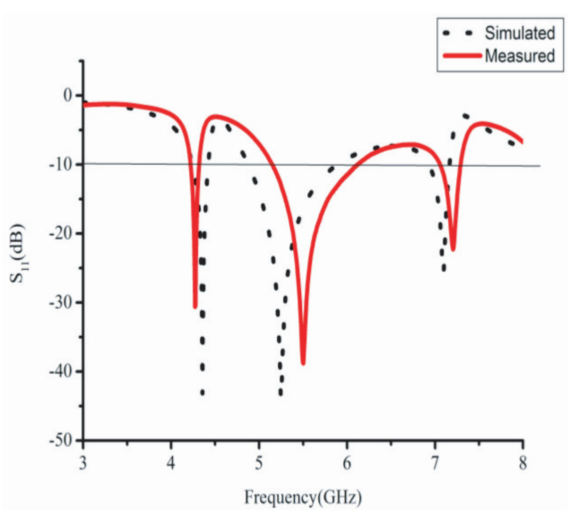

Figure 11. Simulated and measured S_{11} (dB) of antenna.

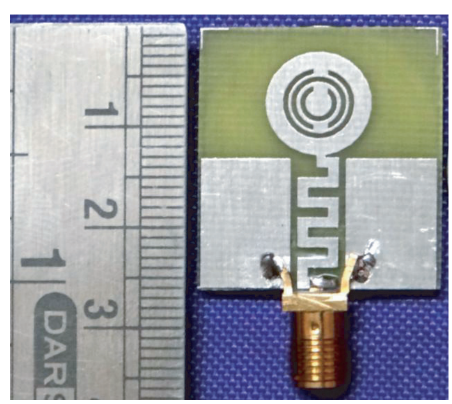

Figure 12. Photograph of the antenna.

4. RESULTS AND DISCUSSION

The return loss characteristic is measured by using vector network analyzer. Figure 11 shows the simulated and measured return losses of the proposed antenna. A photograph of the proposed antenna is shown in Figure 12. The measured impedance bandwidths are 90 MHz (4.23–4.32 GHz), 970 MHz (5.15–6.12 GHz), and 230 MHz (7.06 GHz–7.29 GHz) with resonant frequencies at 4.27 GHz, 5.5 GHz and 7.20 GHz. The simulated and measured far-field radiation patterns in E- and H-planes of the antenna at the resonant frequencies of 4.27 GHz, 5.5 GHz, and 7.20 GHz are shown in Figures 13(a),

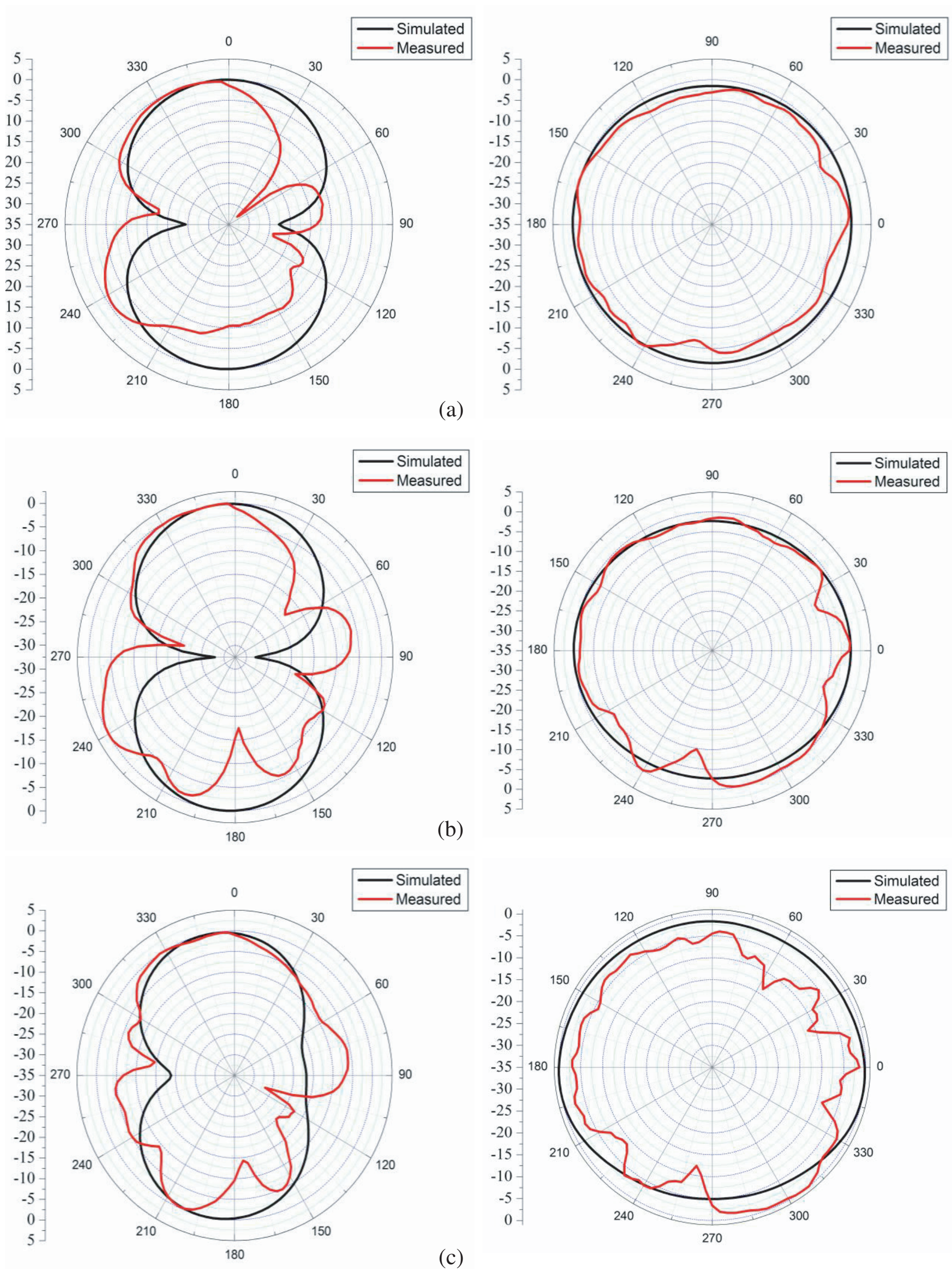

Figure 13. Radiation pattern of proposed antenna at (a) 4.27 GHz, (b) 5.5 GHz, (c) 7.20 GHz. (a) Radiation pattern in E-plane and H-plane at 4.27 GHz. (b) Radiation pattern in E-plane and H-plane at 5.5 GHz. (c) Radiation pattern in E-plane and H-plane at 7.20 GHz.

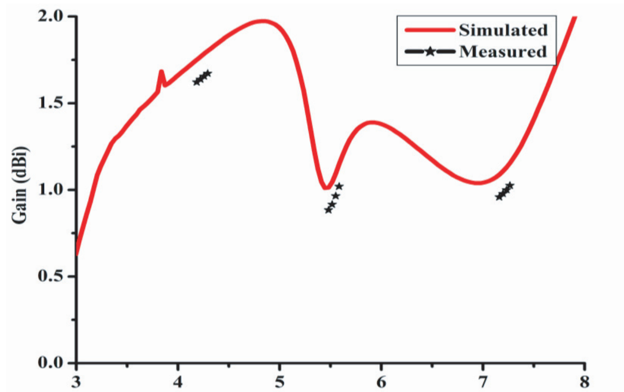

Figure 14. Gain of an antenna over frequency.

(b) and (c), respectively. The results show that omnidirectional pattern is observed in H-plane and bidirectional radiation pattern observed in E-plane. The simulated and measured gains at the resonance frequencies are plotted in Figure 14. The proposed antenna has radiation efficiencies of 86%, 97%, and 40% at the resonance frequencies of 4.27 GHz, 5.5 GHz and 7.20 GHz, respectively.

5. CONCLUSION

In this work, a new design of a compact meandered CPW-fed CSRR loaded circular triple-band antenna is reported. The measured bandwidth shows that the proposed antenna can be used for C-band, Wireless Local Area Network (WLAN) and International Telecommunications Union (ITU) applications. Results are validated with metamaterial characteristics. CSRR with a three slots embedded circular monopole is explored as radiating element for triple-band operation. Good radiation characteristics are observed for all resonance frequencies.

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