Metamaterial inspired multi-split square shaped printed antenna for WLAN applications

S. Imaculate Rosaline
Department of Electronics and Communication Engineering
Ramaiah Institute of Technology, Bangalore, India
Email: imaculaterosaline@gmail.com

Abstract. This paper describes the design of a compact dual band microstrip antenna based on metamaterial inspired split ring radiating element and a complementary split ring resonator (CSRR). The antenna has a very compact dimension of 20×20×0.8 mm³. It covers the 2.5/5.2/5.8 GHz frequencies, pertaining to IEEE 802.11 b/g/a standards suitable for WLAN applications with a -10dB impedance bandwidth of 250 MHz and 860 MHz. The CSRR creates a negative permittivity region, thus providing miniaturization of the antenna and the introduction of additional split gaps in the radiating element creates a positive permeability within the desirable frequency range, yielding better impedance matching. The negative properties of those structures are verified using S-parameter retrieval method. A prototype of the proposed antenna is fabricated and the measured results are fairly in good agreement with the simulation results. Dipole like radiation patterns are observed at both the operating frequencies. The measured peak gains are 0.58 dBi, 1.27 dBi and 2.10 dBi at 2.5, 5.2 and 5.8 GHz respectively.

Keywords - WLAN; dual band; split ring radiating element; CSRR; miniaturization

1. Introduction

Many hand-held and wireless communication devices such as mobile phones, lap-tops and modems require functional, compact and multiband antennas competent to work in different communication standards. The challenges include ease of design, integration and cost effectiveness with optimum performance. Wireless local area network (WLAN) is one of the widely used network for internet access which uses the frequency band of (2.4–2.484) GHz, for the IEEE 802.11b/g standards, and (5.15–5.35) GHz, (5.725–5.825) GHz, for the IEEE 802.11a standard. Different methods to achieve multiband operation are reported in literature. To obtain dual band resonance especially in the WLAN range, several methods have been adopted in the literature, which includes, radiating elements with multiple parasitic branches [1, 2], with several slots [3-5], meandering elements [6] and fractal structures [7]. However, complicated structural design [1,5] or bigger sizes [2,4,6,7] have always been a problem in producing these antennas practically. Even though introducing reactive slots as discussed in [3], is reported to yield compact dimensions, it yields poor impedance matching at few resonant bands. The exploration of electromagnetic metamaterials inspired structures and their complementary counter parts to be used as radiators for achieving compact and multi-band antennas is enormous. These structures have reported to achieve size reduction [8,9], multiband operations [10], and performance improvements like gain and bandwidth [11]. A split ring monopole antenna [12], CSRR based dual band antenna [13] and triangular split ring resonators (SRRs) [14] are few of the designs...
contributed to the WLAN application in the literature. This paper aims in the design of a highly compact and a simple radiating structure. For this purpose, metamaterial inspired elements like SRR

![Fig 1. Evolution of the proposed Geometry](image)

![Fig 2 Schematic presentation of the proposed antenna (a) Top view (b) side view (c) bottom view](image)

![Fig 3 Photograph of the fabricated antenna (a) top view (b) bottom view](image)
and CSRR are exploited in the top and bottom plane of the antenna for providing good impedance.
matching and miniaturization. This resulted in a dual band operation at 2.5/5.5 GHz making it suitable for WLAN applications in compliance with the IEEE standards. The design is novel in sense that it is highly compact (20 × 20 × 0.8 mm³), cost effective with a simple topology. In addition, it has satisfying antenna performances like return loss, bandwidth, radiation pattern and gain making it suitable for practical implementation under mass production.

2. Proposed Antenna Design

The proposed antenna is a printed microstrip type with very compact dimensions of 20×20×0.8 mm³. The substrate chosen is a low cost FR-4 with relative dielectric constant 4.4 and loss tangent 0.018. Fig. 1 shows the evolution in designing the proposed antenna. Configuration #1 consists of two metallic rings, in which the outer ring is open and the inner ring is closed, with a solid ground plane. In the second step, the ground plane is etched with a square SRR, giving rise to its complementary structure (CSRR), which reports for miniaturization, as well as, the existence of another band with poor impedance matching. The length and width of the CSRR along with the split gap is found to have considerable effect on the miniaturization ratio and the lower resonant band. The final proposed antenna design is depicted in configuration #3, where the outer split ring is introduced with two more symmetrical split gaps of dimension L4 × W3, on either side of its centre split, resulting in a better impedance match at the lower resonating frequency. The antenna is excited by a microstrip feed line of dimensions 2 mm × 2 mm to match with the practical 50Ω coaxial connector. The layout and the geometrical details of the proposed configuration are shown in Fig. 2. The structural dimensions are finalized after a series of parametric studies using the optimetrics option available in High Frequency Structure Simulator (HFSS) software and are tabulated in Table 1. Photograph of the fabricated antenna is shown in Fig. 3.

| Table 1. Dimensions of the proposed antenna illustrated in configuration #3 |
| ---------------------- | ------ | ------ | ------ | ------ | ------ | ------ | ------ | ------ | ------ | ------ |
| Parameter             | Ls     | Ws     | L1     | W1     | L2     | W2     | L3     | W3     | L4     | W4     | L5     | W5     | L6     | W6     | L7     | W7     |
| Dimensions (in mm)    | 20     | 20     | 16     | 2      | 10     | 1      | 2      | 1      | 2      | 1.5    | 2      | 2      | 16     | 1      | 1      | 1      |

3. Simulated Results and Parametric Studies

Ansoft High Frequency Structure Simulator (HFSS) V.19.0 commercial software package is used for performing the simulations. Fig. 4 shows the simulated reflection characteristics of all the three configurations described in Fig. 1. It shows that, the configuration #1 has only one operating frequency band centered at 10.7 GHz. Then, the introduction of CSRR backed ground plane (#2), pushes down the fundamental mode resonance to 5.5 GHz, accounting for 48.6 % miniaturization. Also, a lower band resonance at 2.5 GHz is realized with a poor reflection coefficient value of -10.3 dB. The proposed antenna (#3) is observed to improve the impedance matching at the lower operating band and thus achieves a dual band resonance at 2.5/5.5 GHz. It sweeps over the frequency range of (2.40-2.65) GHz and (5.00-5.86) GHz and thus has a wide impedance bandwidth (S11< -10dB) of 250 MHz and 860 MHz. Thus, the upper band resonance at 5.5 GHz is due to the CSRR backed ground plane and the impedance matching in the 2.5 GHz frequency is due to the additional splits etched on the top arm of the radiating element. To validate this statement, separate parametric studies on the radiating element and the CSRR are carried out and the results are discussed here. Initially, a parametric study on the CSRR's electrical length L6 is swept over the range 15 mm to 17 mm with step size 1 mm, by maintaining W6, L7, and W7 as constant for effectiveness. This is depicted in Fig.5 from which it is obvious that, choosing the Length L6 of 16 mm is wiser to achieve miniaturization in the desired WLAN upper frequency range centered at 5.4 GHz. Similarly, a parametric study on the split ring radiating element is performed by varying the number of slit gaps in the range 1, 3 and 5, to
maintain symmetry on either side of the center split. This is shown in Fig. 6 from which we infer that the number of split gaps on the radiating element have considerable effect on impedance matching at 2.5 GHz. Finally, we observed that, by choosing 5 split gaps on the radiating element, impedance matching of 67.6% can be achieved. Also, it has a negligible effect on the upper band.

A. Metamaterial property verification

The radiating element and the CSRR in the ground plane comply with the metamaterial property individually, that is, the split ring radiating element exhibits negative permeability, whereas the CSRR exhibits negative permittivity. Simulation results of the same are briefed in this section.
To confirm negativity in the proposed split ring radiating element, it is placed inside a rectangular waveguide, with no air gaps in the walls of fixture [15]. Perfect electric and perfect magnetic conducting boundaries are assumed on either side of the waveguide walls as shown in Fig. 7. The proposed multiple split ring radiator is excited through one port, and the corresponding transmission ($S_{21}$) and reflection coefficients ($S_{11}$) are measured through the other port. These values are then exported to MATLAB to calculate the complex permeability values using the relation proposed by Smith et.al [16].

The orientation of the magnetic field perpendicular to the split ring axis, induces magnetic dipole moments, which in turn creates negative permeability for frequencies less than its plasmonic frequency. The number of split gaps in the top arm has an influence on this negative permeability region. This is validated in Fig. 8 which shows the real part of extracted permeability as a function of frequency. Except for the proposed case, the remaining two configurations have sharp negative permeability cut off at 2.5 GHz and 2.6 GHz which lies in the desired frequency range of interest. This has resulted in poor impedance matching for the first two configurations. Whereas, for the proposed method, the negative permeability region lies completely outside of our operating band (2.38–2.64) GHz and the permeability is constant and positive over this range. This led to proper impedance matching at 2.5 GHz.

Replacing the radiating element in the waveguide with the ground plane CSRR, the $S_{11}$ and $S_{21}$ values are obtained in the same way. Unlike the split ring elements, their complementary structures are electrically excited which exhibits strong dispersion near its resonant frequency and gives rise to negative permittivity values. Upon plotting the real part of permittivity Vs frequency for various length $L_6$ of the CSRR as shown in Fig. 9, we observed a shift in the negative permittivity region to lower frequencies for increasing order of $L_6$. Also, two negative peaks within short range of frequency can be attributed to the strong mutual coupling between the two slots in the CSRR. Length $L_6$ of 16mm is chosen because it covers the desired frequency range of interest (5–5.9) GHz. This reduces the guided wavelength along the substrate which accounts for lowering the resonant frequency.

The two positive permittivity peaks corresponding to length $L_6$ of 16mm at 5 GHz and 5.7 GHz is responsible for the two dips in the reflection characteristics at those corresponding frequencies as shown in Fig. 6. Thus the radiating element is a µ negative (MNG) structure and the CSRR loaded ground plane is a ε negative (ENG) structure.
B. Surface current distribution

Simulated surface current distributions on the split ring element and the CSRR for the two operating bands centered at 2.5 GHz and 5.5 GHz are shown in Fig.10. At 2.5 GHz, it is seen that the current is concentrated on the feed line, outer ring splits on the radiating element, and along the inner ring’s metal joint of the ground plane CSRR. On the other hand, at 5.5 GHz, a dense current distribution is noticed along the feed line, periphery of the radiating element’s outer ring and along the outer ring’s metal joint of the ground plane CSRR. Hence, this current distribution validates our prediction that lower order frequency is caused by the inner ring’s metal joint in the ground plane and the outer ring splits in the radiating plane, while the higher order frequency is attributed to the outer ring’s metal joint in the ground plane.

4. Experimental Results

![Simulated surface current distribution of the proposed antenna](image)

**Table 2.** Simulated and measured results of the proposed antenna

| Dual band antenna | Center frequency f1, f2 (GHz) | |S11| (dB) | Impedance bandwidth (MHz) | Impedance bandwidth Ratio (%) |
|-------------------|-----------------------------|---|----------------|---------------------|----------------------|
| Simulated         | 2.50                        | -22.36 | 250          | 9.9                 |
|                   | 5.47                        | -28.55 | 860          | 15.83               |
| Measured          | 2.47                        | -29.82 | 240          | 9.5                 |
|                   | 5.56                        | -30.00 | 830          | 15.13               |

**Fig.10** Simulated surface current distribution of the proposed antenna (a) at 2.5 GHz (b) at 5.5 GHz
The reflection characteristics are measured using Agilent Network Analyzer E8362B. Fig. 11 compares the simulated and measured reflection characteristics of the proposed antenna. The measured results show that the antenna has a dual band resonance centered at 2.47 GHz and 5.56 GHz sweeping over a frequency range of (2.40 – 2.64) and (5.07 – 5.90) respectively. The reflection coefficients pertaining to these two frequencies are -29.82 dB and -30.00 dB. These results are fairly in good agreement with the simulation results. Table 2 validates both the results numerically. It is observed that the antenna has 9.5% and 15.13% impedance bandwidth in the lower and upper resonant bands.

A. Radiation characteristics

Far field anechoic chamber is employed to measure the radiation pattern of the proposed antenna. Fig. 12 shows the measured E (x-z) plane and H (y-z) plane pattern at the three operating frequencies. H plane reported an omnidirectional pattern and E plane reported a nearly bidirectional pattern at all the frequencies. The conventional gain transfer method is used for performing gain measurement, where a horn antenna is used as the reference. The gain plot is shown in Fig. 13. The antenna has a peak gain of 0.58 dBi, 1.26 dBi and 2.10 dBi at the three resonant frequencies. This makes the antenna suitable for wireless application devices.

Fig. 11 Simulated and measured reflection characteristics of the proposed antenna
5. CONCLUSION

A compact dual band antenna based on split ring radiating element and a CSRR operating in the 2.5/5.2/5.8 GHz bands suitable for WLAN applications is presented. Integration of ε negative CSRR resulted in 48.6% of miniaturization and modification in the µ negative radiating element enhanced impedance matching by 67.6%. The proposed antenna design is simple and has no complicated geometry making it suitable for easy and cost effective fabrication. It has a sufficient bandwidth of 9.5% and 15.13% at each frequency band. Simulation results verified the existence of negative permeability and negative permittivity regions. Satisfactory dipole like radiation pattern is observed at

Fig. 12 Simulated and measured radiation patterns of the proposed antenna at (a) 2.5 GHz (b) 5.2 GHz (c)
all the frequency ranges of interest with a reasonable gain of 0.58 dBi, 1.26 dBi and 2.10 dBi at the three resonant modes making it suitable for wireless applications.

REFERENCES

[1]. Zhang, Xin-Qian, Xiao-Fei Wang, and Wei-Yang Song. "Compact Triple-band Monopole Antenna with Dual Fork-shaped Strips for WLAN/WiMAX Applications." 2020 International Symposium on Antennas and Propagation (ISAP). IEEE, 2021.

[2]. Naji, Dhirgham Kamal. "Miniature Slotted Semi-Circular Dual-Band Antenna for WiMAX and WLAN Applications." Journal of Electromagnetic Engineering and Science 20.2 (2020): 115-124.

[3]. Sura, Penchala Reddy, and M. Sekhar. "Circularly Polarized Dual Band Dual Slot Antenna for WLAN, Wi-MAX and Wi-Fi Applications." IETE Journal of Research (2021): 1-6.

[4]. Aldhaheri, Rabah W., et al. "A Compact CPW-Fed UWB Antenna with Dual-Band Notched Characteristics for WiMAX/WLAN Applications." Applied Computational Electromagnetics Society Journal 36.2 (2021).

[5]. Zhang X-Q, Jiao Y-C, Wang W-H. Compact wide tri-band slot antenna for WLAN/WiMAX applications. Electron Lett 2012;48(2):64–5.

[6]. Chien H-Y, Sim C-Y-D, Lee C-H. Dual band meander monopole antenna for WLAN operation in laptop computer. IEEE Antennas Wireless Propag Lett 2013; 12:694–7.

[7]. Ghatak R, Mishra RK, Poddar DR. Perturbed Sierpinski Carpet Antenna with CPW Feed for IEEE 802.11 a/b WLAN Application. IEEE Antennas Wireless Propag Lett 2008; 7:742-4.

[8]. Laila D, Suji th R, Shameena VA, Nijas CM, Sarin VP, Mohanan P. Complementary split ring resonator-based microstrip antenna for compact wireless applications. Microw Opt Technol Lett 2013;55(4):814-6.

[9]. Ouedraogo RO, Rothwell EJ, Diaz AR, Fuchi K, Temme A. Miniaturization of patch antennas using a metamaterial-inspired technique. IEEE Trans. Ant P 2012;60(5):2175–82.

[10]. Feng, Caixia, et al. "High-Gain SIR Dual-Band Antenna Based on CSRR-Enhanced SIW for 2.4/5.2/5.8 GHz WLAN." International Journal of Antennas and Propagation 2020 (2020).

[11]. Sumathi, K., et al. "High gain multiband and frequency reconfigurable metamaterial superstrate microstrip patch antenna for C/X/Ku-band wireless network applications." Wireless Networks (2021): 1-16.
[12]. Basaran SC, Erdemli YE. A dual band split ring monopole antenna for WLAN applications. Microw Opt Technol Lett 2009;51(11):2685–8.

[13]. Basaran SC, Olgun U, Sertel K. Multiband monopole antenna with complementary split ring resonators for WLAN and WiMAX applications. Electron Lett 2013;49(10):636–8.

[14]. David, Rajiv Mohan, et al. "A Multiband Antenna Stacked with Novel Metamaterial SCSRR and CSSRR for WiMAX/WLAN Applications." Micromachines 12.2 (2021): 113.

[15]. Chen H, Zhang J, Bai Y, Luo Y, Ran L, Jiang Q, et al. Experimental retrieval of the effective parameters of metamaterials based on a waveguide method. Opt Express 2006;14(26):12944–9.

[16]. Smith DR, Schultz S, Markos P, Soukoulis CM. Determination of effective permittivity and permeability of metamaterials from reflection and transmission coefficients. Phys Rev B 2002; 65:195104–9.