Analysis and Design of a Dual Band-Notched UWB Antenna Using Complementary Split Ring Resonator

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***Abstract*—In this paper, the complementary split ring resonator (CSRR) is studied and applied to design a printed ultra wideband (UWB) antenna with dual band-notched characteristics. Dual band-notched function is obtained by incorporating the CSRR in the radiating element and the ground plane of the proposed UWB antenna. The designed antenna has a small size and operates over the frequency band from 3.2 GHz to 13.5 GHz, with dual-band rejection at 3.5 GHz (WiMAX band) and the other at 5-6 GHz (WLAN band). The antenna electromagnetic characteristics such as the S (11) parameter, the radiation pattern and the gain are simulated using HFSS and CST. The obtained results are in good agreement and show that the proposed antenna can be used for UWB applications.**

***Index Terms*—Metamaterials, complementary split ring resonator, antenna, UWB, notched band.**

I. Introduction

In the latest years, ultra wide band (UWB) technology has become a highly competitive topic in both academy and industry communities of telecommunications. Compared with traditional technology, UWB systems offer important advantages such as high transmission rate, large capacity, low power and cost, etc. As an important component of the UWB system, UWB antenna has developed widely and rapidly since the authorization of the communication band (3.1-10.6 GHz) by the Federal communication commission in 2002 [1].

However, the frequency range for UWB systems will cause interference with existing narrowband wireless communication systems, for instance; the world interoperability for microwave access (WiMAX) operating in the 3.3– 3.7 GHz band, and the wireless local area network (WLAN) operating at 5.2 GHz (5.15–5.35 GHz) and 5.8 GHz (5.725–5.825 GHz). To prevent the electromagnetic interference with the existing systems, many UWB antennas with band-notched characteristic are designed [2-8]; the simple and commonly used approach is to incorporate slots (U-shaped slots, I-shaped slots, L-shaped slots, etc.) [2-5], or parasitic strips in the radiating element of the antenna used as filters to reject these bands [6-8]. But most of the reported antennas are generally designed with only one notched band or two notched bands with coupling influence.Moreover, the notched band cannot be well controlled in terms of frequency selectivity.

To circumvent the above shortcomings, the complementary split ring resonator (CSRR) was used as a band rejection element. First, a CSRR is associated with a transmission line to study the effect of the geometrical parameters on the variation of the transmission zero frequency. This analysis is exploited and applied to design a novel compact UWB antenna with dual notch frequency bands. The rejection function can be controlled easily by adjusting the CSRR dimensions. The proposed antenna fully covers the UWB band and has an almost omnidirectional radiation over the entire operating band. The simulated results have been achieved using commercially available software package; high frequency structure simulator (HFSS) for parametric investigation and the authors try to validate the results by another software package, CST Microwave Studio, for the reason of not having access to the adequate laboratory equipment.

II. Analysis of the Stopband Characteristics of CSRR

The waves that propagate throughout a negative permittivity medium are evanescent waves which make of this medium a good candidate for satisfying the above-mentioned purpose: rejecting frequency bands.

As the negative image of split ring resonators [9], complementary split ring resonators have been recently proposed and applied for the synthesis of transmission lines [10] (SRR and CSRR topologies are shown in Figure 1). It has been demonstrated that CSRR etched in the ground plane or in the conductor strip of planar transmission media (microstrip or CPW) provide a negative effective permittivity to the structure and signal propagation is precluded (stopband behavior) in the vicinity of the resonant frequency [11].

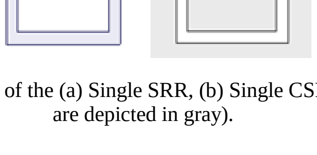

Fig. 1. Topology of the (a) Single SRR, (b) Single CSRR (Metal regions are depicted in gray).

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A rectangular CSRR associated with a transmission line is first studied to see the effect of geometrical parameters on the resonance frequency [10-12]. The structure of the CSRR with the transmission line is shown in Figure 2.

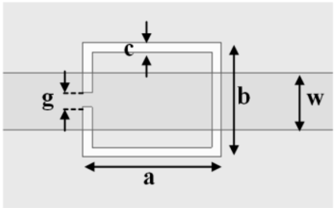


Fig. 2. The CSRR loaded microstrip line and its equivalent circuit model.

The transmission zero frequency (f_Z) of the CSRR loaded microstrip line is defined as [12]:

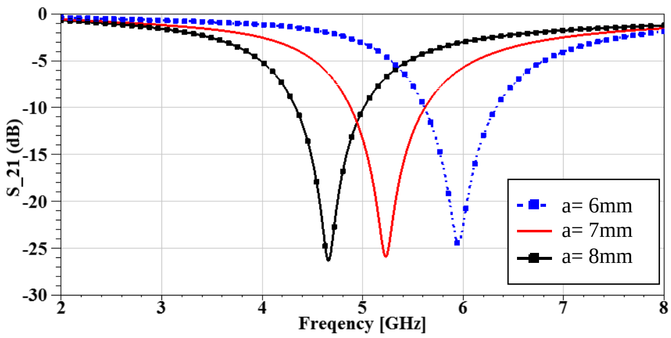
$$f_Z = 1/2\pi\sqrt{L_c(C_c + C)} \quad (1)$$

where C is the coupling capacitance between the line and the CSRR, the CSRR is modeled by means of a parallel tank formed by the capacitance C_c and the inductance L_c.

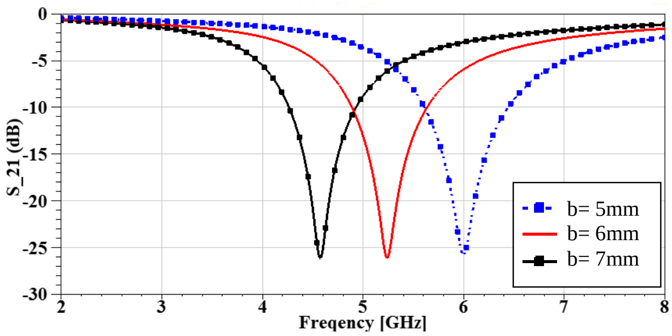
In this study, a transmission line of 50Ω characteristic impedance and a CSRR etched in the ground plane are deposited on the top and the bottom side of a FR4-epoxy substrate (ε_r =4.4, loss tangent of 0.02) respectively.

In each simulation, the one parameter is varied while others are held constant. The initial CSRR dimensions are: a=7 mm, b=6 mm, c = 0.4mm, g = 0.4 mm.

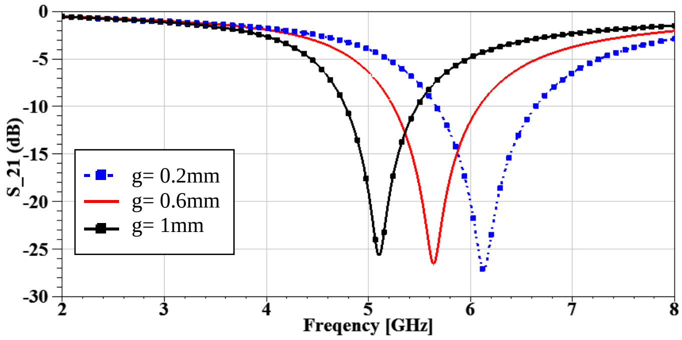
Figure 3 shows the simulated transmission coefficient of CSRR *loaded microstrip line* with different configurations.



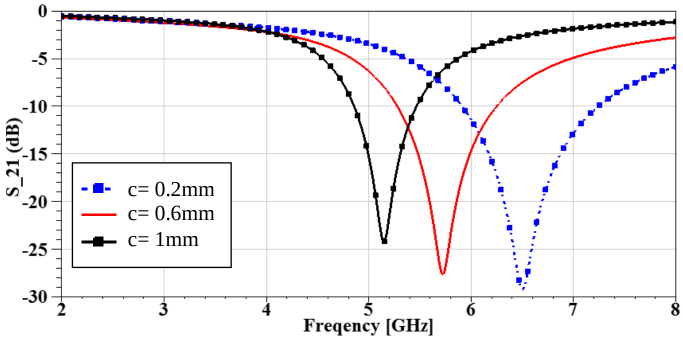
(a)



(b)



(c)



(d)

Fig. 3. Variation of the transmission coefficient (a) length (b) width (c) gap width (d) slot width simulated with HFSS.

From the obtained results, the transmission zero frequency (f_Z) varies *clearly by varying the geometrical parameters* a, b, c, w. It can be shown clearly from the equation (1), that the capacitance value C_c and the inductance L_c affects the frequency f_Z (the inductance L_c variation is neglected), while the larger CSRR (increasing length and width Figure 3(a), 3(b)) corresponds to a larger capacitance (decreased f_Z). On the other hand, f_Z increase in figure 3(c), 3(d) by increasing gap width and wire width, the decrease in capacitance C_c is induced by the fact that the larger space of g or w prevents the current to flow around the ring.

Table I summarizes the variation of the rejection frequency band based on geometric parameters.

TABLE I
FREQUENCY VARIATION (F_Z) AS FUNCTION OF CSRR PARAMETERS

Parameters	f_Z
a ↗	↘
b ↗	↘
c ↗	↗
g ↗	↗

The same effect can be observed by etching CSRR in the transmission line with a slight variation of the transmission zero frequency.

III. ANTENNA CONFIGURATION

The antenna is printed on a FR4 epoxy substrate with a relative permittivity of 4.4, a tangent loss of 0.02, a size of 32x28 mm^2 and a thickness of 1.7 mm. The radiating element and the feeding line are printed on the top side of the substrate, and a partial ground plane (Lg x(W-Wg) mm²) is printed on the bottom side. For better matching, the top corners of the ground plane are rounded, by using a circle of radius R_C=7mm, and a triangular slot (rounded with a circle of radius 2.2mm) is etched in the ground below feeding line. The width of the feed line is set at 2.8 mm. Figure 4 shows the geometry of the proposed antenna.

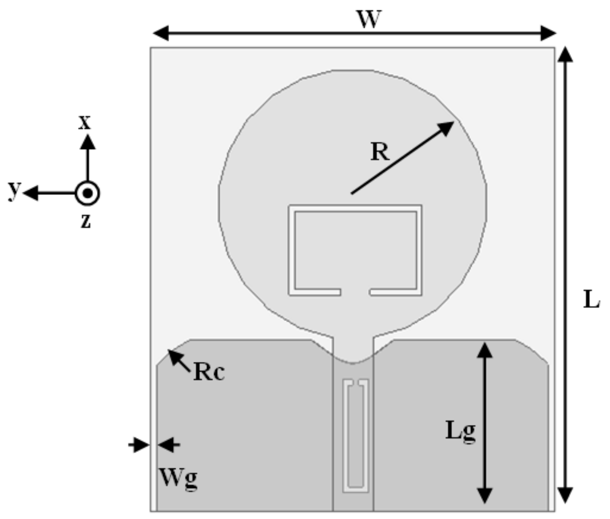


Fig. 4. The proposed Antenna with CSRR loading.

The optimized parameters of the proposed antenna are shown in Table II.

TABLE II
OPTIMIZED GEOMETRIC PARAMETERS OF THE ANTENNA.

Parameters	Value (mm)
L	32
W	28
R	9.3
Lg	11.8
Wg	0.5
Rc	7

The first band rejection is achieved by implementing the complementary Split ring resonator (CSRR) in the radiating element. The CSRR unit cell is designed to operate around 3.5 GHz. The geometry of the CSRR is as follows: a1=6.2 mm, b1=9.2 mm, c1 = 1.1mm, g1 = 2 mm.

To achieve the second frequency notch-band (5 GHz - 6 GHz), The Complementary split ring resonator (CSRR) is loaded in the ground plane. The CSRR dimensions are: a2=7.8 mm, b2=1.8 mm, c2 = 0.8mm, g2 = 0.8 mm.

IV. SIMULATION AND RESULTS

The proposed antenna was simulated using two software package CST and HFSS. The simulated S (11) of the proposed antenna is depicted in the Figure.5. The S (11) parameter of the antenna without CSRR is also plotted for comparison, it can be observed that the antenna without CSRR and with CSRR operates from 3.2 GHz to 13.48GHz for S (11) less than -10dB, it covers the band assigned for UWB application. From the figure it is very clear that the desired filtering property is achieved by introducing two CSRR, the two notched bands are 3.20-3.68GHz and 4.86-6.09GHz with CST and 3.34-3.94GHz and 5.02-5.84GHz with HFSS. The obtained results show a good agreement between simulation results.

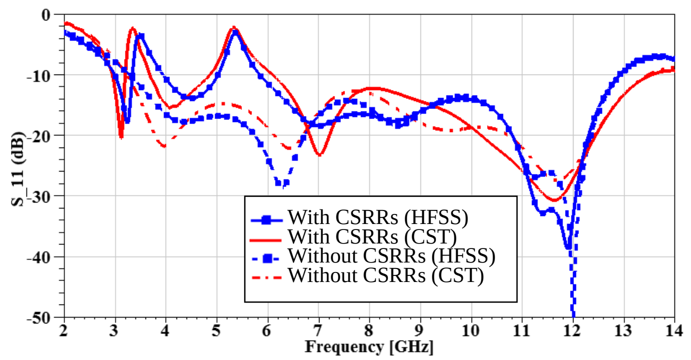
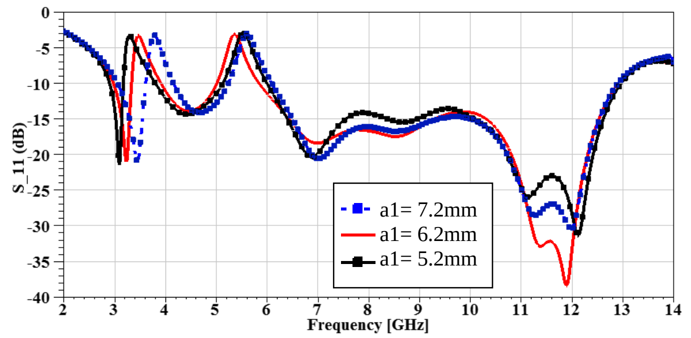


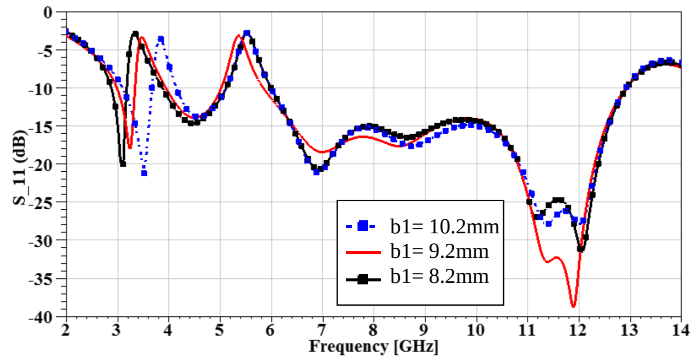
Fig. 5. S (11) parameter of the proposed dual band notched antenna and the reference antenna.

The UWB antenna with dual band notched using CSRRs has been analyzed with a parametric study. The parametric analysis is executed in order to review the effects of CSRRs parameters. All the parameters are kept constant in the simulation with the exception of the selected parameter.

Figure 6 shows the tuning effect by length, width and gap width on the rejection band 3.5GHz, while figure 7 illustrates the effect of varying the length, the width and the slot width on the rejection band 5-6GHz. As mentioned earlier, with adjustment of the aforementioned parameters, the rejection bands of each CSRR can be adjusted at the desired value.



(a)



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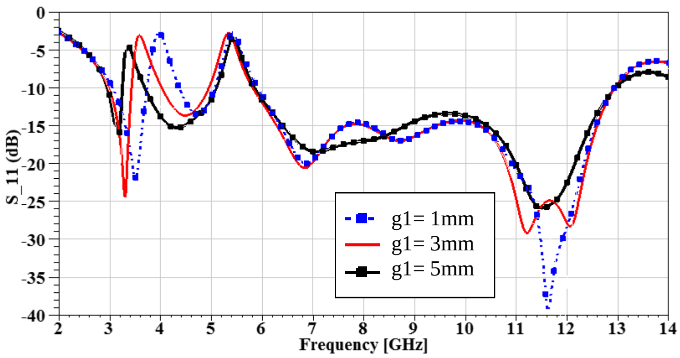
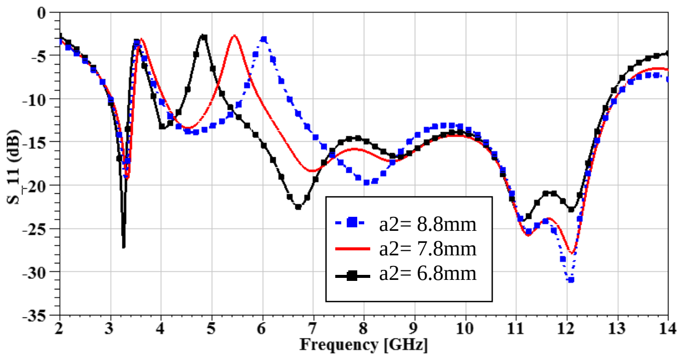
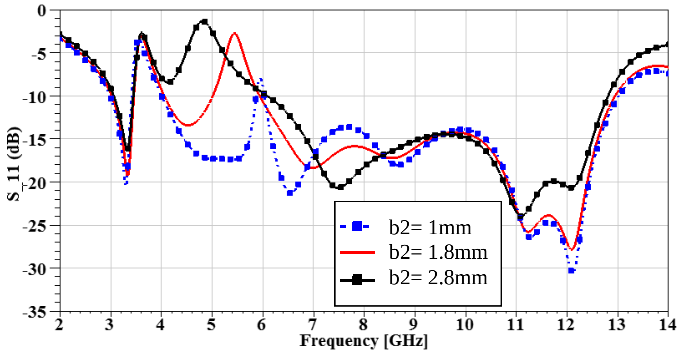


(c)

Fig. 6. S (11) parameter for various : (a) length a1, (b) width b1and (c) gap width g1, simulated with HFSS.



(a)



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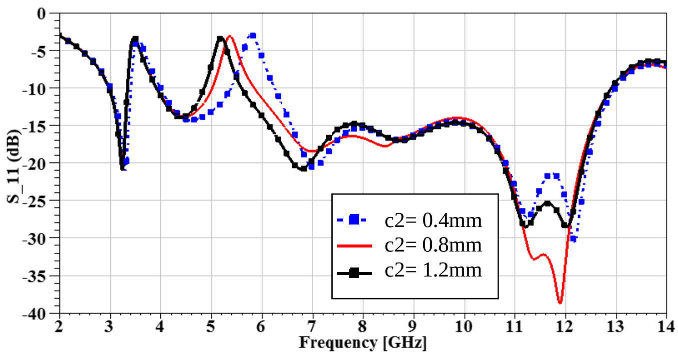


(c)

Fig. 7. S (11) parameter for various : (a) length a1, (b) width b1and (c)slot width c1, simulated with HFSS.

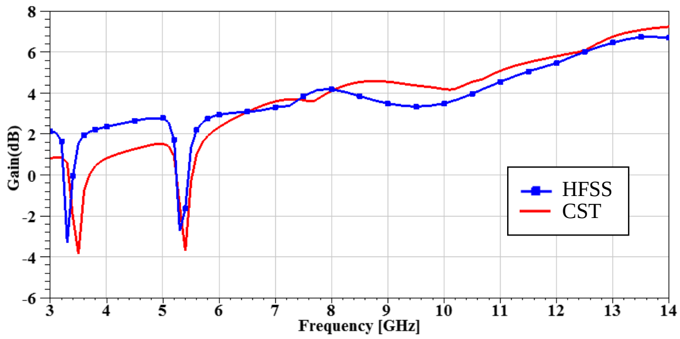
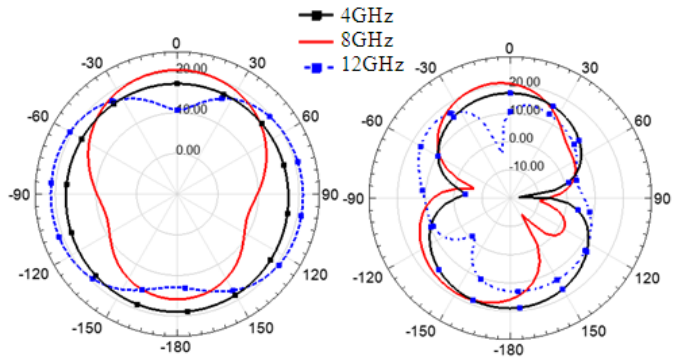


Fig. 8. Gain of the dual band notched antenna.

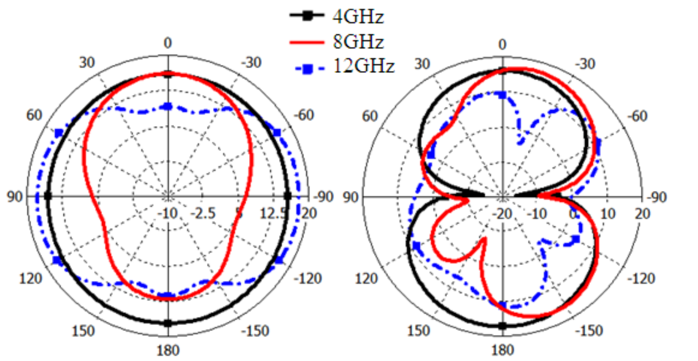
Figure 8 indicates the simulated gain. The gain drops swiftly in the region of the rejection band; which clearly indicates the filtering effect of CSRRs. The antenna discloses relatively stable gain except for the unwanted bands.

Figures 9 and 10 illustrate the radiation patterns of the proposed antenna at the pass band frequencies; 4, 8, and 12 GHz.



(a) (b)

Fig. 9. Radiation pattern : (a) H-plane (b) E-plane simulated with HFSS.



(a) (b)

Fig. 10. Radiation pattern: (a) H-plane (b) E-plane simulated with CST.

It can be seen that a dipole radiation pattern in the E-plane and a nearly omnidirectional radiation in H-plane.

V. CONCLUSION

In this paper, the frequency selective properties of the CSRR cell show a considerable relation with its geometric parameters, which have been analyzed. As application, a printed UWB antenna with dual band notched characteristic is proposed and analyzed. The two stop bands are generated by etching CSRRs in the radiating element and ground plane. The geometric parameters of CSRRs are chosen to eliminate interference with the WiMAX / WLAN systems. The proposed antenna covers the entire UWB frequency band and has good radiation performance. In addition, it has a simple structure and can be manufactured easily, which makes it a good candidate for UWB applications.

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