Dual band compact antenna design using DCSRR

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Abstract. Wireless communication technology has revolutionised the way people interact all around the world. The rate of access and the accuracy of the information conveyed have increased as technology and gadgets have advanced. Multi-frequency systems and devices are the results of the requirement for mobility and the integration of several radio modules into this kind of device. Due to the limited area, integrating many antennas and a diplexer into a single device is very challenging. This means an advanced antenna design must be simple, small, and simple to incorporate in addition to being dual or multiband capable. Microstrip printed antennas are the most promising alternative for use in small systems due to its various features such as low profile, compact configuration, simplicity of integration, and low fabrication cost. There are many techniques to make an antenna operate in multiband such as by incorporating structures like complementary split ring resonator (CSRR), SRS (split ring slot), SRR (split ring resonator) etc., dual polarization method, loading of metamaterial. The DCSRR (D shape complementary split ring resonator) is inserted into the antenna patch to enable multiband operation. So, in this paper, to achieve dual band response using this method, which supports Wi-Fi and C band applications at frequencies of 5.8 GHz and 7.1 GHz, respectively. In the suggested work, a good gain of about 1.98 dB at 5.8 GHz and 2.27 dB at 7.1 GHz was obtained, as well as an efficiency of 80 percent and 81 percent at the relevant frequencies. This characteristic has been achieved without compromising on the compact miniaturized size of antenna, which is 12 x 12 x 1.6 mm³.

Keywords: D-CSRR, compact antenna, dual band, s parameter

1. Introduction

To provide communication, GPS, and other services, modern wireless hand-held devices must operate on multiple bands [1]. With a compact dimension and larger bandwidth, a particular Patch Antenna (MPA) can service entire frequency bands, including Wi-Fi, WLAN, WiMAX, and C band usages. This is the most common strategy for today's wireless handheld devices, rather than using various antennas for different working frequencies. In typical dual-band or multiband MPAs, the dimensions of the radiating patch are taken regarding the smallest frequency band, which requires further size increment. In the case of metamaterials based dual band antennas, the dimensions of the radiating patch are measured in terms of high frequency, which demands a smaller antenna.

The three categories of metamaterials are double negative materials (DNG) and single negative materials such as epsilon negative materials (ENG), permeability negative materials (MNG) [2, 3]. Such type of materials are exhibited by SRR and CSRR structures. Several CSRR/SRR structures [4, 5] have investigated and examined the properties of CSRRs and SRRs. In particular, dual band antennas are provided in [6 - 7] by introducing CSRR into the radiating patch. Single band and multiple band antennas are designed in [8-11] by etching CSRR on the ground plane. The antennas outlined above take up a lot of space in regards of thickness or surface area for Wi-
Fi and WiMAX applications, and they additionally had a low bandwidth. Our goal is to maintain a good level of gain and bandwidth while decreasing the size by introducing a D shape CSRR (DCSRR) on antenna's construction. Suggested design antenna deals with single ring DCSRR created on patch antenna with compact size for 5.8GHz and 7 GHz dual frequencies. This antenna is suited for Wi-Fi and C band communication due to its compact size, low cost, and lightweight. This antenna's major benefit is its simplicity.

2. Antenna Design Structure

The design antenna is made up of three layers: patch, substrate, and ground. All dimensions are given in millimetres. The proposed antenna is built on a lossy dielectric sheet called FR-4 dielectric substrate ($\varepsilon_r = 4.4$) with height of 1.6mm. For better bandwidth partial ground is consider. Figure 1 a, b depicts a basic front and back of microstrip patch antenna with partial ground for 6.8 GHz resonance frequency. Based on transmission line model, the fundamental formula for determining patch antenna length and width is calculated [12] and the dimensions of antenna is given in Table 1.

![Figure 1. Rear side and backside view of patch antenna](image)

| Antenna parameter | dimension (mm) |
|-------------------|----------------|
| $W_s$            | 12             |
| $L_s$            | 12             |
| $W_f$            | 3              |
| $L_f$            | 7              |
| $L_{slot}$       | 5              |
| $W_{slot}$       | 1              |
| $L_g$            | 12             |
| $W_g$            | 1.5            |
| $W_p$            | 8.5            |
| $L_p$            | 5              |
2.1 D shape CSRR design

Figure 2 depicts the structure of the D Shape CSRR (DCSRR). Generally, the CSRR is the dual structure of SRR, according to the concept of Babinet’s principle, wherein the functions of air and metal, as well as magnetic and electric field wherein the capabilities of metal and air, as well as electric and magnetic field characteristics are interchanged. The SRR may be energized by an external magnetic flux as a magnetic dipole, however, being an electric dipole, the CSRR may be activated by an external electric field.

![Figure 2. DCSRR structure](image)

The proposed D shape CSRR resonant frequency is determined by the self-inductance and capacitance per unit length. The design equation of the proposed single D CSRR is calculated using mathematical calculation of resonant frequency, $f_{SRR}$ are calculated using the design equations given by (1), (2) and (6).

The formula for total Inductance,

$$L_t(\mu H) = \frac{0.0002 \times l \times \left[2.303 \times \log \left(\frac{N \times \frac{l}{c+t}}{0.632} \right) - \frac{Y}{2}\right] 	imes 10^{-6}}{2.303 \times \log \left(\frac{N \times \frac{l}{c+t}}{0.632} \right) - \frac{Y}{2}}$$

Where $l$ is per unit length inductance

C is strip width, $t$ is thickness of strip,$N$ is no of strip rings, constant $Y$ is 1.225 for D wire geometry.

Total Equivalent capacitance,

$$C_t = \frac{C_g}{2}$$

Gap capacitance,

$$C_g = \frac{\varepsilon_0 \varepsilon_r c t}{g}$$

where $g$ is split gap in ring, $c$ is strip width, $t$ is thickness of strip,

$$r_{avg} = r_{ext} - \frac{c}{2}$$

Where $r_{avg}$ is average D ring radius,

radius of D SRR ring, $r_{ext} = 3$ mm, $c = 0.8$ mm

The formula for resonance frequency, $f_{SRR}$ is given in equation 6.

$$f_{SRR} = \frac{1}{2\pi \sqrt{C_t L_t}}$$

The theoretical resonant frequency is 5.72 GHz.

$C_{SRR} = C_t = 0.154$ nF, $L_{SRR} = L_t = 5.0215$ pH,

The proposed D shape SRR design resonates at 5.8 GHz.
2.2. Waveguide Analysis of Single D Shape CSRR

The complex permittivity of DCSRR is calculated based on the time-domain transient response over a frequency range. Based on the Nicholson-Ross Weir (NRW) method [16], the parameter extraction is done. Figure 3 illustrates the waveguide setup using the HFSS tool for calculating real and imaginary S parameters of D CSRR. The D CSRR is placed within the waveguide and has perfect magnetic conductor (PMC) and perfect electric conductor (PEC) boundary conditions. EM waves emerge via the input port and the values of S (Real & Imaginary) parameters from port 2 are computed. Extracted the real and imaginary of S parameters of a single D SRR resonating at 5.8 GHz from HFSS simulation.

The negative permittivity ($\varepsilon$) characteristics of DCSRR is extracted from these S-Parameter (S11 and S21) values by using equations (6&7).

$$\varepsilon_r = \frac{2}{jk_o d} \times \frac{1-V_1}{1+V_1} \quad (6)$$

$$\mu_r = \frac{2}{jk_o d} \times \frac{1-V_2}{1+V_2} \quad (7)$$

Where

- $V_1$ is $S_{21}$-$S_{11}$
- $V_2$ is $S_{21}$-$S_{11}$
- $k_o$ is wave number of free space
- $d$ is substrate thickness

![Figure 3. Unit Cell Design of Single D SRR Structure](image)

The extraction of the single D CSRR unit cell of effective permittivity is obtained by the MATLAB tool. It can be seen in Figure 4 that the real permittivity value is negative at 5.8 GHz, which attributes to the D CSRR resonance behaviour.

2.3 Proposed Antenna with DCSRR

The DCSRR structure is etched from the patch antenna after proper optimization based on mode characteristics which is shown in Figure 5. The proposed DCSRR structure creates additional resonance frequency at 5.8 GHz and patch antenna resonance frequency slightly shifted to 7 GHz. The antenna with and without DCSRR return loss response are simulated and plotted in Figure 6.
With DCSRR provides better impedance matching at 5.8GHz around -27 dB after adding D structure. Two responses obtained at 5.8 GHz and 7 GHz, where 10 dB return loss is about -27 dB and -14.6 dB respectively. So, the obtained dual bands, i.e. one band is 5.8 GHz (Wi-Fi) and other is 7 GHz (upper C – Band). The optimization of antenna procedures discussed as follows:

With the patch antenna area dimension as 12 x 12=144 mm² without DCSRR, the antenna resonates at 6.8GHz after introducing DCSRR lower resonance frequency resonates at 5.8 GHz. Nearly 1GHz reduction in frequency response. Hence the proposed antenna achieved 14.7% reduction in size.
2.3.1. Parametric analysis

By adjusting and optimizing the width of the partial ground plane, in order to achieve good return loss at 6.8 GHz frequency which is shown in Figure 7. After introducing D shape CSRR (DCSRR) on the top of the patch the structure creates dual resonance frequencies at both 5.8 GHz and 7 GHz. The dual resonance behaviour is created by negative permittivity of D shape CSRR.

It was found that the obtained frequency with ground width of 1.5 mm is the best result as obtained a good return loss of -27 dB also exactly at desired frequency 5.8 GHz which is shown in Figure 7.

![Figure 7. S11 responses for ground width variation](image)

2.3.2. Surface current Analysis of proposed antenna

The mode of resonance can be determined by analysing the surface current distribution over the antenna surface. Field overlays are an option in HFSS for plotting the field distribution on a surface or object. Surface current analysis ($J_{surf}$), which is available under the Field overlays option, is used to calculate the current distribution on the radiating patch and ground patch. The patch under consideration is chosen, and the surface current distribution at a specific frequency is chosen. The study provides the amplitude and direction variation of the structure's surface current distribution. From Figure 8, clearly shows maximum current distributed near to the D shape strip which is responsible for 5.8 GHz but at 7 GHz the current distribution is very less near to D CSRR strip and maximum current distribution at patch feedlines. So 7 GHz frequency response is almost similar to without DCSRR antenna design response.

From the above analysis, it was concluded that the low frequency band is mainly inspired by the proposed DCSRR structure in the patch antenna which is mainly controlled by the dimensions of the DCSRR. The second band is provided from patch itself with slight disturbance from Split in DCSRR makes the small deviation in higher band frequency.

![Figure 8. Surface current distribution of patch antenna with DCSRR](image)
2.3.3. Radiation pattern of proposed antenna

The 2-D radiation pattern of proposed patch antenna with DCSRR is shown in Figure 9. Both E and H radiation pattern responses at dual band frequencies at 5.8 GHz and 7GHz. The 2-D radiation pattern of patch antenna with DCSRR provides figure of pattern for E plane and omnidirectional pattern obtained for H plane at 5.8 GHz and 7 GHz resonance frequency.

![Radiation pattern plots](image)

(a) Radiation plot at 5.5GHz  (b) Radiation plot at 7.4 GHz

**Figure 9.** 2D radiation pattern of patch antenna with DCSRR

2.3.4 Gain and Efficiency of proposed antenna

The gain response of dual band frequencies is illustrated in Figure 10a. The maximum gain obtained at 5.8GHz and 7 GHz is 1.89 dB and 1.65 dB respectively.

![Gain and Efficiency plots](image)

(a) Gain plot (b) Efficiency plot

**Figure 10.** (a,b) Gain and Efficiency plot of proposed antenna with DCSRR

In the above Figure 10.b, efficiency at both the frequencies has been depicted. At 5.5 GHz, efficiency of about 0.95 (95%) is obtained and at 7.4 GHz, efficiency of about 0.919 (91.9%) is obtained. This proves that a good efficiency of antenna has been achieved at both the bands.

3. Conclusion

The proposed microstrip patch antenna has been incorporated with D structure in its patch, which is a structure similar to metamaterial and also such structures are capable of producing magnetic susceptibility, which referred as DSRR (Double Split Ring Resonator), this is used to achieve multiband operation. Using this technique, we have achieved dual band response to support Wi-Fi and C band application at frequencies 5.8 GHz (5.66-5.97) and 7 GHz (6.45-7.50) respectively. Also, a
good gain of about 1.89 dB at 5.8 GHz and 1.65 dB at 7.4 GHz has been obtained along with the efficiency of 95% and 91.9% at the respective frequencies in the proposed work. This characteristic has been achieved with the compact miniaturized size of antenna 12 x 12 x 1.6 mm$^3$ which is 14.7%. All the limitations such as size, gain, efficiency etc. identified in the existing structure and concept has been addressed and overcame in our proposed work. Therefore, the proposed antenna design has satisfactory characteristics for use in wireless communication system.

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