Compact UWB Antenna with Controllable Band Notches Based On Co-directional CSRR

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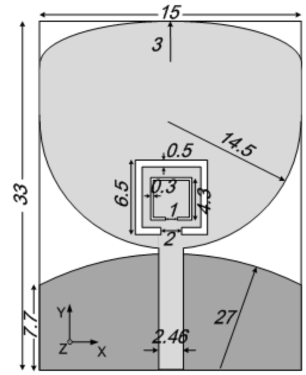
***Abstract-* In this paper, compact ultra-wideband (UWB) antenna with controllable notched bands is proposed for UWB communication applications. The antenna utilizes co-directional complementary split ring resonator (CSRR) to achieve dual suitable notched bands in small enough size. The center frequencies of the notched bands can be electronically tuned by changing the effective electrical length of the CSRR, which is achieved by employing varactor diodes. The proposed antenna can also achieve reconfigurable notched bands by replacing the varactor diodes with two electronic switches. The total antenna dimensions are only 25 × 33 mm^2 and shows good environmental adaptation, which makes it a good candidate for UWB applications.**

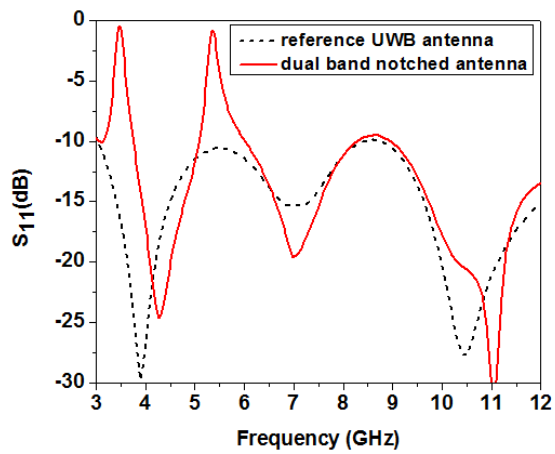
I. INTRODUCTION

In recent years, ultra-wideband (UWB) technology has become a very promising wireless technology because of the attractive benefits it provides, such as low power consumption, high data transmission rates, resistant to severe multipath and jamming, etc.[1]. The high demands on such communication systems have stimulated research into UWB antenna designs. A UWB antenna should be capable of operating over a frequency band from 3.1 to 10.6 GHz, the commercial usage for UWB radio system approved by the Federal Communications Commission (FCC), and exhibit stable radiation patterns in the entire bandwidth. In addition, it needs to have a compact size and low manufacturing cost for consumer electronics applications. Most importantly, the antenna should overcome electromagnetic interference (EMI) problems. The EMI problems are quite serious since there exist several other wireless narrowband standards within UWB bandwidth, such as IEEE 802.16 world interoperability for microwave access (WiMAX) system from 3.3 to 3.6 GHz, and IEEE 802.11a wireless local area network (WLAN) in the frequency band of 5.15-5.825 GHz.

Lately, lots of antennas with band-notched characteristic have been discussed. The commonly used methods are embedding slots on the patch or on the ground plane and adding parasitic elements, as reported in [2]-[5]. However, these antennas still have some shortcomings in practical applications. The conventional method to implement multi-notched function is loading notch elements of different types, different numbers at different spaces, thus it requires too much space and results in complicated design. Moreover, once the antenna is fabricated, the notched bands are also fixed.



(a)

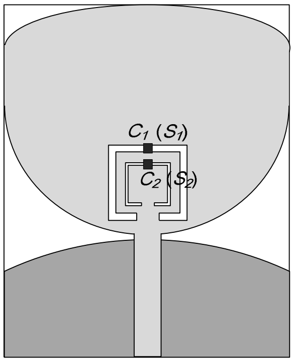


(b)

Figure 1. Dual band-notched UWB antenna. (a) Geometry with dimensions. (b) Simulated return loss.

However, the existing undesired narrowband radio signals vary from place to place and from time to time. Therefore, multiple band notches with frequency controllable capabilities in a compact antenna size are highly required.

In this paper, a compact UWB antenna with controllable notch band capability is presented. The antenna utilizes co-directional complementary split ring resonator (CSRR) to achieve dual suitable notched bands in small enough size. To achieve band notch controllability, varactor diodes and electronic switches are mounted across the slots, thus helping in the adaptation against environmental changes and increasing the antenna performance.



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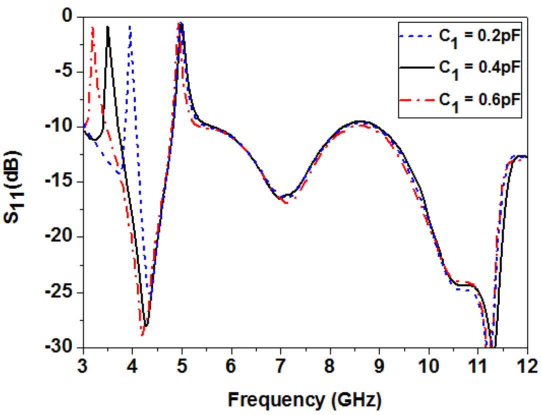

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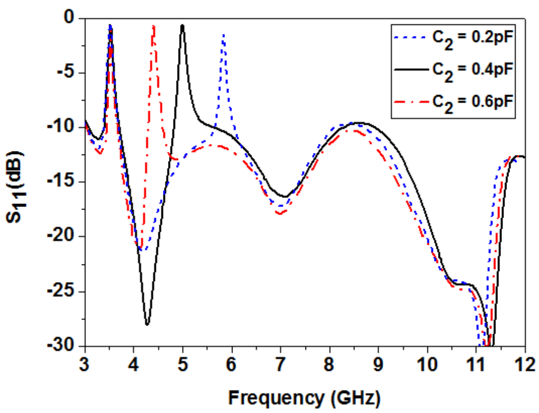

(c)

Figure 2. (a) Geometry of the UWB antenna with controllable band notches. (b) Effect of varactor diodes capacitance C1 and (c) C2 on return loss.

II. Antenna Configuration and Design

A. *Compact UWB Antenna with Dual Band Notches*

Fig. 1(a) shows the geometry and dimensions of the proposed compact dual band-notched UWB antenna. The antenna is designed on a 1.5 mm-thick substrate with permittivity constant $\varepsilon_r = 2.65$, loss tangent of 0.0015, and the overall size is 25×33 mm^2. Both the radiating monopole and the ground plane have rounded edges to broaden the bandwidth and to produce smooth transitions from one resonant mode to another. This characteristic helps to achieve

TABLE I
DIFFERENT SWITCHING CASES AND CORRESPONDING NOTCHED BANDS

Case	Notched bands (GHz)	S1	S2
1	None (UWB operation)	ON	ON
2	5.26	ON	OFF
3	3.4	OFF	ON
4	3.5 , 5.26	OFF	OFF

miniaturization and ensures a good impedance match over the entire UWB frequency range.

To generate band notches, co-directional complementary split ring resonator (CSRR) are etched on the patch. Originally proposed by Pendry [6], SRR is an electrically small resonator with a very high quality factor. When applying a time varying external magnetic field along the axis of the ring, SRR exhibits a strong magnetic response and restrain signal propagation in a narrow band in the vicinity of the resonant frequency. Analogously, the corresponding CSRR structure has the similar characteristic. Compared to traditional CSRR, co-directional CSRR can exhibit dual distinct fundamental magnetic resonance frequencies for each ring due to the weaker mutual coupling between inner and outer rings, thus it is utilized here to achieve dual band-notches. The co-directional CSRR is arranged close to feedline with the gap opposite to y-axis. The sizes are optimized so that the outer split-ring generates a notch at 3.5 GHz and the inner one at 5.2 GHz. Fig. 1(b) exhibits the simulated return loss of the proposed dual band notched antenna, while the return loss of the original UWB antenna without any slots is also shown as a reference. As can be seen, the antenna provides a wide impendence bandwidth of 3 - 12 GHz with dual effective notched bands of 3.2-3.7 GHz and 5.1-5.93 GHz respectively, covering WiMax and WLAN successfully.

B. *Controllable Band Notches Design*

Since the interference signals vary with environmental changes, it is more desirable to introduce tunable notched bands within operating band of the antenna. As shown in Fig. 2(a), two varactor diodes C1 and C2 are mounted across the co-directional CSRR to achieve this function. Each CSRR can be considered as a LC resonator and its effective capacitance varies by changing the capacitance of the varactor diode, thus producing tunable notched bands. A parametric analysis for the effect of tuning varactor diodes on the resonance frequencies is shown in Fig. 2 (b)(c), where several specific capacitance values are chosen to simulate the varactor diodes' changing process. As the capacitance of C1 increases from 0.2 pF to 0.6 pF, the central frequency of the lower notch varies from 3.9 to 3.2 GHz and almost has little effect on the central frequency of the higher notch. A same situation happens when we tune the capacitance of C2. By varying it from 0.2 pF to 0.6 pF, the higher notch changes from 5.8 GHz to 4.4 GHz. From Fig. 2, it is observed that the increase of capacitance results in the decrease of notch frequency and each notched band can be controlled independently.

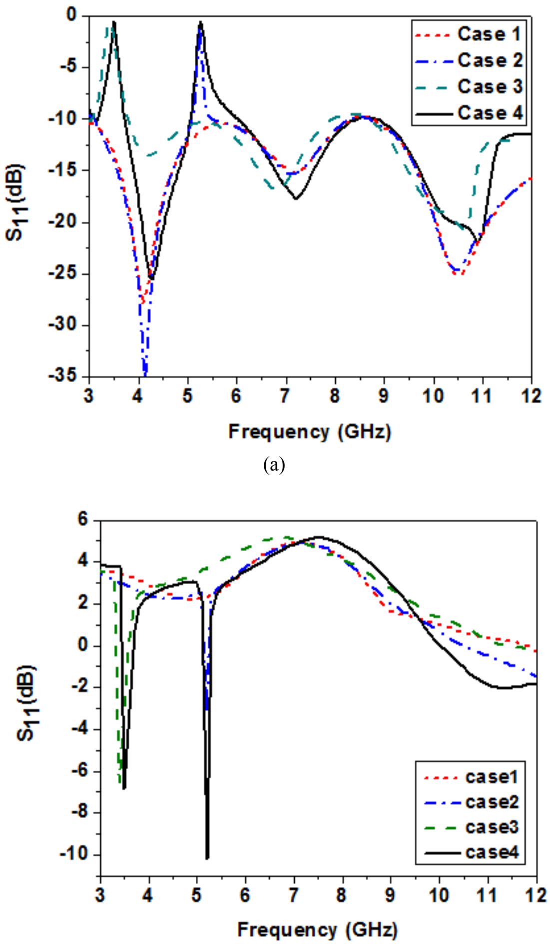

Figure 3. Simulated (a) return loss and (b) gains for different switching cases.

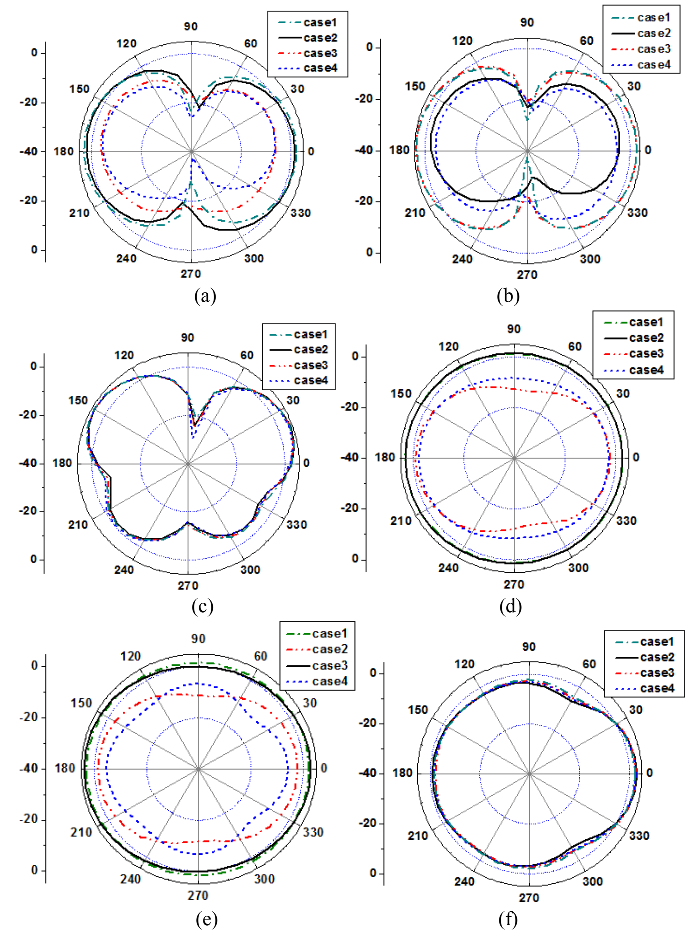

Figure 4. Simulated radiation patterns (a) E plane at 3.5 GHz (b) E plane at 5.2 GHz (c) E plane at 8 GHz, (d) H plane at 3.5 GHz (e) H plane at 5.2 GHz (f) H plane at 8 GHz.

For the uncertainty of interference, sometimes there might exist only one or no interference signal, thus it is necessary for a UWB antenna to have reconfigurable notched bands. To achieve reconfigurability, the varactor diodes in Fig. 2(a) were replaced by two electronic switches S1 and S2, the state of which determines whether or not a notched band is induced. When the switch is OFF, the corresponding slot behaves as a single-ring CSRR, causing a notch in its resonant band. While closing the switch (ON) shorts the slot and effectively eliminates the resonance, consequently the notched band disappears. When S1 is OFF, the outer CSRR resonates, thus inducing a notch in the 3.5 GHz band. This notch disappears when S1 is ON. For the inner CSRR, a notch in the 5.2 GHz band appears when S2 is OFF, and disappears when it is ON. The different switching cases lead to different band notch combinations which include one, two band notches, or no notch at all. Different switching cases listed in Table I are simulated, and the return loss plots of these cases are illustrated in Fig. 3(a). For case 1, both switches are ON, which is needed when there exists no interference. In this case, none of the slots resonates, resulting in a UWB response with no notches in the operating band of the antenna. In case 2 and 3, only one switch is ON, producing a single notched band at 5.26 GHz and 3.4 GHz respectively. With both switches OFF in case 4, the co-directional CSRR resonates normally and dual band notches are obtained.

Fig. 4 shows the simulated radiation patterns for the reconfigurable band-notched antenna in different cases at 3.5 GHz, 5.2 GHz and 9 GHz, respectively. It is seen that the state of the switches does not affect the radiation performance of the antennas in working frequencies [Fig. 4(c) and (f)]. However, within the notched band in each case, the radiated intensity degrades. This degradation in the band-notch range is also verified from the gain simulation shown in Fig. 3(b).

III. Conclusion

In this paper, a compact UWB antenna with controllable band notches is proposed. Simulations show that the antenna can achieve dual independently band notches which are induced by co-directional CSRRs, and controlled by varactor diodes and electronic switches mounted across the CSRRs. The antenna shows good environmental adaptation and can be a good candidate for practical applications. Fabrication and further measurements are ongoing.

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