A Compact Ultra-Wideband Band-Notched Monopole Microstrip Antenna with Modified Complementary Split Ring Resonator

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Abstract **─** A simple and compact microstrip ultra-wideband printed monopole antenna with filtering characteristic is presented. The proposed antenna comprises of a wave ground structure and a swallow radiating patch with co-directional modified pentagon complementary split-ring resonators, which are notched by altering three parameters, respectively. By using a modified wave ground structure, impedance matching characteristic that involves operating frequency band of C-band satellite communication systems and WLAN is obtained. The designed antenna has a compact size of 25×27.9 mm^2 and provides the impedance bandwidth of more than 137% from 2.2 GHz to 11.8 GHz, with notch frequency band at 3.59-4.255 GHz, 5.12-5.41 GHz and 5.69-6.03 GHz. The antenna demonstrates omni-directional and stable radiation patterns across all the relevant bands. Moreover, a prototype of the proposed antenna is fabricated and the measured results are shown to be in good agreement with the simulated results.

Index Terms **─** Multiband, notch bands, printed slot antenna, Ultra-Wideband (UWB).

I. INTRODUCTION

With development of Ultra-Wideband (UWB) technology, there is an increasing demand for small low-cost antennas with omni-directional radiation patterns and wide bandwidth [1]. Printed monopole antennas have received great attention in UWB applications due to their advantages of light weight, low cost, low profile, simple structure, wide impedance bandwidth, easy fabrication, and easy integration with other microstrip circuits [2]. With respect to frequency band defined by the Federal Communications Commission (FCC) for UWB applications, which is from 3.1 GHz to 10.6 GHz, several printed monopole antennas with different geometries have been reported recently [3]. However, due to interference from other services, it is often desirable to block out narrow frequency bands from the UWB spectrum. It is desired to design antenna that provides both the wide frequency range and narrow band notch, which should be tunable within a certain range, such as Dedicated Short-Range Communication (DSRC) systems for IEEE 802.11p operating in the 5.850-5.925 GHz band and WLAN operating in 5.15-5.35 GHz and 5.725-5.825 GHz. In order to reduce such frequency interferences, the UWB antennas with band-notched characteristics can be utilized [4-5].

Here, we present a compact printed antenna with co-directional pentagon Complementary Split-Ring Resonators (CSRR), which has a UWB operating bandwidth with a controllable triple-notched frequency at 3.9 GHz, 5.2 GHz and 5.9 GHz. Band-notched operation is achieved by embedding co-directional modified CSRR slots on radiating patch. The CSRR is currently under investigation by researchers to implement left-hand materials; the co-directional modified CSRR is promising for UWB antennas to ensure multiple notched bands. If the length of the CSRR is roughly the same as the half wavelength of the corresponding central band-notched frequency, the current is restricted around the CSRR resulting in the antenna not radiating, which is due to band-notched. In order to attain three bands, three co-directional pentagon CSRR are embedded into the radiating patch in the antenna.

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This can be expressed as [6]:

$$L = \frac{C}{2 f_{notch} \sqrt{\varepsilon_r}},$$

f is the central frequency of the notched band, C represents the free-space light speed, ε_r is the effective dielectric constant.

Depending on the design rules of CSRR, both triple-band-notched characteristics and compact size are achieved. The antenna has several promising features, including good impedance matching performance over the whole operating frequency band, stable radiation patterns and flexible frequency notched function.

II. ANTENNA DESIGN

Figure 1 illustrates the geometry of the synthesized UWB microstrip-fed co-directional pentagon complementary split-ring resonators slotted patch antenna. It is evolved from a swallow patch. This patch as a radiator was etched on the top portion of one side of a Rogers5880 substrate with initial dimensions of 25 (W) × 27.9 (L) mm^2, which is in general approaching the size of a portable USB device [7-8]. For improving the matching condition and then effectively extending the impedance bandwidth, the wave ground plane with a wave-like shape edge was printed on the other side of the substrate [9]. The specified characteristics of this substrate are 0.508 mm in thickness and 2.2 in relative permittivity (ε_r). The swallow patch with dimensions of 25 (W) × 14.95 ($L/2$) mm^2 was used to evolve th is design. A 50 Ω -microstrip line of width 1.5 mm and length 10.8 mm, was subsequently adopted for feeding the patch [10]. Satisfactory performance of multiple band-notched characteristic is simply accomplished by embedding common direction pentagon complementary split ring resonators to the swallow patch. These optimization works were conducted by using commercial 3-D electromagnetic software High Frequency Structure Simulator [11-13].

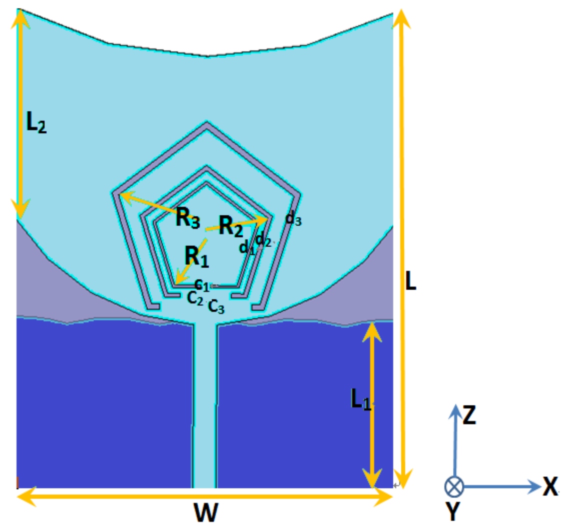
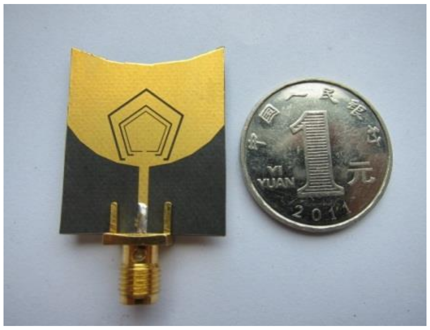


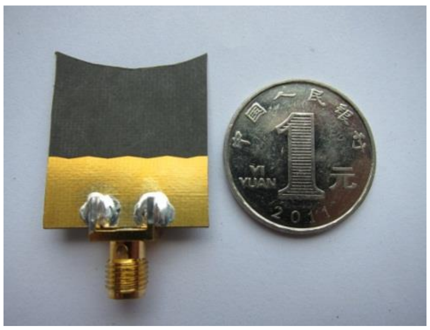
Fig. 1. Geometry of antenna, with dimensions: R_1=4.01 mm, R_2=4.90 mm, R_3=6.98 mm, C_1=0.6 mm, C_2=3.35 mm, C_3=6 mm, d_1=0.2 mm, d_2=0.32 mm, d_3=0.45 mm, W=25 mm, L=27.9 mm, L_1=10.78 mm and L_2=12.89 mm.

III. RESULTS AND DISCUSSION

To demonstrate the above discussed design strategy, an antenna prototype is designed and fabricated, as shown in Fig. 2. For comparison, both the measured and simulated VSWR characteristics of the proposed antenna are illustrated in Fig. 3. Excellent agreement has been observed for band notch character, especially the two notches at the lower frequency. The discrepancy notch between the measured and simulated results at high frequency is probably owing to the fabrication tolerance of the prototype. From software simulation, we also know that the performances of the antenna are equally sensitive to the thickness of the substrate. In the simulation, we set the metal to an ideal conductor, so we ignore the thickness of the metal [14]. The fabricated antenna has the frequency range from 2.2 to 11.8 GHz with VSWR< 2.0, covering the entire UWB band with three notched bands of 3.59-4.255 GHz, 5.12-5.41 GHz and 5.69-6.03 GHz, respectively.



(a)



(b)

Fig. 2. Photograph of the proposed antenna: (a) front view and (b) bottom view.

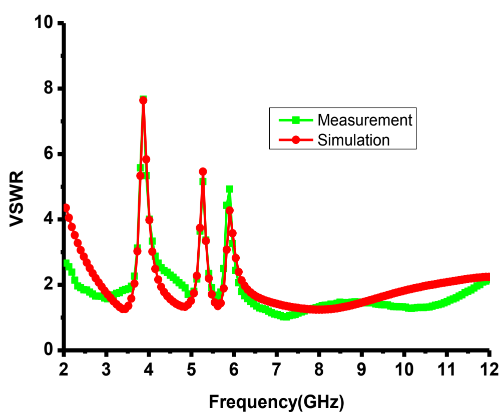
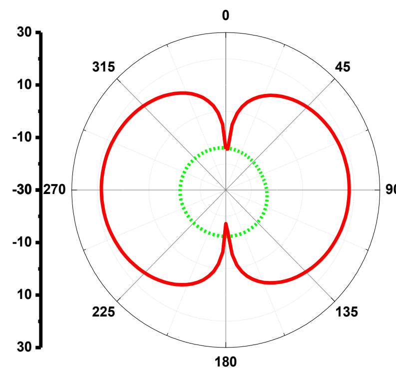
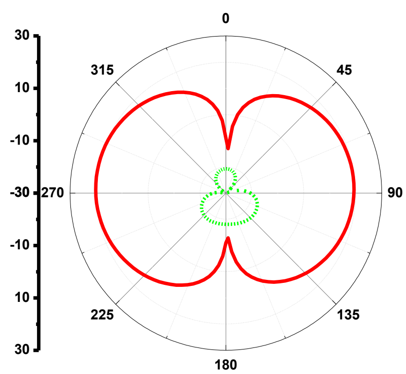


Fig. 3. Comparison of simulated and measured VSWR of the proposed antenna.

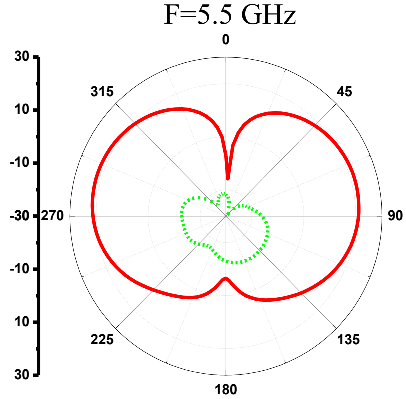
The simulated and measured 2-D far-field radiation characteristics at 3.5 GHz, 5.5 GHz and 7.5 GHz, are given in Figs. 4 and 5, respectively. Nearly omni-directional radiation patterns in the xy-plane and dipole-like radiation patterns in the yz-plane are achieved at these frequencies [15]. By comparing with simulated and measured radiation patterns, the results show slight deterioration in co-polarization and cross-polarization electric field. To some extent, this is because of the measurement environment; especially, the SMA feeding connector may cause interference to radiation field during the test. Due to the limitations of laboratory's instruments, the radiation patterns above 12 GHz were not measured. All the obtained radiation patterns accord with those of the conventional printed UWB monopole antennas. The proposed antenna has turned out to be capable of providing favorable spatial-independent band-notched characteristics.



F=3.5 GHz



F=5.5 GHz



F=7.5 GHz

(a)

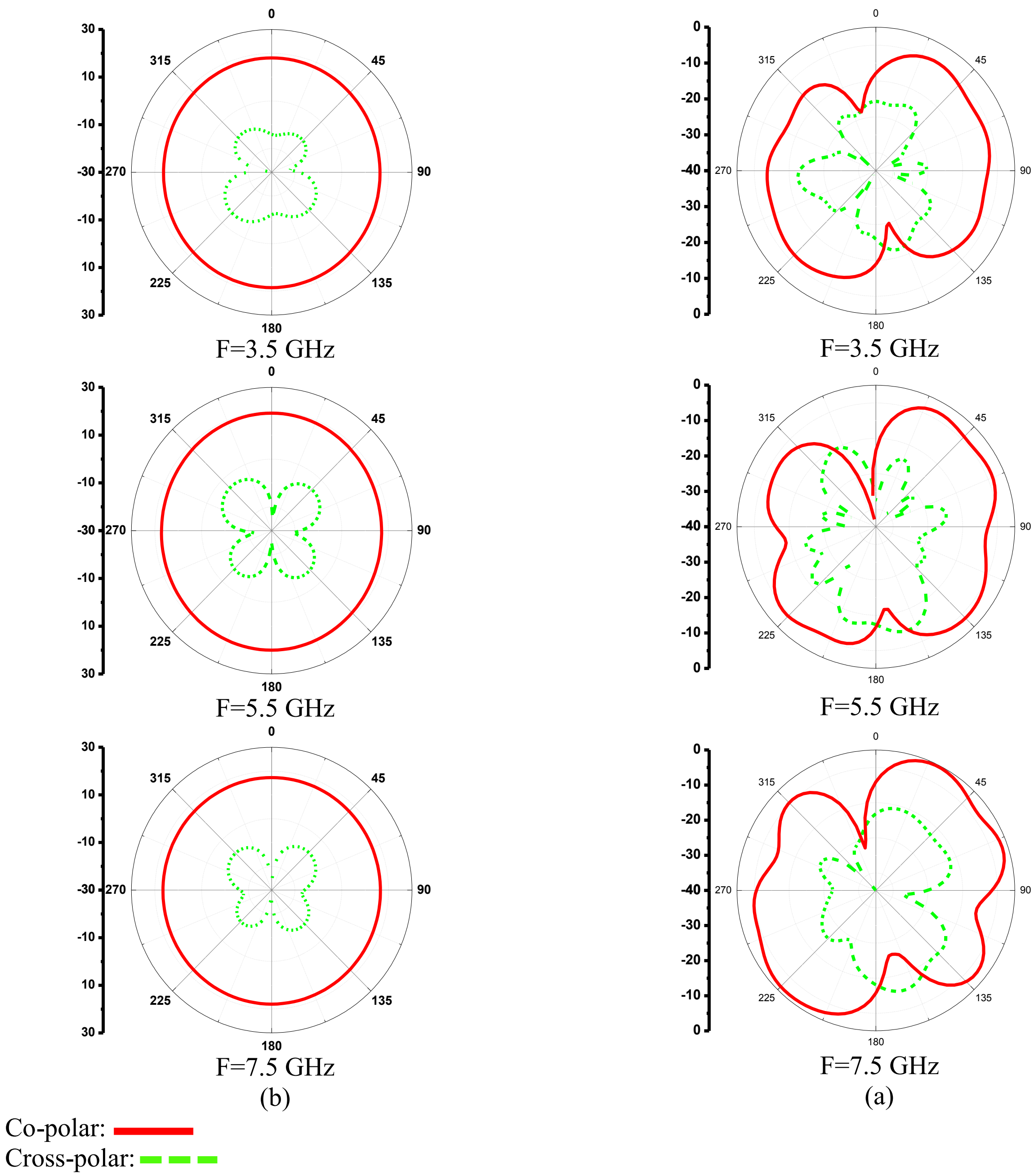


Fig. 4. Simulated radiation patterns in: (a) yz-plane and (b) xy-plane.

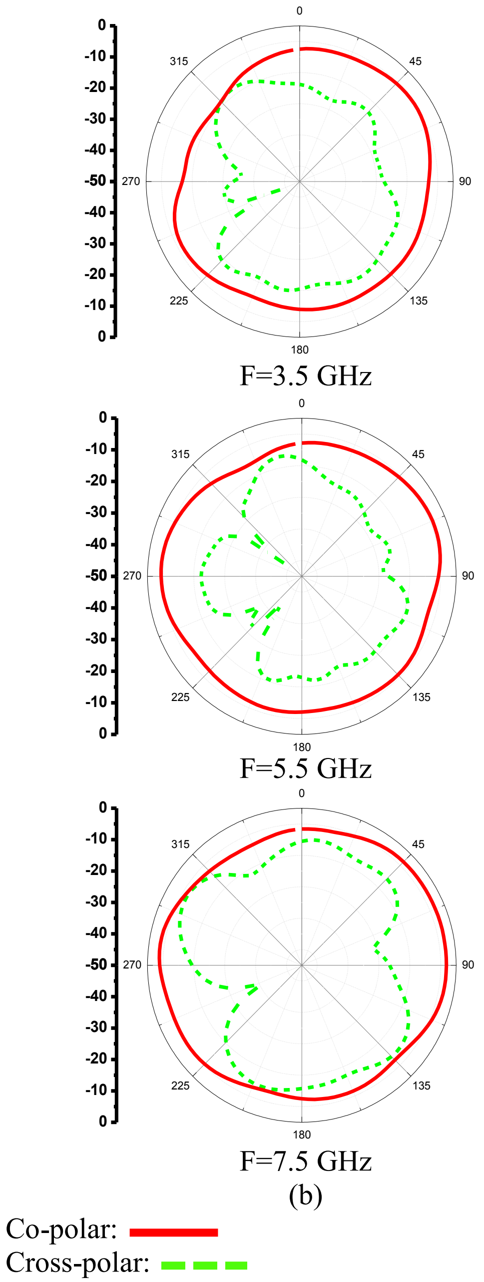


Fig. 5. Measured radiation patterns in: (a) yz-plane and (b) xy-plane.

The measured gain and the measured radiation efficiency of the proposed antenna are illustrated in Figs. 6 and 7, respectively. It can be seen that stable antenna gain with a variation of less than 3 dBi is achieved except for smaller values in the notched band, within which the smallest one is as low as -12 dBi. The proposed antenna features an efficiency between 50% and 70% over the entire UWB frequency and lower than 10% in the notch band. This confirms that the proposed antenna provides a high level of rejection to signal frequencies within the notched band [16-19].

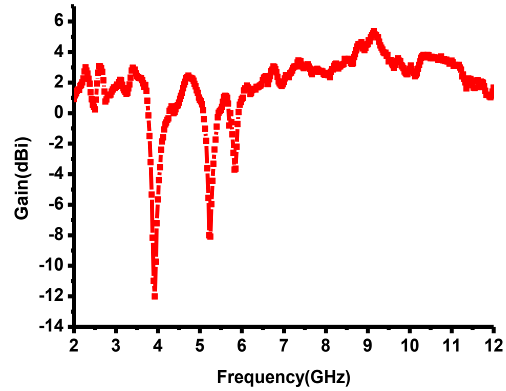


Fig. 6. Measured gain of the proposed antenna.

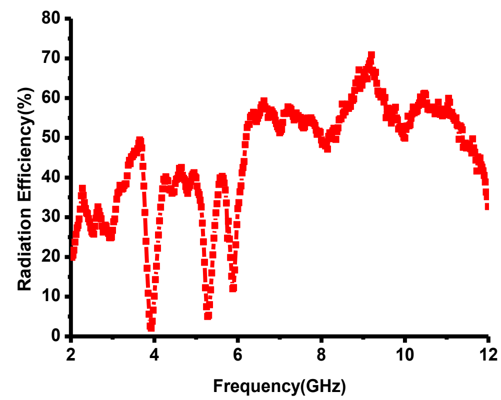


Fig. 7. Measured radiation efficiency of the proposed antenna.

IV. CONCLUSION

The design of a UWB slot antenna with an extra band and dual notched bands has been presented. The UWB slot antenna has a swallow shape. By attaching three modified co-directional pentagon complementary SRRs with quarter-wavelength to the radiation pattern, an extra band at 3.9 GHz (C-band satellite communication systems) and two notched bands centered at 5.2 GHz and 5.8 GHz (WLAN) are created. The co-directional pentagon complementary SRRs slots act independently, and their addition to the swallow antenna does not change the behavior of the original UWB characteristics. The quality of the rejected bands is quite obedient. The measured results are in agreement with the simulated ones. Therefore, the results of work are useful for short-range wireless communication systems.

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