A Compact CSRR Loaded Monopole Antenna with Defected Ground Structure for Mobile WLAN and WiMAX Applications

N.A. Jan[1(✉)], A.M. Saleh[1], M. Lashab[2], F.M. Abdussalam[1], L. Djouablia[2], and R.A. Abd-Alhameed[1]

[1] Faculty of Engineering and Informatics, University of Bradford, Bradford, UK
kakarnayeem@yahoo.com, {A.M.S.Saleh,R.A.A.Abd}@bradford.ac.uk
[2] Skikda University, Skikda, Algeria

Abstract. A physically compact dual band antenna design is presented for use in mobile WLAN and mid-band WiMAX applications. The antenna design is based on a monopole, with a combination of metamaterial inspired features, based on a defected ground structure (GDS) and a complementary split-ring resonator (CSRR). A single CSRR unit cell is placed over a pentagonal monopole antenna, producing a narrow stop-band frequency in the range from 2.40 GHz to 2.49 GHz. The second operating frequency ranges from 3.44 GHz to 6.25 GHz, the broadbanding being due to the influence of the defected ground structure. The antenna design was optimized using HFSS, paying close attention to size constraints, and ease of integration with the radio front end. Simulation results for return loss, gain and radiation pattern are analyzed and presented.

Keywords: Defected ground structure (DGS) · High frequency structure simulator (HFSS) · Complementary split ring resonator (CSRR) · Metamaterial-inspired antenna · Double negative (DNG) behavior

1 Introduction

The antenna design proposed in this paper is intended to address the need for dual-band antennas for use in overlapping WLAN (2.4 GHz, 5.2 GHz, 5.8 GHz) and mid-band WiMAX (3.5 GHz) applications, which do not intefere with one another [1]. Various techniques have been investigated to achieve a suitable miniaturization of the radiating elements. Of interest are etched L-shaped. U-shaped and G-shaped metalization patches [4, 5, 6]; loading planar surfaces with complementary split ring resonator (CSRR) metamaterial [7]; and placing insertions such as shortening pins or resonators in the neighbourhood of the radiating element [8]. The complementary split ring resonator (CSRR) is the dual of the split ring resonator (SRR) [3].

In [9] CSRR along with EBG is used for miniaturization but the antenna is resonatiing in 2.6 GHZ and 3.23 GHz with limited bandwidth and gain results. The antenna design presented in this paper is said to be metamaterial inspired in the sense that only a unit cell of the CSRR metamaterial is needed to realize the design. As compared to [9], the antenna

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presented here has better and widen bandwidth and both the frequencies are adjusted for WLAN and WiMax applications at the cost of small increase in size. The CSRR unit cell structure was designed in HFSS, with the constutuitive parameter extraction being performed through matlab. This design suggests a double negative result at a resonance frequency of 2.45 GHz, which is then utilised to provide the lower band (WLAN) requirement, and to achieve a miniaturised radiator structure. A defected ground structure is then utlised to provide the mid-band WiMAX (3.5 GHz) and upper WLAN (5.2 GHz and 5.8 GHz) service bands, and also constributes to a stable radiation pattern.

2 Metamaterial Unit Cell Design

The geometrical configuration of the CSRR unit cell is shown in Fig. 2. The unit cell is designed and simulated using HFSS. Matlab is used here to retrieve constitutive parameters i.e. effective permeability and permittivity of the unit cell, which determine the response of the material to electromagnetic radiation. The single unit cell, which has no periodicity, normally generates negative permeability only [2]. Unit cell or metamaterial-inclusion can be used for different applications. In [2] though the application of the unit cell is to increase the isolation between MIMO, but in this paper the unit cell is used to attain miniaturization and to make antenna resonate at lower frequency of ISM 2.45 GHz. The unit cell analysed here produces negative permittivity and permeability values from the introduction of symmetrical periodicity in the armatures, and lengths of the unit cell. This unit cell of size 9 mm × 5.5 mm is then etched on top of the monopole to make antenna electrically small and resonant in the ISM 2.45 GHz service band. The optimized parameters of the unit cell are given in Table 1.

Table 1. The optimized parameter of the proposed CSRR unit cell

Parameter	Value (mm)	Parameter	Value (mm)
H	5.5	W_p	4
F	9.75	W_u	2.5
h_1	1.5	g_u	0.5
h_2	1.5	s	0.5

The transmission coefficient of the metamaterial unit cell is given in Fig. 3, it can be seen that the unit cell has a resonance at 2.45 GHz. Extracted values of the effective constitutive parameters with negative real parts at the resonance frequency were observed for this resonance, as shown in Figs. 4 and 5, respectively.

3 Antenna Design and Results

The geometrical configuration of the metamaterial inspired antenna structure is shown in Fig. 1. A finite element model of the antenna was analysed using HFSS. The substrate was a 1.6 mm thick FR4 material with a relative permittivity of 4.4 and loss tangent of 0.02. The pentagonal monopole is loaded with a CSRR unit cell. This metamaterial unit cell displays double negative (DNG) behaviour at a resonant frequency of 2.45 GHz. The feed line is a 50 Ω microstrip stub, with a width of 3 mm. The overall antenna volume is 26 × 25 × 1.6 mm^3. The defected ground structure has dimensions of 22 mm × 12 mm, and a further 3 mm-radius semi-circle was cut from each side of the ground to enhance the wideband performance in the upper WLAN frequency range. The optimised CSRR parameters are given in Table 2. Figure 6 shows the 'three step evolution' of the metamaterial inspired design.

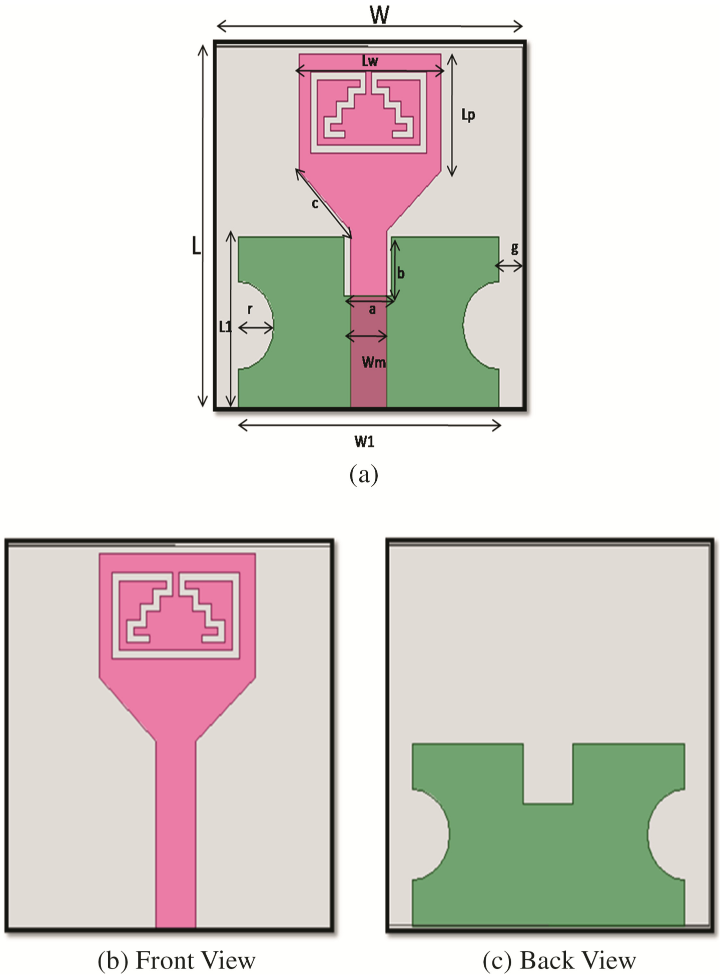


Fig. 1. Monopole antenna loaded with CSRR and DGS.

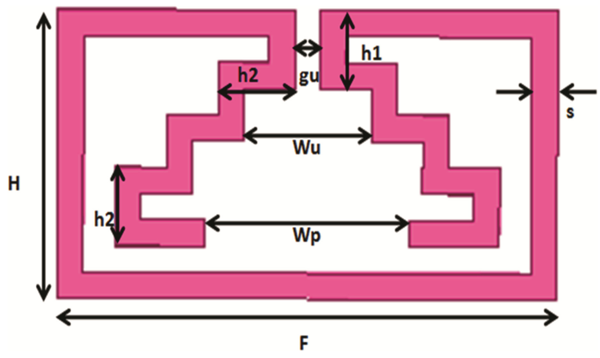


Fig. 2. Geometrical configuration of CSRR unit cell

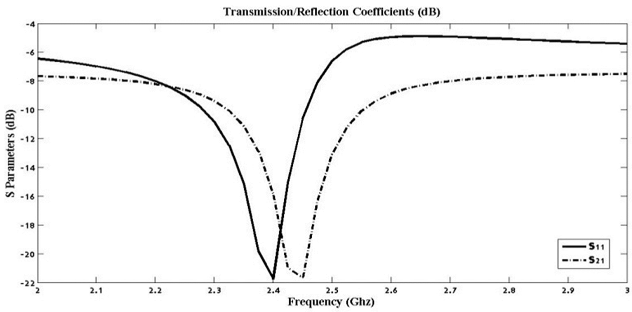


Fig. 3. Transmission/Reflection Coefficient of a unit cell

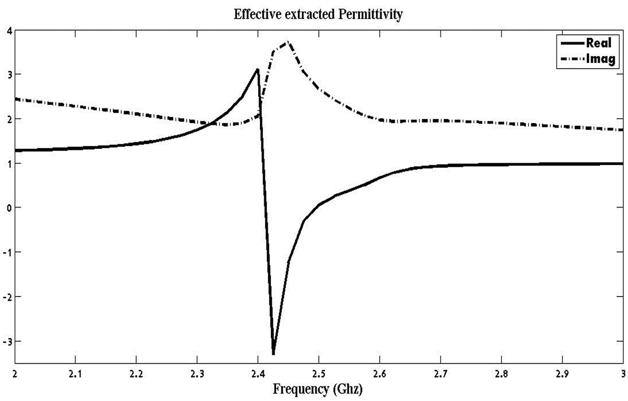


Fig. 4. Effective extracted permittivity of a unit cell

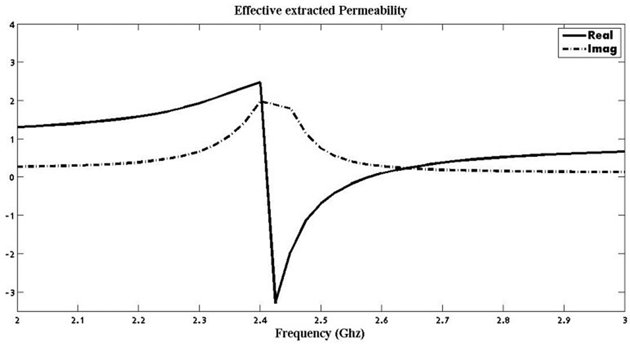
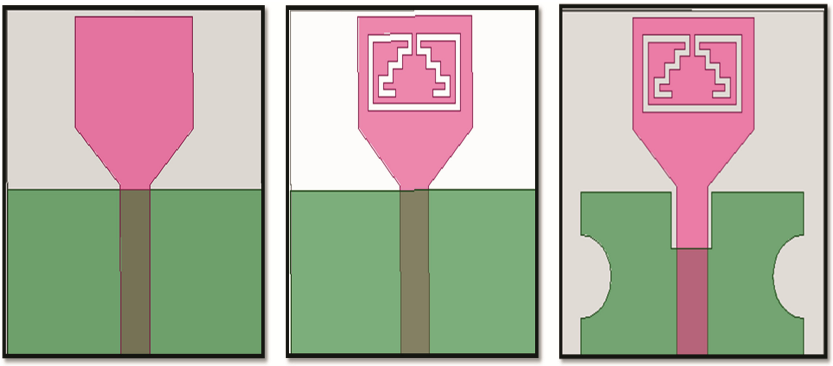


Fig. 5. Effective extracted permeability of a unit cell

Table 2. The optimized parameter of the proposed Metamaterial-inspired antenna

Parameter	Value (mm)	Parameter	Value (mm)
L	25	C	4
W	26	R	3
L_1	12	G	2
W_1	22	W_m	3
a	4	L_w	12
b	4	L_p	8



(a) (b) (c)

Fig. 6. Metamaterial-inspired antenna design evolution; (a) conventional antenna, (b) Monopole With CSRR, (c) Monopole CSRR with DGS

The results of all the three antennas were simulated in HFSS, these are summarised in Fig. 7. This indicates that the antenna with CSRR loading and DGS has an overall better performance in terms of the realized impedance bandwidth and return loss, as compared to the conventional and CSRR loaded monopole antennas.

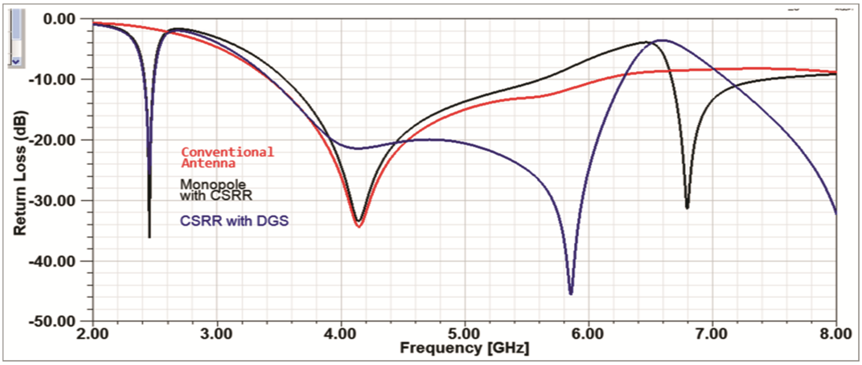


Fig. 7. Reflection coefficient of the conventional, CSRR and CSRR along DGS monopole antenna

Simulated gain values of the Monopole CSRR with DGS antenna is given in the Fig. 8 throughout the whole operational band.

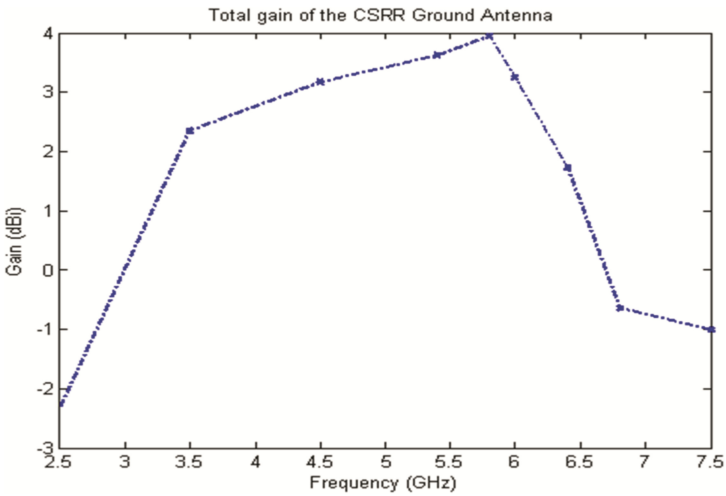


Fig. 8. Total gain of the Monopole CSRR with DGS antenna

The simulated E-plane and H-plane radiation patterns are shown in Fig. 9. This shows a very stable radiation pattern in the frequency band of interest.

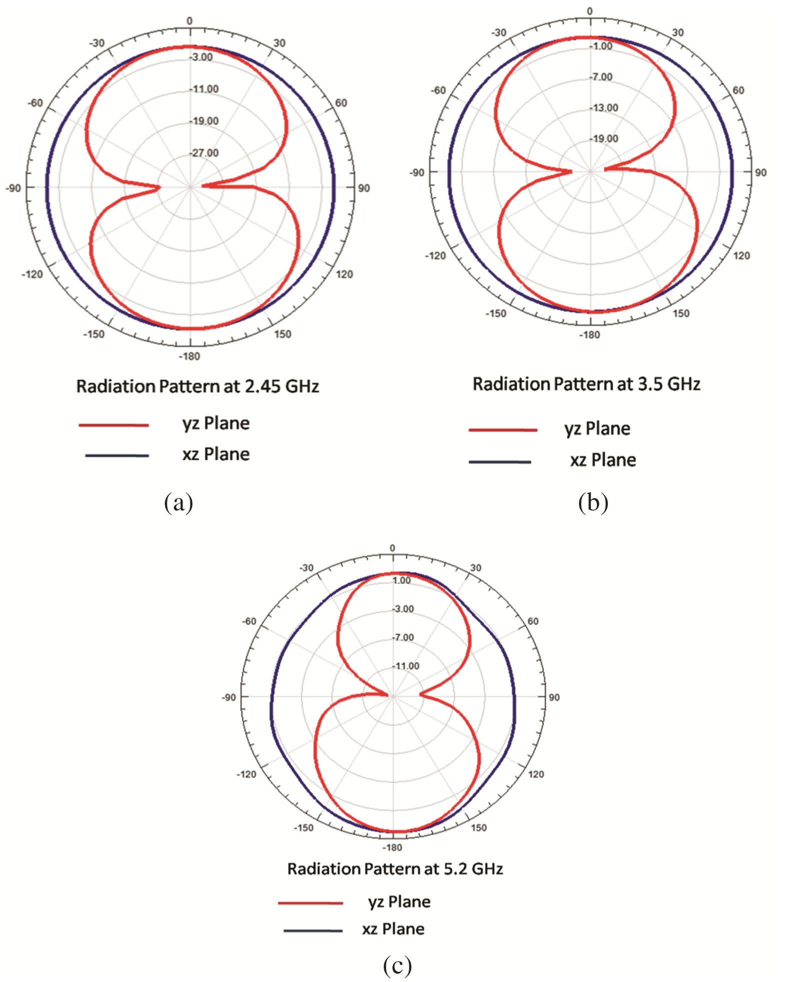


Fig. 9. Simulated E-Plane and H-Plane at (a) 2.45 GHz, (b) 3.5 GHz, (c) 5.2 GHz.

4 Conclusions

A CSRR loaded dual-band monopole antenna with a defected ground structure has been presented for combined WLAN/WiMAX applications. The antenna is fed by a micro-strip feed line. The forecasted antenna volume is 26 mm × 25 mm × 1.6 mm. The simulation model suggests an impedance bandwidth of 3.86% centred on 2.45 GHz for the first band, and a wide upper band from 3.44 GHz to 6.25 GHz. Both bands display a good omni-directional monopole radiation pattern.

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