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A ring monopole quad band antenna loaded with metamaterial and slots for wireless applications

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ABSTRACT

The present wireless applications demand a compact, multi-operated, and stable radiation pattern antenna with good gain and impedance matching performance. To accomplish this requirement. In this paper, we propose a compact metamaterial structure loaded quad band antenna. The structural specifications/layout of the antenna consists of a circular ring monopole fed by a microstrip line. The ground part of the antenna is loaded with a metamaterial rectangular split-ring resonator (RSRR), an L-shaped slot, and two horizontally placed rectangular slots parallel to each other. No external matching circuit is utilized and impedance matching is solely controlled by the placement of slots. The antenna shows operation at 2.1 GHz (2.01-2.24 GHz, a bandwidth of 230 MHz (WLAN)), 4.5 GHz (4.35-4.66 GHz, a bandwidth of 310 MHz (C-band)), 5.5 GHz (5.37-5.77 GHz bandwidth of 400 MHz (WiMAX)), and 7.2 GHz (7.08-7.33 GHz, a bandwidth of 250 MHz (satellite band)). The antenna exhibits good gain and stable radiation pattern in both the plane and thus can be utilized for aforementioned applications.

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1. INTRODUCTION

The recent development in modern wireless communication systems stresses challenging antenna features. The microstrip patch antennas (MPA's) are increasingly fetching a wide range of applications in wireless communication as these antennas can be easily printed onto a circuit board. The MPAs are fascinating due to their compact conformal low profile configuration, easier to assimilate with monolithic microwave integrated circuits (MMICs), multiband operations, helps in achieving linear and circular polarization, and ease in voluminous production as it uses printed circuit technology, and so on. As the wireless devices now are more enthusiastic towards integrating multiple services from a single antenna, thus the development of multiband has become a prime area of research. More specifically the compact antenna with multiband nature has become the current demand of all the wireless devices [1]-[5].

In regard to this literature reports various method to achieve multiband in an antenna like utilization of slots and slits in the radiating or ground part [6]-[9], parasitic elements [10], [11], fractals [12]-[19], stubs [20], [21] various feeding techniques [22]-[24]. Recently, the usage of metamaterial to incorporate multiband phenomenon in antenna design has gained the significant attention. The striking properties of metamaterials such as negative permeability, permittivity and refractive index helps in accomplishing the narrowband operation at the required frequency. The first concept of metamaterial was proposed by Veselgo in 1968 [25].

Till date various metamaterial structures have been proposed like split ring resonator [26], square complimentary split ring resonator [27], circular split ring resonator [28], gapless circular split ring resonator [29] to accomplish multiband operation in the antenna.

In this study, a compact rectangular split-ring resonator (RSRR) loaded antenna is designed. The antenna has a circular ring-like monopole structure and is loaded with slots and metamaterial structure RSRR. The loading of these structures in the antenna results in operation at four bands i.e., 2.1, 4.2, 5.5, and 7.2 GHz. Detailed parametric analysis is carried out to fix the dimension of the antenna. The antenna performances are studied with the help of S-parameters, current distribution, VSWR, impedance behaviour, and 3D gain pattern. The main advantage of the antenna is its compact dimension and quad band operations with good gain and radiation performance. All the analysis of the antenna is performed in HFSS.

2. DESIGN METHODOLOGY AND CONFIGURATION

The objective of the proposed study is to design a metamaterial-loaded dual-band antenna. To incorporate this the said antenna is designed into six steps and this design is demonstrated in Figure 1. Initially, a circular patch is chosen with a full ground part. The main idea behind choosing the circular radiating part is to accomplish uniform backflow of current from edges to center. However in the case of step 1 termed as “Ant-1”, there is no operating band obtained (as no portion of the graph is below S_{11}<-10 dB) as depicted in Figure 2. To accomplish the operating band, the circular shape radiating part is transformed into a circular ring-like structure to disturb the radiator current flow. Also, the ground part is etched to three fourth and termed as “Ant-2” as demonstrated in Figure 1. By utilizing this configuration one can see that due to the circular ring radiator two wideband operating bands are achieved around 5.8 GHz and 7.3 GHz. The wideband nature of this band is due to the etching of the ground plane. However, to get a narrow multiband operation, the ground plane of “Ant-2” is again modified by introducing an L-shaped slot, while retaining the circular ring radiator structure. The obtained structure is termed as “Ant-3” as depicted in Figure1 and its corresponding S11response is outlined in Figure 2. From the S_{11} response curve, one can notice that due to the addition of an L-shaped slot, the antenna now shows triple-band operation, wherein the fundamental operating mode is obtained around 4.6 GHz, while the other two wideband operating bands are obtained around 6 GHz and 7.4 GHz. However, the demerit of this configuration is that there is a poor impedance matching observed around 6.5 to 7 GHz. To solve this design problem a horizontal rectangular slot is placed beside the L-shaped slot in the ground part of “Ant-3”. The addition of this part gives rise to a new configuration and is termed as “Ant-4”. The addition of a rectangular slot solves the problem of impedance matching of “Ant-3”. But demerit now is that the obtain configuration (i.e., “Ant-4”) operates at only two bands (i.e., at 4.2 GHz and 5.4 GHz) as shown in Figure 2. To achieve triple-band from this configuration, “Ant-4” is further modified by placing one more slot parallel to the above introduced rectangular slot and this configuration is termed as “Ant-5”. It can be noticed from Figure 2, that this antenna shows three bands of operation with good impedance matching. These bands are obtained at 4.2 GHz (C-band), 5.1GHz (WLAN), and 7.4 GHz (satellite band).

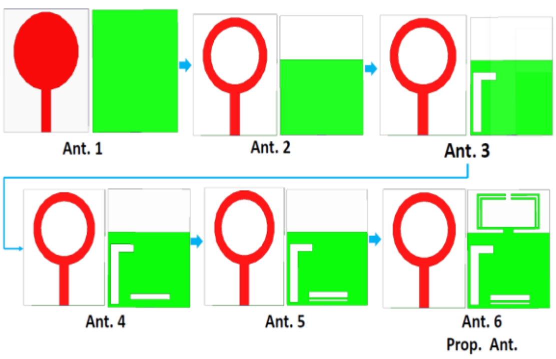


Figure 1. Evolution of proposed antenna

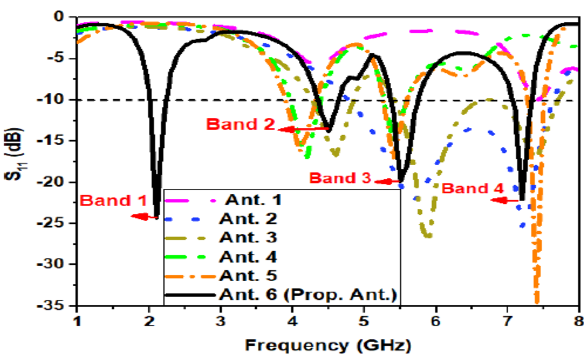


Figure 2. S-parameter of the evolution of the antenna

To make the antenna more versatile and operates at one more band (quad band) a metamaterial structure is loaded at the ground plane. This metamaterial structure is nothing but a rectangular split-ring resonator (RSRR) and is supported on a small rectangular stub. This structure is now called “Ant-6” and also the proposed antenna as shown in Figure 1. The loading of this metamaterial structure results in a solenoidal current which induces fluctuations in the magnetic field thereby resulting in narrowband operation (magnetic response) at 2.1 GHz (WLAN) as shown in Figure 2. It is to be noticed here that the radiator shape is still unchanged and it remains to be a circular ring. The detailed analysis of metamaterial structure is RSRR is further discussed in section 4. Thus the proposed antenna now finally operates at quad band (i.e., 2.1, 4.5, 5.5, and 7.2 GHz) with better impedance matching at all the bands.

The proposed antenna nomenclature is demonstrated in Figure 3. It can be studied that the antenna consists of a circular ring-like radiator which is fed by a microstrip line to achieve an impedance matching of 50 Ω. The ground plane consists of Land rectangular slots with a metamaterial loading. The detailed dimension layout of the said antenna is further illustrated in Figure 4. The inner and outer radius of the rings are represented as R_1 and R_2. The overall size of the substrate is given as $(L_s \times W_s)$. The metamaterial structure has an overall dimension of $(M_5 \times M_1)$ with a split gap of M_3. The L-shaped slot has a dimension of $(L_1 \times L_2 \times L_3)$, the upper rectangular slot at the ground plane has a dimension of $(S_2 \times S_1)$ while the below rectangular slot is placed parallelly to the upper rectangular slot has a dimension of $(S_4 \times S_2)$. The dimension of the overall antenna is outlined in Table 1.

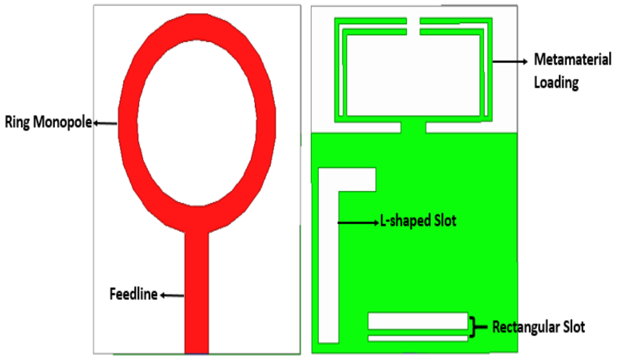


Figure 3. Nomenclature of the proposed antenna

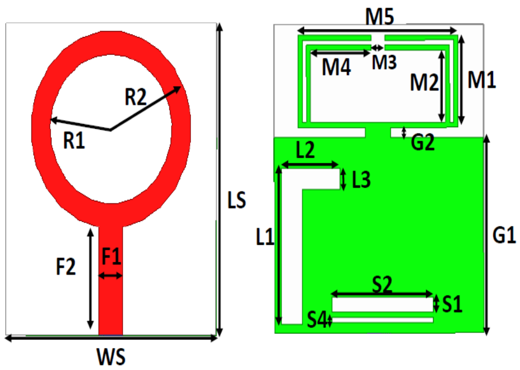


Figure 4. Geometrical dimensions of the proposed antenna

Table 1. Dimension (millimeter) of antenna

value (mm)	value (mm)	value (mm)
$W_s = 24.8$	$M_5 = 19$	$L_2 = 7, L_3 = 2$
$L_s = 30$	$M_1 = 9$	$S_1 = 1.5$
$F_1 = 2.8$	$M_2 = 7.5$	$S_2 = 12$
$F_2 = 10.4$	$M_4 = 7.7$	$S_4 = 0.5$
$R_1 = 6.7$	$M_3 = 1.6$	$G_1 = 19$
$R_2 = 9.5$	$L_1 = 15.2$	$G_2 = 1$

3. ANALYSIS OF THE METAMATERIAL STRUCTURE RSRR

The main purpose of using RSRR is to accomplish a narrowband operation around 2.1 GHz (WLAN), without physically increasing the overall size of the antenna. As it can be noticed that, this RSRR is just supported on a rectangular stub on the ground part of the antenna, thus retaining the compact size of the antenna. To study the metamaterial properties behavior of the proposed RSRR its analysis is carried out in waveguide medium [30] as demonstrated in Figure 5. The RSRR is placed inside a waveguide environment where it is subjected to boundary conditions (i.e., perfect electric conductor at top plane and perfect magnetic conductor at front plane). To study the reflected signal behavior (S-parameters), the power is applied at port 1 and the corresponding output behavior is observed at port 2. The obtained passband characteristic of this RSRR is depicted in Figure 6. It is observed that the transmission coefficient (S21) at 1.6 GHz is below -10 dB whereas the S11 is around 0 dB. This exhibits the passband behavior of the proposed RSRR at 1.6 GHz when it is utilized as a radiator at the ground part of the antenna. It is worthy to note here that due to integration of RSRR with antenna this band get shifted to 2.1 GHz, which is mainly due to the increases the total current length path of the antenna, thereby changing the wavelength.

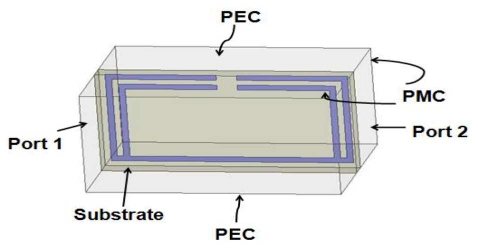


Figure 5. RSRR analysis in waveguide medium

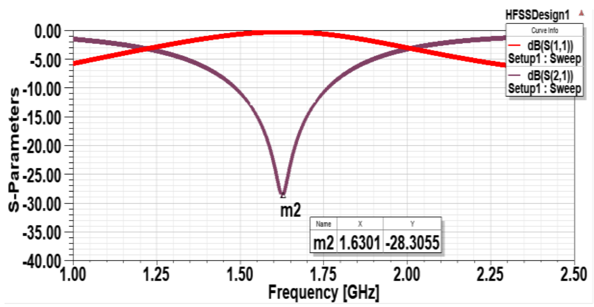


Figure 6. S-parameters of the RSRR

4. PARAMETRIC STUDY OF THE ANTENNA

To accomplish the optimum dimension of the antenna its parametric investigations are carried out and are described in Figures 7 to Figure 10.

4.1. Effect of $\mathbf{R_2}$

To observe the effect of R2on the operating performance of the antenna, its study is demonstrated in Figure 7 by varying R2 from 9.45 mm to 9.55 mm. At 9.45 mm only triple-band operations are observed while the S11 value of the fundamental band is around -5 dB. At R2=9.55 mm quad band operation is observed, however the impedance matching of the first resonance is poor. At fixed dimension R2=9.55 mm all four quad band are obtained with better impedance matching.

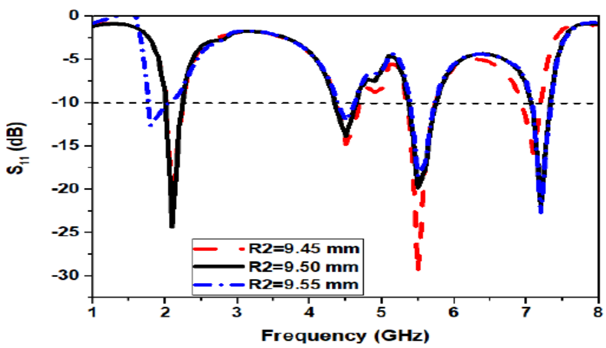


Figure 7. Parametric analysis by varying R2

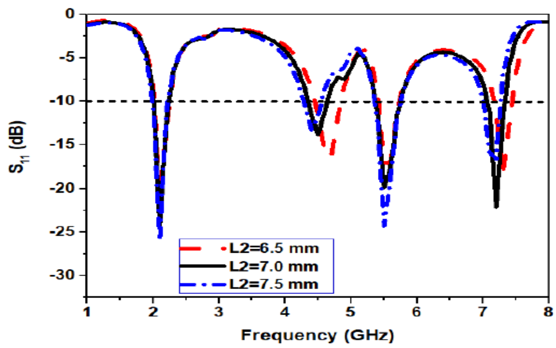


Figure 8. Parametric analysis by varying L2

4.2. Effect of L_2

To study the L2 on the performance antenna, its dimension is varied from 6.5 mm to 7.5 mm and is demonstrated in Figure 8. At L2=6.5 mm all four bands are obtained however the S11 value at each operating band is relatively less. At L2=7.5 mm also all four bands are obtained however poor impedance matching is observed at the second resonance. At optimized dimension L2=7 mm all four bands are obtained with better S11<-10 dB value.

4.3. Effect of S_2

To observe the effect of S2 its parametric investigation is performed by varying S2 from 11.5 mm to 12.5 mm as depicted in Figure 9. At S2=11.5 mm only dual operation is achieved since the S11 value at first and second resonance is above -10 dB. At S2=12.5 mm all four bands are obtained but with poor impedance matching at the second band. At the fixed dimension. At S2=12 mm quad band operation is achieved with better impedance matching.

4.4. Effect of S_4

Similar to the parametric study above, S4 parametric analysis is carried out by varying it from 0 mm (no slot) to 1.5 mm. when the lower slot width is kept 0 mm (no slot) and 1.5 mm then we can observe from Figure 10 that there is a very poor impedance matching at second and fourth resonance. At S4=0.5 mm all four bands with better impedance matching are obtained.

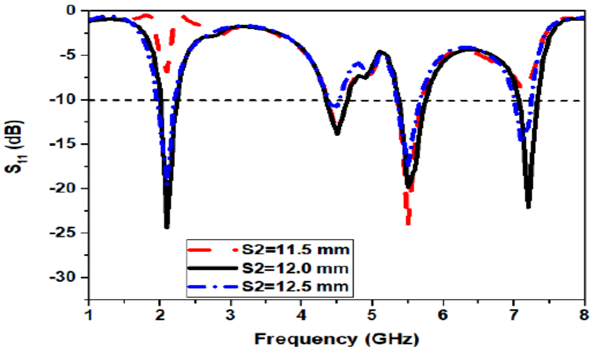


Figure 9. Parametric analysis by varying S2

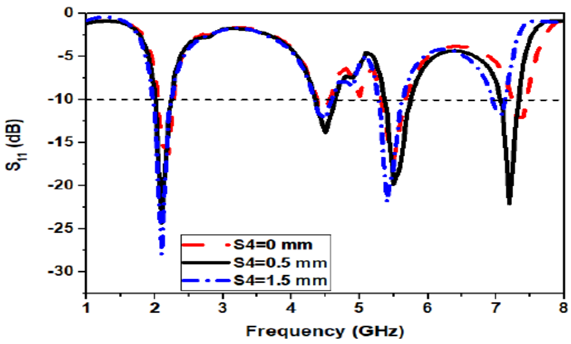


Figure 10. Parametric analysis by varying S4

5. RESULTS AND DISCUSSIONS

The Proposed design in Figure 4 is simulated in HFSS, using lumped port excitation in FR4 substrate with dielectric constant 4.4 and thickness 1.6 mm and loss tangent of 0.02. The prototype of the fabricated antenna is illustrated in Figure 11. The final S11 obtained after the simulation and measurement is depicted in Figure 12. The antenna shows the first resonance operation from 2.01 to 2.24 GHz, with a center frequency of 2.1 GHz (WLAN) in simulation and from 2.1 to 2.3 GHz, with a center frequency of 2.2 GHz in measurement. The second band operation ranges from 4.35 to 4.66 GHz, with a center frequency of 4.5 GHz (C-band) in simulation and from 4.3 to 4.7 GHz, with a center frequency of 4.6 GHz in measurement. The third band operation is observed from 5.37 to 5.77 GHz, with a center frequency of 5.5 GHz (WiMAX)) in simulation and from 5.4 to 5.8 GHz, with a center frequency of 5.6 GHz in measurement. The fourth band operation ranges from 7.08 to 7.33 GHz, with a center frequency of 7.2 GHz (Satellite band) in simulation and from 7.2 to 7.5 GHz, with a center frequency of 7.3 GHz in measurement.

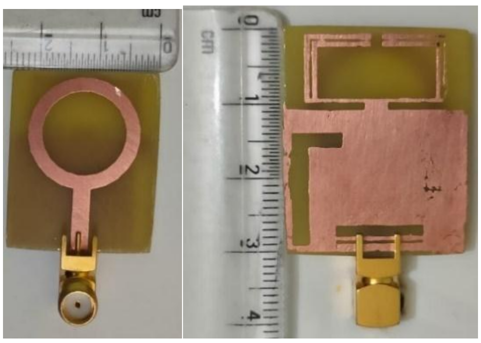


Figure 11. Prototype of the proposed antenna

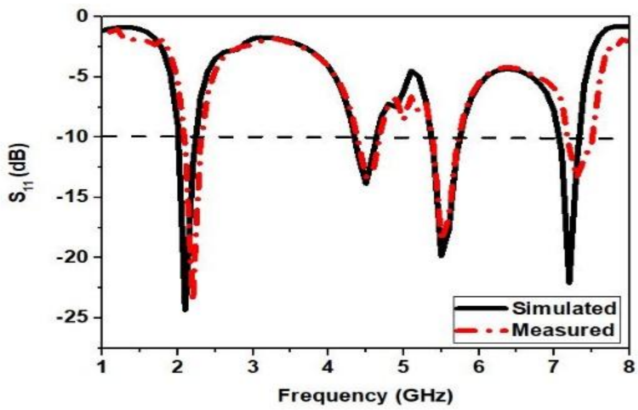
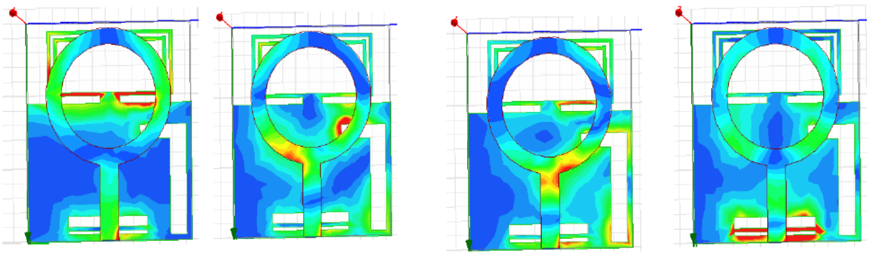


Figure 12. Simulated and measured S11 of the proposed antenna

The surface current pattern of the proposed RSRR loaded antenna is depicted in Figure 13. At 2.1 GHz high current density is seen around the RSRR, thereby proving that this operation is due to metamaterial structure. At 4.5 GHz the lower-left portion of the circular ring radiator and the L-shaped slot shows a good current pattern. At 5.5 GHz, a dense current is observed around the right position of the circular ring radiator and the center back part of the ground plane. At 7.2 GHz the impedance matching is improved by a lower rectangular slot, thus a dense current is observed in a parallel path between horizontal rectangular slots.

The impedance plot of the proposed antenna is depicted in Figure 14. At 2.1 GHz, the antenna shows an impedance of (52.6 - j5.68) Ω. At 4.5 GHz, it exhibits an impedance of (73.3 – j9.3) Ω. Similarly, at 5.5 and 7.2 GHz it depicts an impedance of (54.9 – j 9.5) and (44.2 – j 4.6) respectively. Thus it can observe that impedances are closed to 50 Ω except at 4.1 GHz which may be due to the utilization of slotted structure at the ground part.



(a) (b) (c) (d)

Figure 13. Surface current distribution of the proposed antenna at (a) 2.1 GHz, (b) 4.5, (c) 5.5 and 7.2 GHz

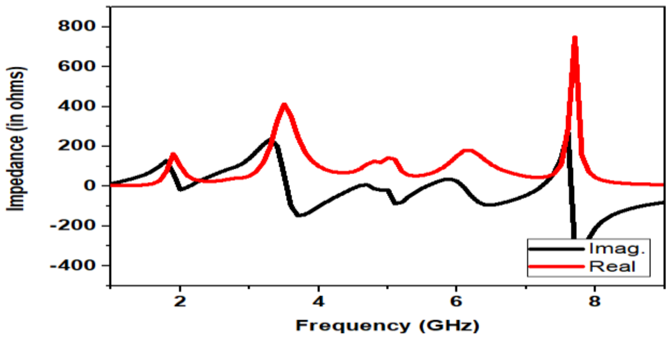
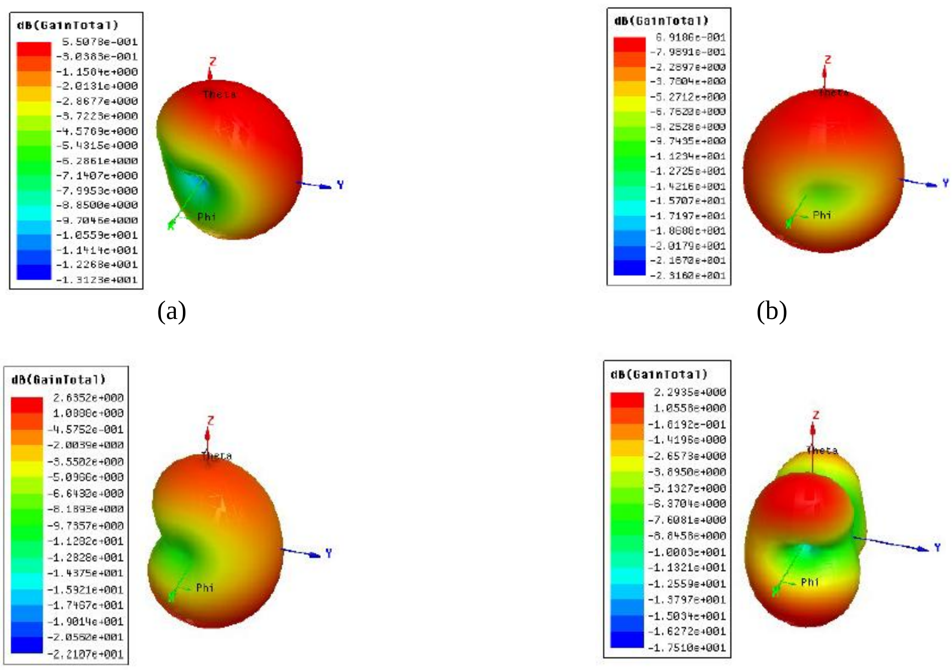


Figure 14. Z-parameter of the proposed antenna

The 3D gain radiation pattern of the RSRR antenna is illustrated in Figure 15. At 2.1 GHz, a bidirectional pattern with a gain of 0.55 dB is observed. At 4.1 GHz an omnidirectional pattern with a gain of around 0.69dB is obtained. At 5.5 and 7.2 GHz, the radiation is bidirectional and shows a gain of around 2.6 and 2.2 dB respectively. Thus the obtained gain is good enough to be utilized for the aforementioned wireless communication.



(a) (b)

(c) (d)

Figure 15. 3D gain pattern of the proposed antenna at, (a) 2.1 GHz, (b) 4.5, (c) 5.5, (d) 7.2 GHz

6. CONCLUSION

The design of a metamaterial structure RSRR loaded antenna with slots is accomplished. The antenna shows an operation at 2.1 (WLAN), 4.5 (C-band), 5.5 (WiMAX), and 7.2 GHz (satellite band) with better impedance matching at all the bands. To fix the dimension of a particular parameter of the antenna, parametric investigations are carried out. This investigation shows that even the incremental variation in the dimensions of the antenna its performance is affected to large extent in terms of the number of operating band and impedance matching. The designed antenna is compact and exhibits good gain and stable radiation at all the operating frequencies and thus can be considered a very suitable candidate for the aforementioned wireless applications.

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