I.J. Wireless and Microwave Technologies, **2014, 3, 16-25**
Published Online October 2014 in MECS(http://www.mecs-press.net)
DOI: 10.5815/ijwmt.2014.03.02

A Novel Design of Patch Antenna Loaded with Complementary Split-Ring Resonator and L- Shape Slot for (WiMAX/WLAN) Applications

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Abstract

In this paper, a novel compact dual-band complementary split ring resonator (CSRR)-loaded microstrip patch antenna placed on ground plane loaded with L-shape slot is proposed for satisfying WLAN and WiMAX applications simultaneously. The proposed antenna consists of a complementary split ring resonator (CSRR) embedded on the patch structure and an L-shape slot on the ground plane. The resonant frequency and effective parameters of the CSRR are also determined. In addition, a design evolution and various parametric analysis of the antenna are carried out in order to study the effects of various parameters and to provide information for designing, modifying, and optimizing such an antenna. The CSRR is exploited to create resonance at 5.775 GHz while the L-shape slot resonates at 3.550GHz for dual-band operation. The -10dB return loss bandwidths of the antenna are 290 MHz (3.40-3.69) GHz and 210MHz (5.65-5.86) GHz, which cover both the WiMAX frequency band (3.4-3.69) GHz and the WLAN frequency band (5.725-5.825) GHz. The overall size of the antenna is 37mm×25mm×1.6mm. Gains of 0.5dB and 2 dB are obtained at 3.550 GHz and 5.775 GHz, respectively.

Index Terms: Metamaterial, dual-band, CSRR, L-shape slot, WLAN, WiMAX.

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1. Introduction

Microstrip patch antennas have a great demand for wireless communication system because of their attractive features such as low profile, light weight, low cost, low losses, easy fabrication, integrability with microwave and millimeter-wave integrated circuit, and conformability to curved surfaces [1]. In recent years, due to the rapid growth of the wireless communication system, especially for WLAN and WiMAX communications, a

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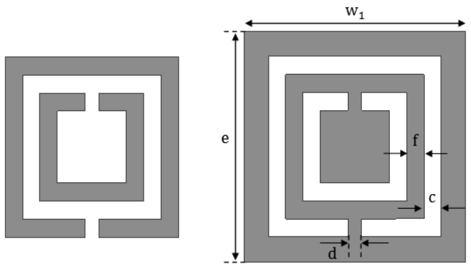
number of antennas designs have been proposed to be with dual- or multi-band operation to satisfy WiMAX (2.5-2.69) GHz, (3.4-3.69) GHz and (5.25-5.85) GHz and WLAN (2.4-2.484) GHz, (5.15-5.35) GHz and (5.725-5.825) GHz applications [2-3]. These applications require compact antennas to satisfy the severe constraints on physical dimensions of portable equipments and to avoid the use of multiple antennas by integrating the receiving and transmitting functions on the same antenna. There are many antenna configurations and techniques proposed to achieve dual-band or multi-band characteristics for (WLAN/WiMAX) applications such as the ring patch antenna [4-5], the monopole antennas [6], the slot antennas [7]. Recently, researchers have focused on using metamaterial concept in performance enhancement as well as miniaturization of the microstrip antennas [8-9]. Complementary split ring resonators (CSRRs) are metamaterials that can achieve negative dielectric constant (ε) [10]. Artificial transmission lines based on CSRR are useful for implementation in microstrip antennas due to their peculiar nature and small size.

In this paper, a compact dual-band microstrip antenna based on metamaterial complementary split ring resonator (CSRR) loading and L-shape slot on the ground plane is proposed. The CSRR is exploited to excite a resonance at 5.775GHz that covers the upper WLAN band (5.65-5.86) GHz, in addition to a resonance at 3.550GHz created by L-shape slot on the ground to cover the middle WiMAX band (3.4-3.69) GHz. Finite Element Method (FEM) software, High Frequency Structure Simulator, HFSS Ver.13 is used for the analysis of the antenna and optimization of its geometrical parameters [11].

This paper is organized as follows: Section 2 shows the determination of the resonant frequency and effective parameters of the CSRR. Section 3 offers the geometry of the proposed antenna. Section 4 presents the parametric study of the optimized antenna. Section 5 shows the optimal parameters and simulation results. Section 6 gives a brief conclusion of this work.

2. Determination of Resonant Frequency and Effective Parameters of CSRR

According to the Babinet's principle [12], the complementary split-ring resonator (CSRR), or dual split-ring resonator (DSRR) as it is called, of a planar metallic structure is obtained by replacing the metal parts of the original structure with apertures, and the apertures with metal plates. These apertures have the exact dimensions as the corresponding split ring resonator (SRR). As shown in Fig. 1, the original split-ring resonator is the dual of its complementary one. Hence, due to the duality theorem, these two structures have approximately the same resonant frequency. The main difference between SRR and CSRR is that SRR has negative permeability characteristics, while CSRR has negative permittivity characteristics. The geometrical parameters of the CSRR unit cell, shown in Fig. 1(b), have been optimized to obtained a resonance frequency at 5.775 GHz. These parameters can be tuned to get the desired negative permittivity at a certain frequency range. The substrate type is FR-4 material with a thickness of 1.6 mm, dielectric loss tangent = 0.02, and relative permittivity $\varepsilon_r = 4.4$. The coated copper thickness and conductivity are 17μm and 5.8×10^7 Sm^{-1}, respectively. The optimized parameters of the CSRR unit cell are: c = 0.5 mm, d = 0.4 mm, e = 4 mm, f = 0.5 mm, w_1 = 5 mm.



(a) (b)

Fig 1. Geometry of (a) SSR and (b) CSRR.

The electromagnetic response of CSRR unit cell is numerically calculated under plane wave excitation. A 3-dimensional full-wave model of the unit cell inside a two-port waveguide was created in HFSS v13, as shown in Fig. 2. A TEM environment is built on the faces of the waveguide and these faces are excited with the TEM wave. Perfect magnetic conductor (PMC) boundary condition is set on the left and right faces of the waveguide, and perfect electric conductor (PEC) boundary condition is set on the top and bottom of the waveguide. The scattering parameters are calculated over the frequency range (4.5-6.5) GHz in order to determine the resonant frequency and the effective parameters caused by the CSRR. The incident TEM wave propagates in the z-axis direction. The E-field of the incident wave is polarized along the y-axis, and the H-field is polarized along the x-axis.

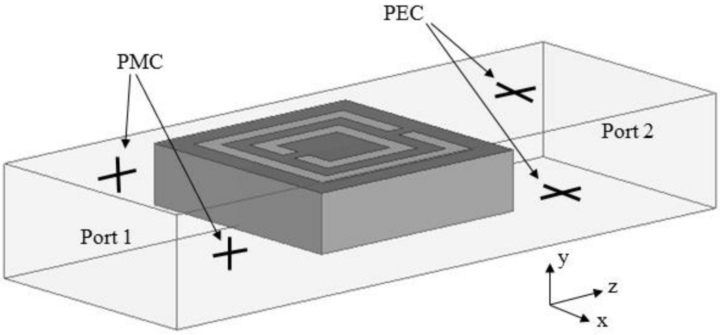


Fig 2. The waveguide setup of the unit cell for transmission analysis.

The S-parameter and its corresponding phases are retrieved and plotted in Fig. 3 and 4, respectively. It may be noted that the resonant frequency of the CSR is observed around 5.775 GHz. A resonance frequency at 5.775 GHz is expected when the CSRR is loaded on patch.

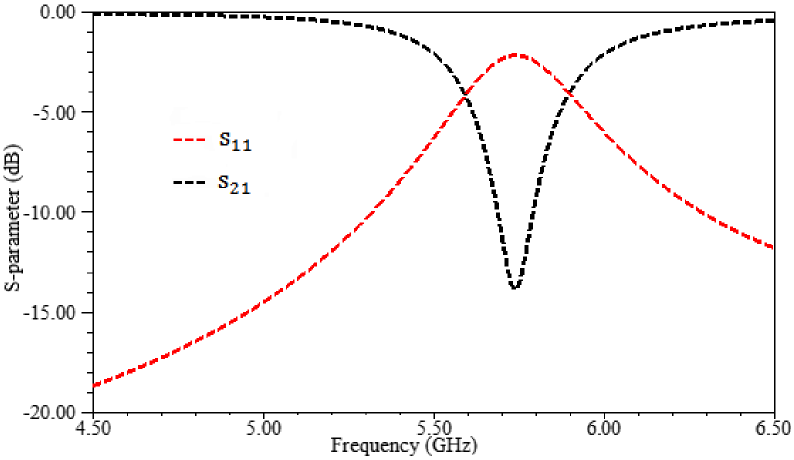


Fig 3. The magnitude of S-parameter of the CSRR unit cell.

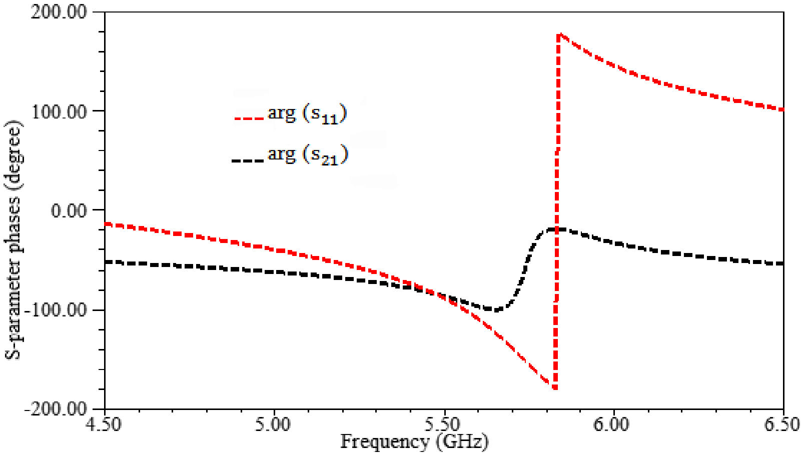


Fig 4. The phase of S-parameter of the CSRR unit cell.

Fig. 5 shows the effective parameters (negative epsilon and positive mu) of the CSRR. Here, the effective material parameter extraction algorithm presented in [13] is employed to retrieve the effective permittivity and permeability from the scattering parameters.

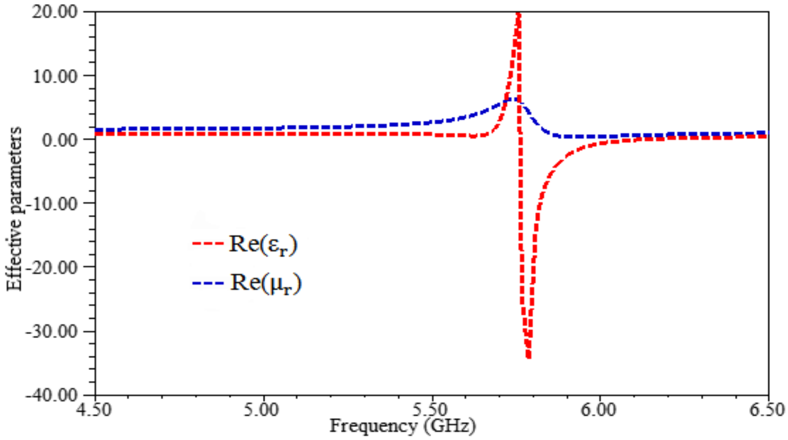
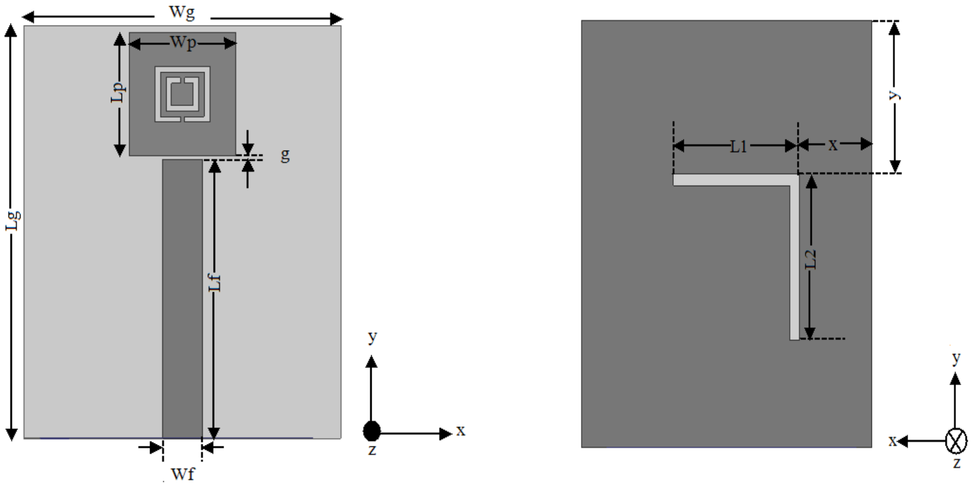


Fig 5. The extracted relative permittivity and permeability of the metamaterial unit cell.

3. Antenna Geometry

The geometry and dimensions of the proposed dual-band microstrip antenna are shown in Fig. 6 (a) and (b), respectively. The antenna is designed on a 1.6 mm-thick FR-4 substrate with a relative permittivity of ε_r = 4.4 and loss tangent of 0.02. The proposed antenna consists of a complementary split ring resonator (CSRR) that it is loaded on a rectangular patch to create resonance at 5.775 GHz. An L-shape slot, with a fixed position of x=7.2 mm and y=13.3 mm, is cut out from the ground plane to excite resonance at 3.550 GHz as shown in Fig. 6 (b). A 50 Ω microstrip transmission line with a width of 3.6 mm is used for feeding the antenna. A feeding gap coupled is used for impedance matching. This gap can be varied to get proper impedance matching. The outside dimensions of the proposed antenna are 37mm×29mm×1.6mm.



(a) (b)

Fig 6. The proposed dual-band microstrip antenna (a) top view (b) bottom view

4. Parametric Study of the optimized Antenna

Fig. 7 shows the design evolution of the proposed antenna and its corresponding frequency response of return losses. The basic antenna structure (Antenna I), shown in Fig.7 (a), consists of a 50Ω microstrip transmission line and a rectangular ground plane. As shown in Fig.7 (b), there is no corresponding resonance frequency for Antenna I because there no resonator is loaded. After adding an L-shape slot on the ground (Antenna II), resonant mode worked at 3.550 GHz can be excited. With the use of the CSRR only (Antenna III), a resonant frequency excited at 5.775 GHz can be obtained as it is expected previously. A dual-resonant response is obtained by using the two resonators at the same time (Proposed antenna). Various parametric analyses of the proposed antenna are carried out and presented in the following subsections.

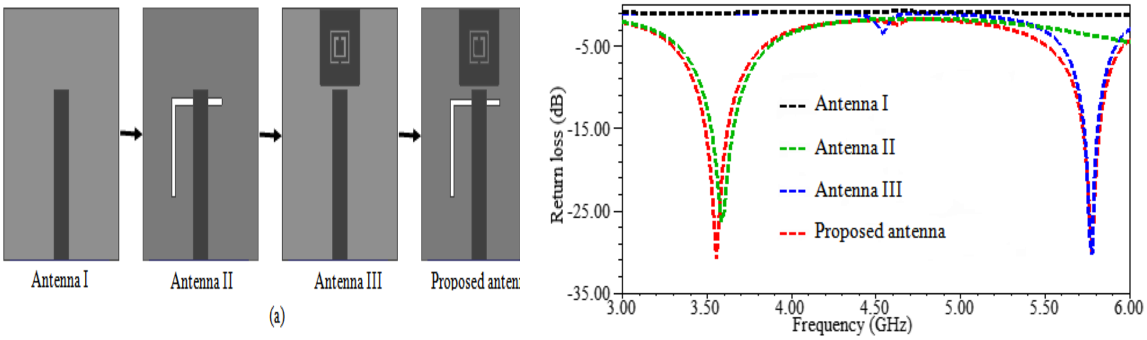


Fig 7. Design evolution of the proposed antenna and the corresponding simulated return loss results.

3.1. Effect of Feeding Gap Distance (g)

Fig. 8 shows the return loss values of the dual-band antenna for different coupled feeding gap distances keeping other dimensions of the antenna fixed as given in Table 1. It can be seen that as the distance decreases, the impedance matching is improved for both the upper and lower bands.

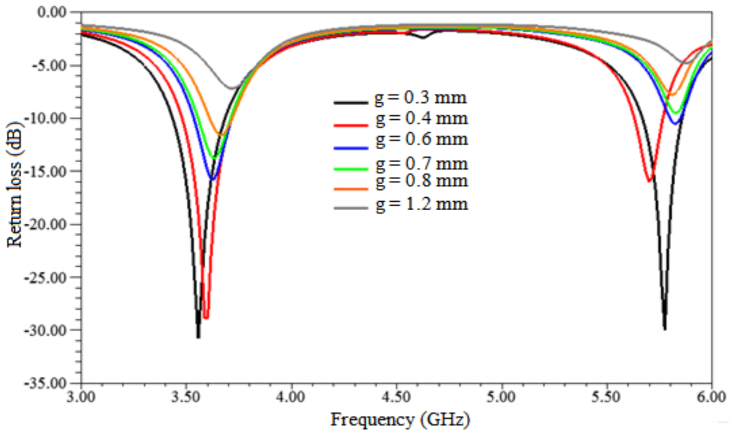


Fig 8. The return loss for different values of (g).

3.2. *Effect of Slot Length (L1)*

Fig. 9 gives the return loss of the antenna for different values of slot length (L1) keeping other dimensions of the antenna fixed as given in Table 1. As the length of slot (L1) increases from 9.8mm to 12.6mm, the resonance frequency of the lower band shifts down to cover the middle WiMAX band (3.4 to 3.69) GHz.

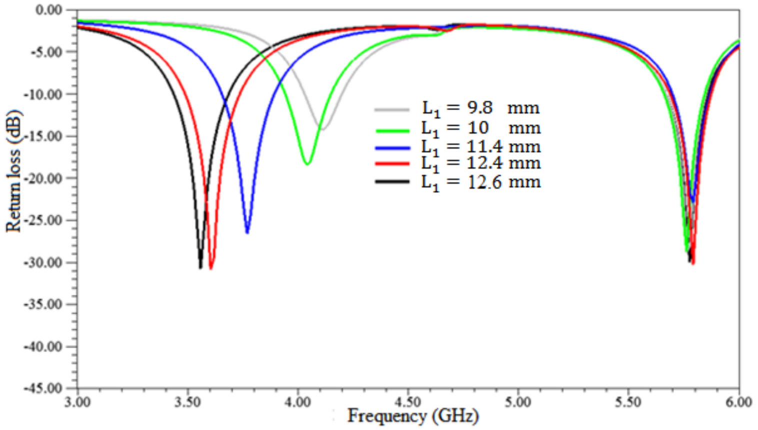


Fig 9. The return loss for different values of (L1).

3.3. *Effect of Slot Length (L2)*

Fig.10 presents the return loss of the antenna for different values of slot length (L2) keeping other dimensions of the antenna fixed as given in Table 1. It can be seen from the figure that this length affects the lower frequency resonance. As the length of slot (L2) increases from 11.9 mm to 14.4mm, a good impedance matching is got and the middle WiMAX band (3.4-3.69) GHz can be covered. A little effect occurs at the impedance matching of the upper frequency.

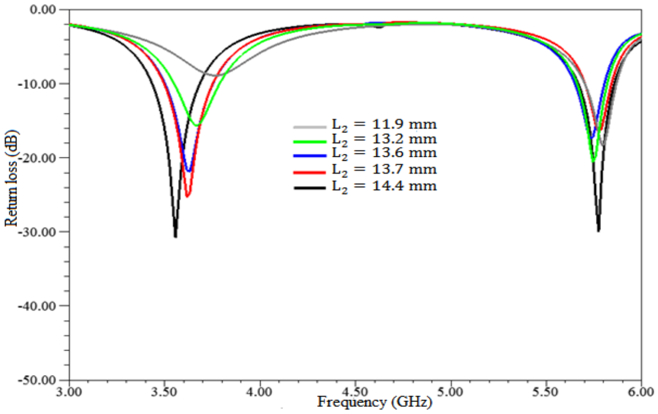


Fig 10. The return loss for different values of (L2).

5. Optimal Parameters and Simulation Results

The optimal values of the antenna are listed in Table 1. The simulated return loss of the proposed antenna is shown in Fig.11. It can be observed that the antenna exhibits two resonance modes at the frequencies 3.550GHz and 5.775GHz. The L-shape slot creates a resonance at 3.550GHz while the CSRR is exploited to make a resonance at 5.775GHz. The -10dB return loss bandwidths of the antenna are 290MHz (3.4-3.69) GHz and 210MHz (5.65- 5.86) GHz, which make it suitable for the middle WiMAX band (3.4-3.69) GHz and the upper WLAN band (5.725-5.825) GHz.

Table 1. The optimal parameter values

Parameter	L_g	W_g	L_p	W_p	L_f	W_f	W_1	c
Value (mm)	37	29	11.1	9.8	25	3.6	5	0.5
Parameter	d	e	f	x	y	L_1	L_2	g
Value (mm)	0.4	4	0.5	7.2	13.3	12.6	14.4	0.3

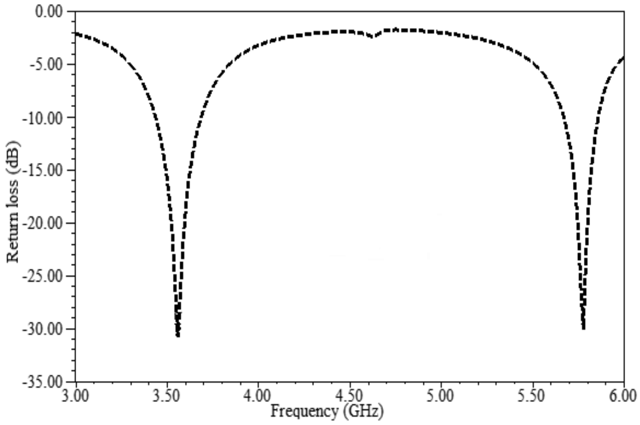


Fig 11. The simulated return loss of the proposed antenna.

Fig. 12 presents the gain of the proposed dual- band antenna. The antenna gain ranges from 0.3 dB to 1 dB for the middle WiMAX band and from 1.7 dB to 2.2 dB for the upper WLAN band. It can be clearly seen that appreciable gains are obtained over the two operating bands.

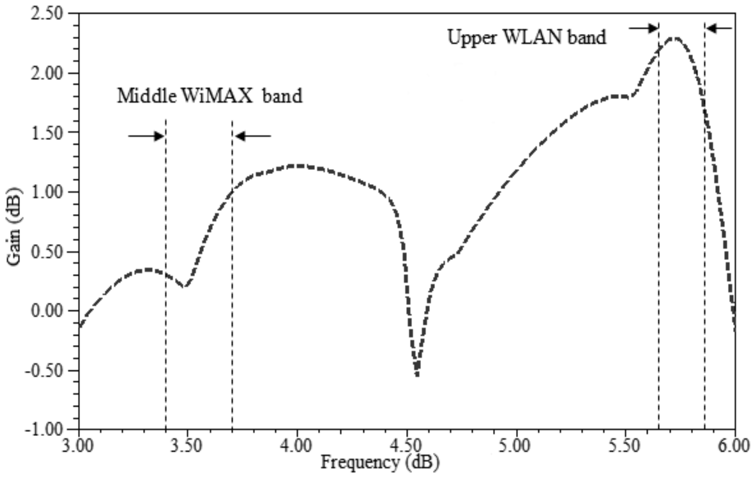
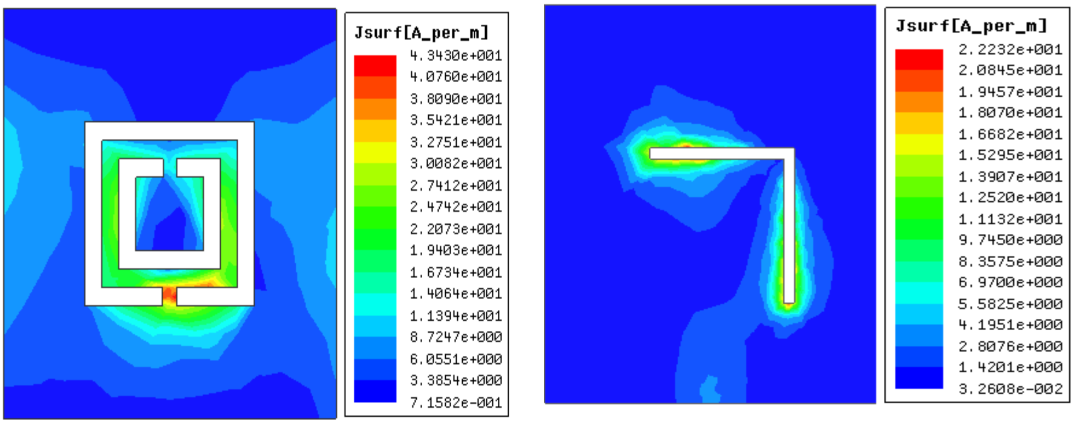


Fig 12. The gain of the proposed dual-band antenna.

The current distribution on the surface of the antenna at 3.550 GHz and 5.775 GHz are shown in Fig.13. It can be observed from Fig.13 (a) that the current density is maximum (hot spot) at the patch due to the presence of CSRR which excites a resonance at 5.775GHz. Fig.13 (b) shows that the L-shape slot creates a hot spot at its two endings which makes a resonance at 3.550GHz.



(a) (b)

Fig 13. (a) Current distribution on antenna surface at (a) 5.775 GHz (b) 3.550 GHz.

The far-field radiation patterns in the E-plane and H-plane are shown in Fig. 14 at 3.550GHz and 5.775GHz, respectively.

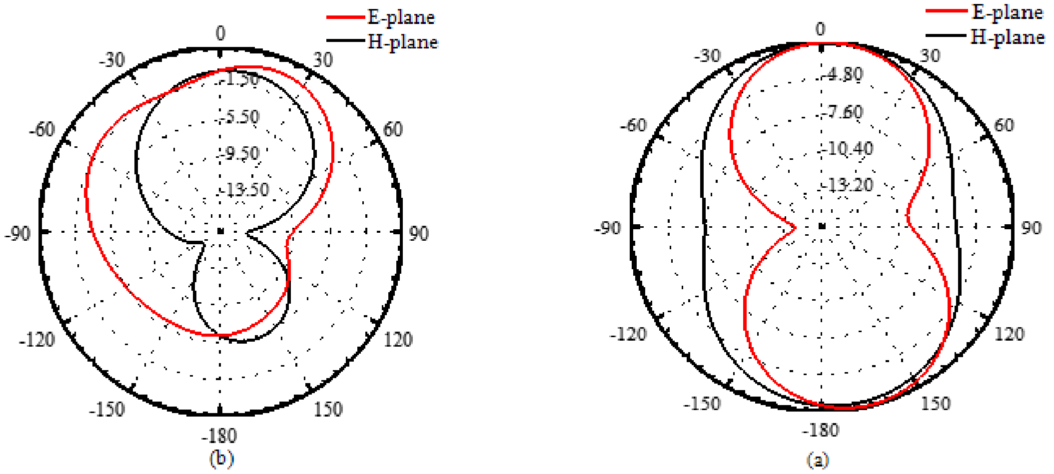


Fig 14. The radiation patterns in the E-plane and H-plane of the proposed antenna at (a) 3.55 GHz (b) 5.775 GHz.

6. Conclusion

In this paper, compact dual-band microstrip patch antenna based on complementary split resonator (CSRR) and L-shape slot loaded ground plane for (WiMAX/WLAN) is proposed. The CSRR is exploited to create resonance at 5.775 GHz while the L-shape slot resonates at 3.550 GHz for dual-band operation. The -10 dB return loss bandwidths of the antenna are found to be 290MHz (3.40-3.69) GHz and 210MHz (5.65-5.86) GHz for both the WiMAX frequency band (3.4-3.69) GHz and the WLAN frequency band (5.725-5.825) GHz. The antenna gain ranges from 0.3dB to 1dB and from 1.7dB to 2.2dB for the middle WiMAX band and the upper WLAN band, respectively.

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How to cite this paper: Ali A. Saleh, Abdulkareem S. Abdullah,"A Novel Design of Patch Antenna Loaded with Complementary Split-Ring Resonator and L- Shape Slot for (WiMAX/WLAN) Applications", IJWMT, vol.4, no.3, pp.16-25, 2014.DOI: 10.5815/ijwmt.2014.03.02