URSI AP-RASC 2019, New Delhi, India, 09 - 15 March 2019

Realization of Sharp Triple Notch bands on Printed Ultra-Wideband Antenna using Slot and Circular SRR to eliminate WiMAX and WLAN Interferences

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Abstract

A triple band notched leaf shaped co-planar waveguide fed ultra-wideband antenna is proposed in this article. Prominent notch bands at 3.3–3.92, 5.1–5.4 and 5.68–6.02 GHz are realized by embedding slot on patch and adding dual circular split ring resonator pairs at the bottom of substrate, opposite to feed line. The antenna provides monopole like E-plane pattern and omnidirectional H-plane pattern with gain variation between 2-5 dBi and average radiation efficiency of 86% in its pass band of operation. The antenna gain and efficiency reduced significantly in the notch bands.

1. Introduction

Profound research interest in the printed ultra-wideband (UWB) antenna design process and performance evaluation can be traced among researchers to explore the wide range of uses and working capability of UWB antenna in its unlicensed band of 3.1-10.6 GHz [1]. Printed UWB antennas are usually capable to provide large bandwidth with high data rate and omni-directional coverage. Also stable gain response, compactness and light weight make printed UWB antennas a suitable solution for various wireless applications, ranging from consumer electronic items to radar, remote sensing and navigation. One essential GPR antenna design consideration is suitable frequency stop band creation in the unlicensed band to avoid possible interference from co-existing wireless applications such as IEEE 802.16 WiMAX, and IEEE 802.11a WLAN. Implementation of frequency notch in the antenna geometry is key design challenge. Embedding slots on the radiating patch, feed line and ground plane of printed UWB antenna [2-5] were widely adopted in literature because of design simplicity and easy fabrication but it affects the antenna efficiency, gain and H-plane patterns [18]. Various slot shapes were considered earlier such as Arc [2], U [3], V [4], C [5] etc. All these slot methods are capable to provide only single notch band mainly to eliminate the 5-GHz WLAN with improper tuning of notch frequency that results loss of valuable spectrum due to wide frequency stop band. Frequency notch realization by embedding different resonators such as split ring resonator (SRR), open loop resonator and CPW resonator were also proposed in literature [6-9]. S. J. Wu et al. proposed a fork shaped planar monopole with open looped resonator to realize frequency notch around 5 GHz [6]. In [7], a notch band from 4.5 to 5.38 GHz was reported in the impedance band of 3–10.28 GHz by using microstrip open loop resonator that was fabricated at the bottom of substrate. J. Y. Siddiqui et al. proposed a circular disk monopole antenna of dimension 50×50×1.575 mm^3 that can provide an impedance band from 2.6 to 10.8 GHz with notch centre frequency at 6.39 GHz [8]. The frequency notch was created by loading split ring resonator (SRR) at the back end of feed line. The antenna gain response varies between 0–4 dBi in the pass band of operation. All these reported work [6–8] succeed to possess single notch band. In a similar kind of extended work of [8], dual notch bands centered at 5.39 and 7.95 GHz were created by adding dual SRR pairs [9]. Multi-band notched antenna design is comparatively difficult due to the strong coupling between similar notch generation structures. In [10], triple notch bands of 2.95–3.72 GHz, 5.12–6.07 GHz and 8.04–8.65 GHz were realized by etching out two elliptical single complementary split-ring resonators (ESCSRR) of different dimensions from the antenna patch and inserting two rectangular SRRs near the feed to patch connection. The design flaw of this work is improperly tuned notch bands that results spectrum losses.

A leaf shaped ultra-wideband antenna with sharp triple notch bands to eliminate WiMAX (3.3-3.7 GHz), and WLAN (5.15-5.35 GHz and 5.725-5.825 GHz) interferences is proposed in this article. The notch bands are realized by embedding slot on patch and loading dual circular split ring resonator (CSRR) pairs at the bottom of substrate, opposite to the feed line.

2. Antenna Design

As shown the antenna geometry in Fig. 1, the radiating patch is formed by joining two circular disks and an elliptical disk. Radius of both the circles differs by the value of substrate thickness whereas the major axis radius of ellipse is equal to the radius of the bigger circle. Effective patch size is increased in the leaf shaped radiator compared to the conventional circular disk monopole without hampering the design simplicity. Co-planar ground plane is also bended to realize multiple resonances at higher frequency resulting in broadening of the antenna impedance bandwidth. Inspired from [11], two transitions are introduced in the feed line to get better impedance matching of the antenna. Triple notch bands are generated on leaf shaped printed monopole by etching out rectangular split ring shaped slot on radiating patch and adding dual CSRR pairs at the bottom of substrate, opposite to feed line. The rectangular split ring shaped strip is etched out at the lower end of patch to introduce WIMAX band rejection. The dimension of slot can be obtained from equation 1,

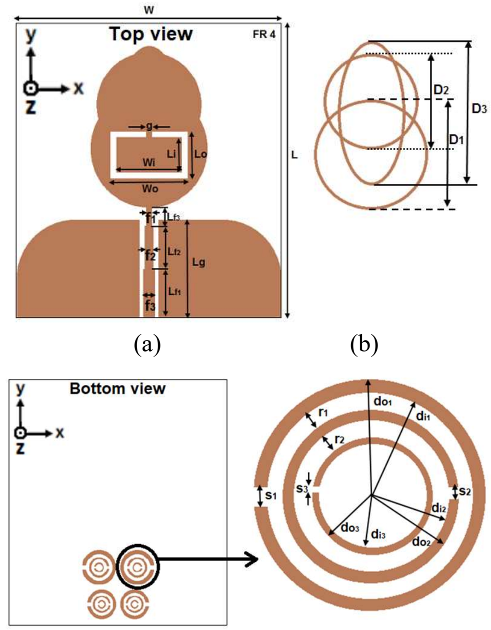
$$f_{notch} = \frac{c}{4[L_o+W_o-(L_o-L_i+2g)]\sqrt{\varepsilon_{eff}}} \qquad (1)$$

Here $\varepsilon_{eff} = \frac{\varepsilon_r+1}{2}$ and ε_r represents relative permittivity of the substrate material that is chosen as 4.4. L_o and W_o represent the outer length and width of the slot respectively. L_i indicates the inner length of the slot, g represents the split gap as shown in Fig. 1 (a) and c represents speed of light. The frequency notch band can be controlled by varying the dimensions of slot. As shown in Fig. 1 (c), two CSRR pairs are incorporated at the bottom of the substrate, opposite to the feed line to generate notches in the WLAN bands and IEEE 802.11p DSRC band (5.85–5.925 GHz). Upper and bigger SRR pair is used to generate notch in the 5.15–5.35 GHz band centered at 5.25 GHz. Lower and smaller SRR pair is used to generate notch in the 5.725–5.925 GHz band centered at 5.825 GHz. Robust resonances can be formed with such SRR pairs in the parallel polarization. Fig. 1 (d) illustrates the geometry of the circular SRR. The CSRR consists of three circular split rings, in which the outer and inner are co-directional. Three layered resonator structure is introduced to generate sharp notches that can avoid the losses of valuable spectrum. This effective resonator structure can deliver better Q operation where Q is the quality factor and defined as the ratio of notch center frequency to the notch bandwidth. Dimension of the SRR can be calculated from the equation (2) as mentioned below.

$$f_{notch} = \frac{c\sqrt{3r/d}}{2\pi^2 d(\sqrt{\varepsilon_{eff}}+s)} \qquad (2)$$

Here $r = \frac{r_1+r_2}{2}$ where r_1 and r_2 represents spacing between rings as shown in Fig. 1.d. Also in this equation, $\varepsilon_{eff} = \frac{\varepsilon_r+1}{2}$, $s = \frac{s_1+s_2+s_3}{3}$ and $d = \frac{d_1+d_2}{2}$ where, $d_1 = \frac{d_{i1}+d_{o2}}{2}$; $d_2 = \frac{d_{i2}+d_{o3}}{2}$.

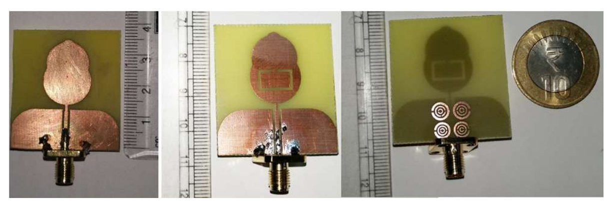
The proposed triple notched antenna is simulated and optimized in CST-MWS simulator [12]. Optimal dimensions of antenna and SRR are listed in Table 1 and 2 respectively. As shown in Fig. 2, the proposed antenna is fabricated on cheap and easily available FR4 substrate that has relative permittivity of 4.4, loss tangent of 0.02 and thickness of 0.8 mm.



(a) (b)

(c) (d)

Figure 1. Schematic of triple notched leaf shaped antenna. (a) Top view (b) construction of patch using two circular and one elliptical disks (c) Bottom view (d) dimension of the SRR.



(a) (b) (c)

Figure 2. Fabricated prototypes of the (a) reference leaf shaped antenna (b) triple notched antenna (front view) (c) triple-notched antenna with dual circular SRR pairs (back view).

Table 1. Optimal dimensions of triple notched antenna.

Value (Val.) of all parameters (Param.) are in mm					
Param.	Val.	Param.	Val.	Param.	Val.
L	38.3	g	0.8	L_{f1}	6.38
W	34.5	L_i	4.6	L_{f2}	5.58
H	0.8	W_i	8.6	L_{f3}	2.32
Lg	12.8	D_1	15.32	f_3	1.6
L_o	6	D_2	13.72	f_2	1.2
W_o	10	D_3	15.32	f_1	0.8

Table 2. Dimensions of the bigger and smaller SRR.

Param.	Value for SRR (mm)		Param.	Value for SRR (mm)	
	Bigger	Smaller		Bigger	Smaller
d_{o1}	2.71	2.32	s_1	0.54	0.43
d_{i1}	2.03	1.74	s_2	0.326	0.26
d_{o2}	1.62	1.38	s_3	0.226	0.18
d_{i2}	1.22	1.04	r_1	0.41	0.36
d_{o3}	0.79	0.68	r_2	0.43	0.36
d_{i3}	0.47	0.40			

3. Results and Discussion

Simulated and measured VSWR of the reference leaf shaped antenna and proposed triple notch antenna are plotted in Fig. 3. The reference leaf shaped antenna [13] has an impedance band from 2.8 to more than 12 GHz. The addition of slot and circular SRR in the proposed antenna generate three notch bands at 3.3–3.92, 5.1–5.4 and 5.68–6.02 GHz with the center frequencies at 3.7, 5.24 and 5.85 GHz respectively in a wide bandwidth from 2.6 to 10.58 GHz, covering the unlicensed UWB band of 3.1–10.6 GHz.

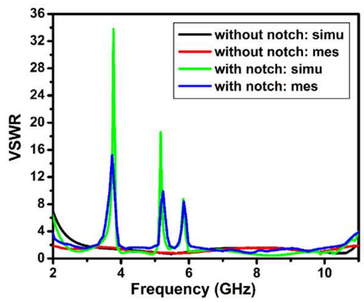
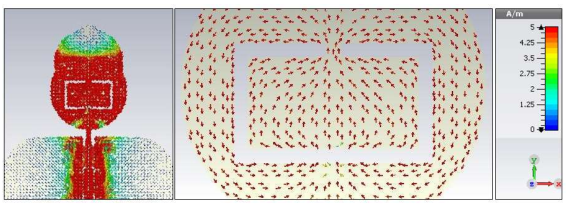
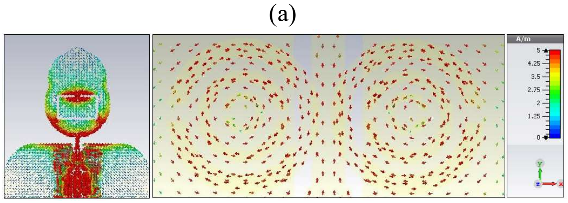


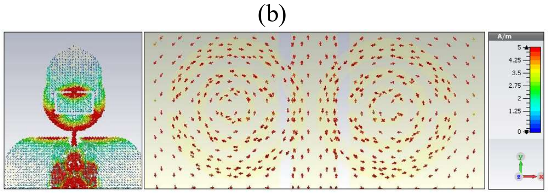
Figure 3. Comparison of the VSWR between the reference antenna and the triple notched antenna



(a)



(b)

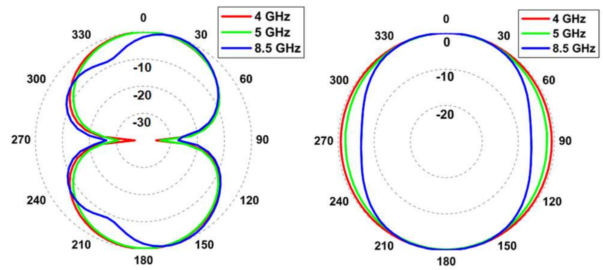


(c)

Figure 4. Simulated surface current distribution on the antenna at (a) 3.7 GHz (b) 5.24 GHz and (c) 5.85 GHz

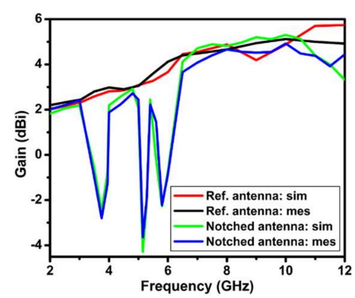
Simulated surface current distribution on the antenna surface and notch structures at three notch center frequencies are shown in Fig. 4. As can be seen from Fig. 4 (a), dense current concentration at antenna radiating patch around slot and feed indicates strong notch resonance. Also the opposite directional current flow inside and outside the slot can be observed. The opposite directional current flow makes the net current zero and results strong frequency notch. As shown in Fig. 4 (b) and (c), high current concentrates around respective resonator structure and negligible current flows on patch surface at notch center frequency of 5.24 and 5.85 GHz respectively. Clockwise and counter-clockwise current flow inside the circular layer of resonators result nullification of net current and thus create strong frequency rejection.

As can be seen in Fig. 5, co-polarized radiation pattern of the antenna are measured at three distinct frequencies of 4, 5 and 8.5 GHz in the pass band of operation. It can be seen that the antenna provides monopole like E-plane pattern and omnidirectional H-plane pattern at all three frequencies. Radiation patterns of the proposed antenna differ little bit from the usual monopole like pattern at higher frequency (8.5 GHz).

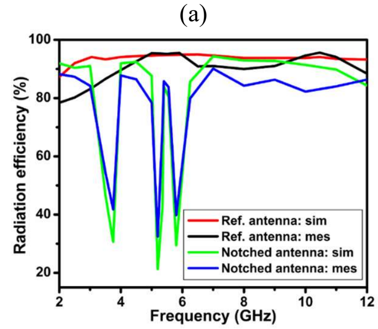


(a) (b)

Figure 5. Measured radiation pattern of the antenna at (a) E-plane and (b) H-plane at different frequencies.



(a)



(b)

Figure 6. Simulated and measured results of (a) gain and (b) radiation efficiency for the antenna with and without notches.

The simulated and measured gain of reference leaf shaped antenna and triple notched antenna are plotted in Fig. 6 (a).

Reference antenna gain varies between 2.5-5 dBi in its operational bandwidth. Triple notch antenna gain follows the reference antenna gain in its pass bandwidth whereas significant drop in the gain value can be observed in the frequency stop band. Radiation efficiency of the reference and proposed antenna are shown in Fig. 6 (b). Reference antenna provides an efficiency of 90% whereas for the notched antenna the radiation efficiency varies around an average value of 86%. The efficiency measurement was conducted following the modified wheeler's cap method as stated in [14].

4. Conclusion

The proposed printed antenna with rectangular split ring shaped slot on the leaf shaped patch and couple of circular split ring resonators at the bottom of substrate, opposite to the feed line is capable to cover unlicensed UWB of 3.1-10.6 GHz with very sharp triple frequency notches to eliminate WiMAX and WLAN interferences. The generation of sharp notch bands is crucial achievement to utilize the valuable spectrum efficiently. The antenna performance is evaluated by simulation and experimental measurements. Proper agreement is observed between the simulated and measured results. The proposed antenna is capable to work for short range, high speed wireless UWB communication applications without interfering to the co-existing applications.

5. Acknowledgements

The author is thankful to National Institute of Technology Sikkim for providing all necessary research facilities.

6. References

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