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A Novel Bow-Tie Antenna with Triple Band-Notched Characteristics for UWB Applications

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Abstract

This paper presents the design of a compact bow-tie antenna with triple band notched characteristics for UWB applications. The proposed antenna can operate from 3.1 to 10.6 GHz with VSWR < 2. Three Complementary Split Ring Resonators CSRRs are placed on the bow-tie antenna where each CSRR rejects one specific band. The CSRR1 rejects the IUT service band (8.025 - 8.4 GHz) centered at 8.1 GHz, the CSRR2 rejects the WLAN band (5.15 - 5.85 GHz) centered at 5.6 GHz, and the CSRR3 rejects the band (4.10 - 4.47 GHz) centered at 4.32 GHz. Compared with recent design, this antenna is more compact, and presents better simulation results of its characteristics. Our newly designed antenna is a potential candidate for application in UWB communication systems.

Keywords

Bow-Tie Antenna, Ultra Wide Band (UWB) Antenna, CSRRs, Notch Band

1. Introduction

The Ultra Wide Band (UWB) for wireless communication systems has received much attention since the allocation of 3.1 - 10.6 GHz band for this standard in

2002 by the Federal Communications Commission [1]. The UWB technology can cover multi standards applications, offering several advantages in terms of high data transmission rate with low power consumption, low cost and low complexity.

This technology faces enormous challenges including electromagnetic interference with existing narrowband microwave frequency, such as IEEE 802.16 WiMAX system (3.3 - 3.7 GHz), IEEE 802.11a WLAN system (5.725 - 5.825 GHz), downlink of X-band satellite communication (7.25 - 7.75 GHz) and ITU service (8.025 - 8.4 GHz). To overcome the problems resulting from electromagnetic interference, UWB antennas are used with discrete band stop filters.

Different types of UWB antenna topologies with single, dual, triple or quadruple band notched characteristics have been designed and reported in the literature [2]-[10]. Most common among these topologies-related fabrication-methods are etching techniques of various slots with different shapes (U-Shaped, C-Shaped, nested C-shaped, L-Shaped, Split Ring Resonators-SRR, Complementary SRR…). They are located either on the radiating element, or on the feed line or on the ground plane. The total size of the used slot calculated at the intended notch frequency defines the band-notched function [2]. Such size is about a half of the guided wavelength.

In [3] [4], the authors proposed a UWB antenna with one band-notched function. The UWB antennas with dual band-notch were presented successively in [2] [5] [6] [7], triple band-notch in [8] [9] [10] and multiple band-notch in [11] [12] [13]. Recently, a new approach is a design of reconfigurable UWB antenna with SRRs and CSRRs for notch single/multiple band [14] [15].

In [6], two band-notches are obtained by embedding г-shaped stubs in the patch and a modified G-slot defected ground structure in the feeding line. In [7], the authors also used U-slot defected ground structure of the feeding line combined with an E-slot etched on the radiating element.

In [8], the authors are using one, two and three CCL (Capacitively-Loaded Loop) elements placed near the feed line to notch one, two and three band-frequencies. In [9], the same technique as [8] is proposed but with two Elliptic Single Complementary Split-Ring Resonators (ESCSRRs) to notch two band-frequencies and also place two Rectangular Split-Ring Resonators near the feed line to obtain the rejection of the third band-frequency.

In this paper, a simple bow-tie UWB antenna with triple band-notched characteristics is proposed and studied. By introducing three CSRRs in the radiation element, triple band-stop filter is achieved.

The bow-tie antenna is considered as a planar biconical antenna version, it has a symmetric structure for which the currents are mostly focused on the edges [16]. We have chosen this type of antenna because of its attractive radiation characteristics, its compactness and its lightness. It also has a dipole type radiation, omnidirectional in the H plane.

The CSRRs elements are optimized, by adjusting their positions and dimensions in order to reduce mutual coupling. The design procedures are given in section II. One design example, using the procedure and simulation data is described in section III. Although the band rejection procedure in this paper is applied to a bow-tie antenna, it could be employed to design other type of antenna. Note that all simulations presented in this work are conducted using Ansoft High Frequency Structure Simulator (HFSS 17.0) simulator.

2. UWB Bow-Tie Antenna Design and Geometry

The topologies of the proposed antenna with and without CSRRs are shown in Figure 1(a) & Figure 1(b).

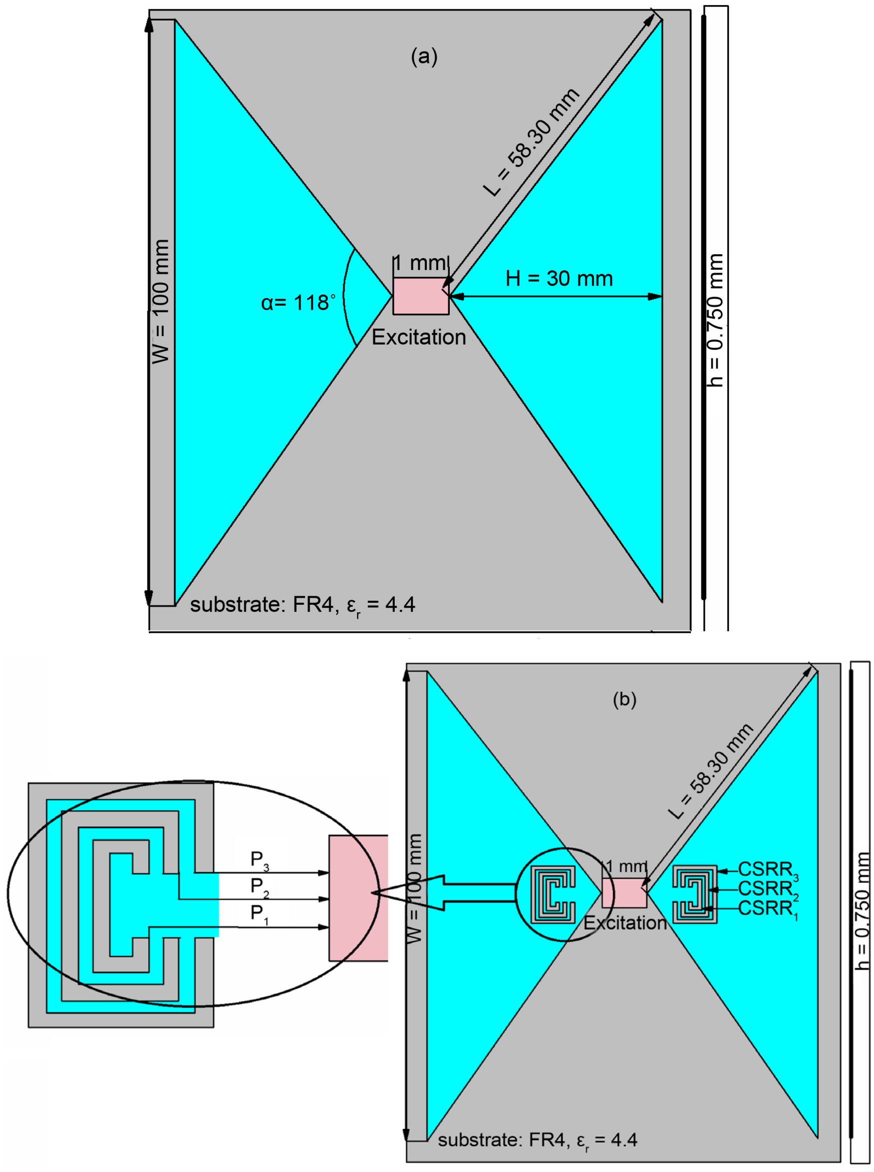

Figure 1. (a) Geometry of antenna without CSRRs. (b) Geometry of antenna with CSRRs.

Bow-tie UWB antenna has been employed for many years in the VHF and UHF frequency ranges. However, the description of its behavior and its sizing are very fewly detailed in the literature. It consists of two triangles (characterized by the height H and the flare angle α) symmetrical with respect to the feeding point. The antenna is designed on FR4 substrate for $\varepsilon_r = 4.4$ and loss tangent of 0.02 with thickness of 0.750 mm (**Figure 1(a)** & **Figure 1(b)**). It is fed by a 50 Ω coaxial cable.

2.1. Flare Angle α and Triangle Height H

Small advances in the description of bow-tie UWB antenna were made by Balanis C.A. and Chen Z.N. who proposed respectively in [16] and [17] formulae that can be used to calculate the dimensions of the structures very close to the bow-tie antenna. Unfortunately, these formulae do not give concordant results in all cases.

Taking into account the above-mentioned remarks, and referring to the experimental work of Brown G.H. [18] on the triangular structure antennas, we used the formula (1) assuming that the flare angle is between 110˚ and 140˚ and that the first resonance is around 3 GHz.

$$H = \frac{110}{360}\lambda = 30.5\text{ mm} \tag{1}$$

2.2. CSRRs Dimension and Geometry

Since the triangles are symmetrical and equipotential with respect to the feeding point, the CSRRs must be also symmetric with respect to the feeding point to have the same potential on the entire radiation element. That allows a good band rejection.

The various dimensions of the CSRRs cells determined according to the following formula (2) are shown in **Figure 2**.

$$\frac{\lambda_g}{2} = \frac{c}{2 f_{notch}\sqrt{\varepsilon_{eff}}} = L_{\text{CSRR}} \tag{2}$$

In "Equation (2)", λ_g is the guided wavelength, c is speed of light in free space, ε_{eff} is the effective dielectric constant and f_{notch} represents the central frequency of the notched band.

$$L_{\text{CSRR}_1} = \frac{c}{2 f_{notch,1}\sqrt{\varepsilon_{eff}}} = 2(a_1 + b_1) - G_S = \frac{\lambda_{g,1}}{2} \tag{3}$$

$$L_{\text{CSRR}_2} = \frac{c}{2 f_{notch,2}\sqrt{\varepsilon_{eff}}} = 2(a_2 + b_2) - G_S = \frac{\lambda_{g,2}}{2} \tag{4}$$

$$L_{\text{CSRR}_3} = \frac{c}{2 f_{notch,3}\sqrt{\varepsilon_{eff}}} = 2(a_3 + b_3) - G_S = \frac{\lambda_{g,3}}{2} \tag{5}$$

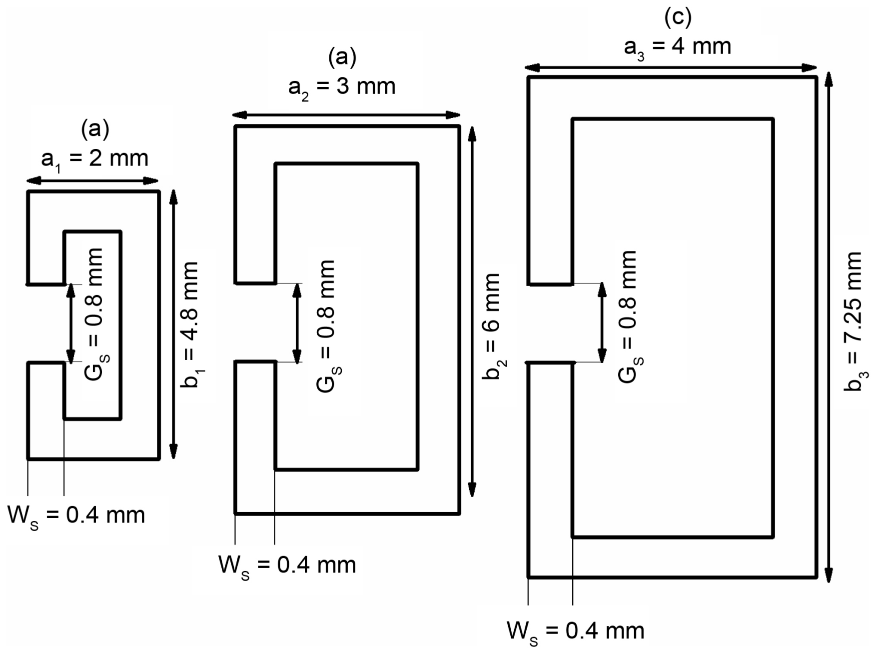

Figure 2. Geometry of CSRRs, (a): configuration for CSRR1 to notch 8.1 GHz band; (b): configuration for CSRR2 to notch 5.6 GHz band; (c): configuration for CSRR3 to notch 4.32 GHz band.

3. Result and Discussion

The bow-tie antenna (**Figure 1**) is designed with the optimized parameters values listed in **Table 1** such that it covers the entire FCC band from 3.1 GHz to 10.6 GHz. The simulation result of the proposed antenna is shown in **Figure 3**.

At first, study was made only with a CSRR1 in bow-tie antenna. Insertion on both sides of the dipole is made not only to ensure symmetry (equipotentiality) between the triangles but also to improve the level of the frequency band rejection [16]. In his description of bow-tie antenna, it is shown that the currents are concentrated mainly on the edges. This implies that if the CSRRs cells are close to the feed point, there will be a better coupling thus allowing for good rejection of the solicited band. It should be noted that as the CSRR1 is close to the feed point, the band rejection level is excellent (VWSR = 8 at 8.3 GHz). Furthermore, if the size (width) of the CSRR is increased, the band shifts towards lower frequency (8.1 GHz if a_1 = 2 mm). By a series of parametric study, the optimized value of the width and the position (P_1 = 3.2 mm) of the CSRR1 are determined. A good band rejection is obtained at 8.1 GHz. **Figure 4** & **Figure 5** shows the effect of the CSRR1 position and width on the simulated VSWR of the prototype.

In a subsequent step, CSRR1 and CSRR 2 with bow-tie antenna were studied. The two CSRRs are nested for two reasons: the first is that we want to put both near the feed point in order to have a good level of frequency band rejection on every two CSRRs cells; the second is that CSRR2 is greater than CSRR1

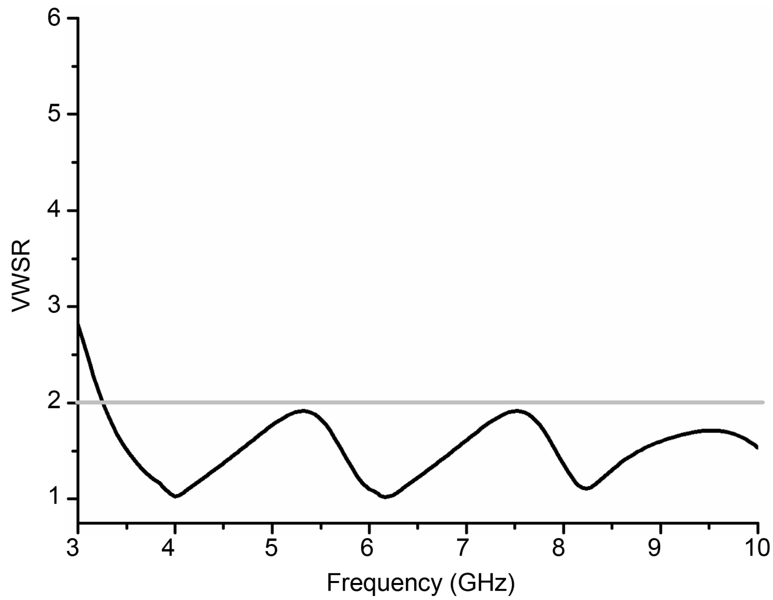

Figure 3. Simulated VWSR of antenna without CSRRs.

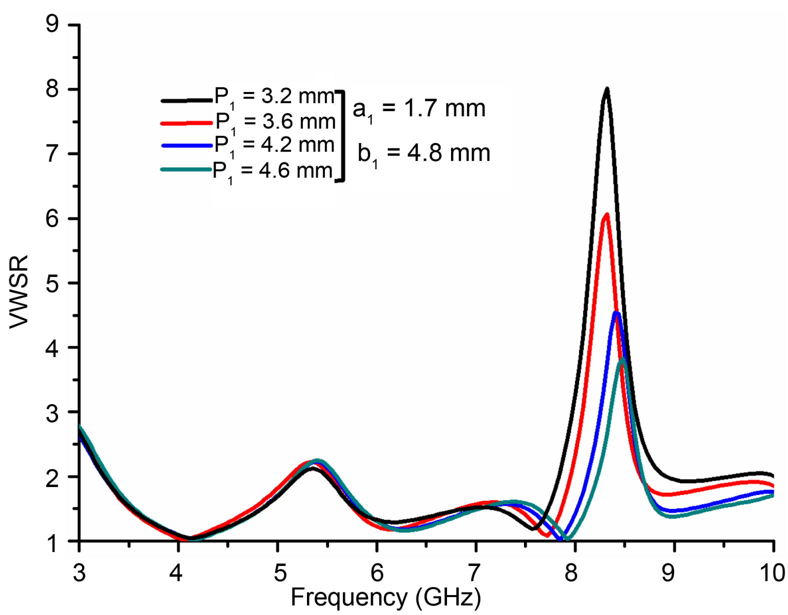

Figure 4. Simulated VWSR of the UWB bow-tie antenna with CSRR1: effect of CSRR position.

thus a cells nest allows us less clutter. A parametric study was made to investigate this effect on the influence of the positions of CSRR1 and CSRR2 (P_1 and P_2 respectively). It is observed (**Figure 6**) that the optimal positions of the CSRRs elements are P_1 = 4.1mm and P_2 = 3.6mm with virtually VWSR = 5.20 in both rejected bands centered at 8.1 GHz and 5.6 GHz.

Figure 7 & **Figure 8** shows respectively return loss S11, radiation efficiency and Peak Gain of bow-tie antenna with two CSRRs.

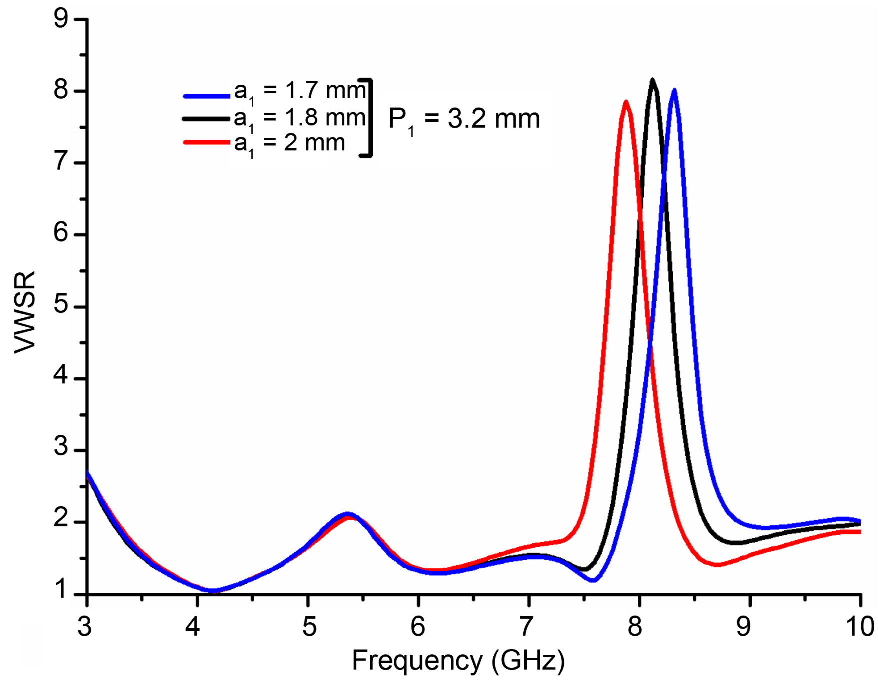

Figure 5. Simulated VWSR of the UWB bow-tie antenna with CSRR1: effect of CSRR size (width).

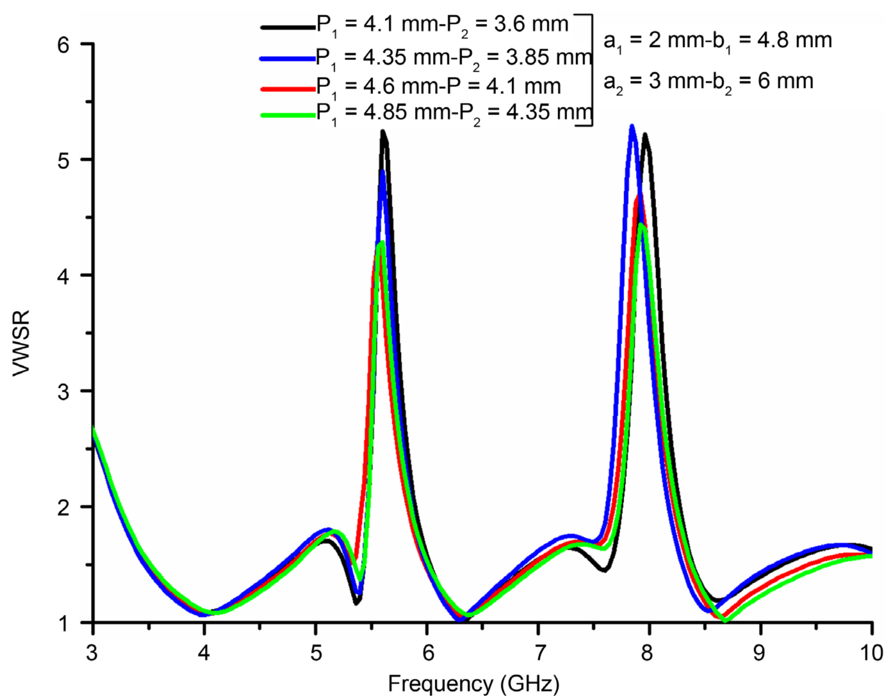

Figure 6. Simulated VWSR of the UWB bow-tie antenna with CSRR1 and 2: effect of CSRRs positions.

In a final step, CSRR1, 2 and 3 with bow-tie antenna was studied. For this step, the first two cells are remotely set by occupying positions P_1 = 4.6 mm-P_2 =

Table 1. Parameters of bow-tie antenna with and without CSRRs.

Antenna parameters	H	W	L	h	t
Values (mm)	30	100	58.30	0.750	0.035
CSRR1 parameters	a_1	b_1	G_S	W_S	L_{CSRR1}
Values (mm)	2	4.8	0.8	0.4	12.8
CSRR2 parameters	a_2	b_2	G_S	W_S	L_{CSRR2}
Values (mm)	3	6	0.8	0.4	17.2
CSRR3 parameters	a_3	b_3	G_S	W_S	L_{CSRR3}
Values (mm)	4	7.25	0.8	0.4	21.7

Where W is the width of the triangles, L is length and h is the thickness, $\alpha = 118^{\circ}$.

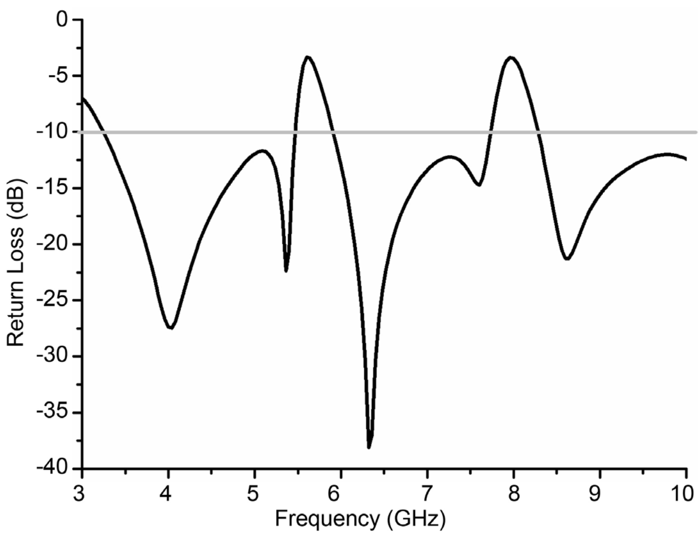

Figure 7. Simulated Return Loss of bow-tie antenna with two band notched characteristics: CSRRs optimized positions P_1 = 4.1 mm-P_2 = 3.6 mm.

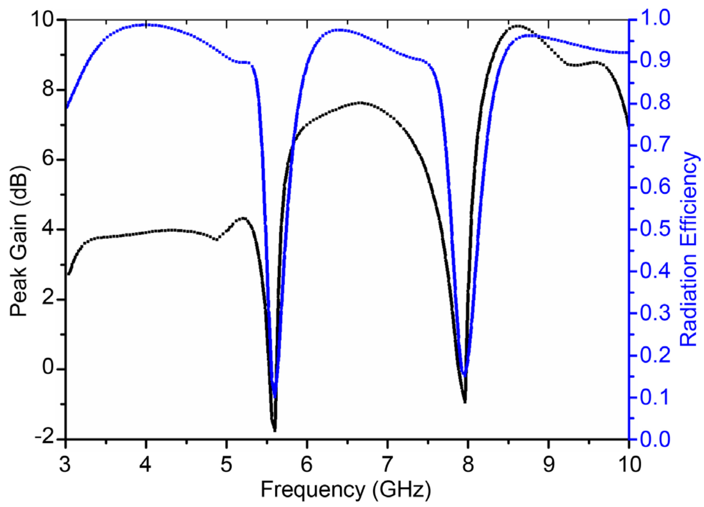

Figure 8. Simulated Peak Gain and radiation efficiency of bow-tie antenna with two band notched characteristics.

4.1 mm and leaving thus the third cell to P_3 = 3.6 mm position (shown in **Figure 1(b)**). Again, after a series of simulation and parametric studies, it is observed that this is the only position of the CSRRs where the bands rejection level is good.

Figure 9 and **Figure 10** show VSWR and S11 parameter of the proposed antenna after optimization of CSRRs positions. The simulated gain and efficiency shown in **Figure 11** also validate the triple band-notch behavior of the

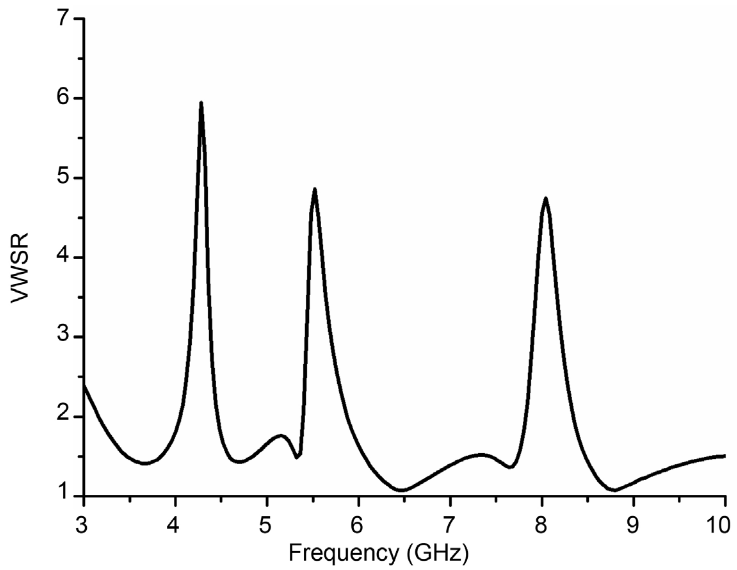

Figure 9. Simulated VWSR of bow-tie antenna with triple band notched characteristics: CSRRs optimized positions P_1 = 4.6 mm-P_2 = 4.1 mm-P_3 = 3.6 mm.

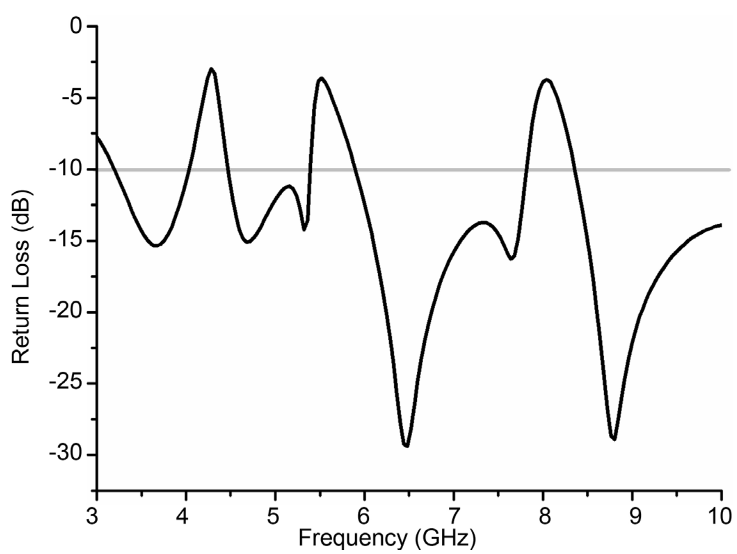

Figure 10. Simulated Return Loss of bow-tie antenna with triple band notched characteristics: CSRRs optimized positions P_1 = 4.6 mm-P_2 = 4.1 mm-P_3 = 3.6 mm.

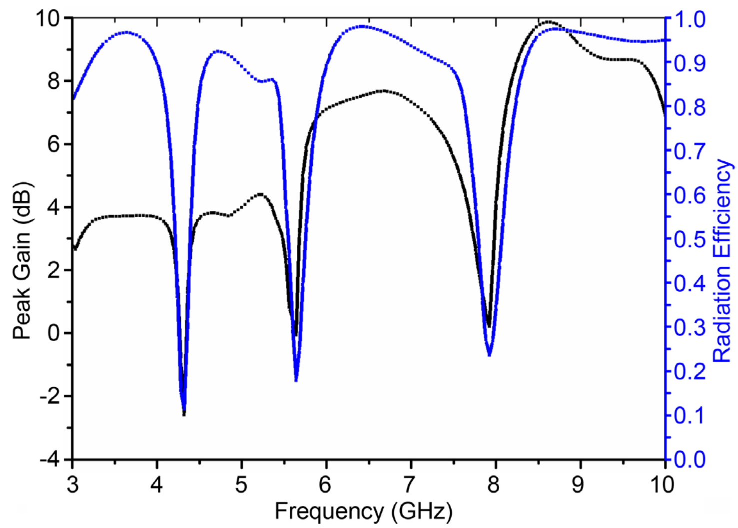

Figure 11. Simulated Peak Gain and radiation efficiency of bow-tie antenna with triple band notched characteristics.

proposed antenna. It is observed that for band-pass, the proposed antenna exhibits a nearly stable gain response.

4. Conclusion

In this letter, a compact triple band-notched UWB bow-tie antenna embedding Complementary Split Rings Resonators (CSRRs) in the antenna is presented. The proposed antenna has bandwidth covering the entire FCC range (3.1 - 10.6 GHz), along with the band notched characteristics in the IUT service band (8.025 - 8.4 GHz), in the WLAN system (5.15 - 5.85 GHz), and another band frequencies (4.10 - 4.47 GHz). The design and parametrical studies are described and validated via ANSYS EM simulations. VSWR, Return loss, Peak Gain, and Radiation efficiency triple-notch behavior of the proposed antenna. Stable antenna performance ensures that the proposed antenna can be utilized for various UWB applications with high immunity from electromagnetic interference.

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