Compact UWB Antenna with Dual Functionality

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Abstract **─** A novel Ultra-Wideband (UWB) monopole antenna is proposed that exhibits stop-band functionality at the WLAN frequency band. It consists of an annular ring shaped radiating patch that is excited with a 50 Ω feedline. The stop-band is generated by etching a parasitic ring on the reverse side of the antenna's substrate. The antenna's impedance bandwidth was enhanced by including a semi-circular notch in the trapezoidal shaped ground-plane in the vicinity of the parasitic ring. The measured results confirm the impedance bandwidth covers a frequency range between 2.42-11.4 GHz for VSWR≤2, which corresponds to a fractional bandwidth of 130%. The UWB antenna is omni-directional in the xz-plane and approximately bi-directional in the yz-plane. The antenna is compact in size with overall dimensions of 30×30×1.6 mm^3.

Index Terms **─** Band-notched antenna, microstrip fed antenna, monopole antenna, ultra-wideband and WLAN.

I. INTRODUCTION

High data rate wireless communications technology is developing rapidly since the release of the Ultra-Wideband (UWB) frequency range by the Federal Communications Commission (FCC) [1]. As in the case of conventional narrowband wireless systems, antennas play a crucial role in UWB systems. However, the design of antennas for UWB systems is more challenging as they need to operate over a bandwidth of 7.5 GHz from 3.1 GHz to 10.6 and at the same time satisfactorily, radiating energy over the entire UWB frequency range. For this, application printed monopole antennas are attractive as they provide the following features:

(i) Large impedance bandwidth.
(ii) Ease of fabrication using conventional microwave integrated circuit technology.
(iii) Ease of fabrication using conventional microwave integrated circuit technology and possessing acceptable radiation characteristics [2]-[4].

Within the UWB spectrum coexists other narrowband systems including WLAN (5.15-5.35 GHz and 5.725-5.825 GHz). As these systems operate using a significantly stronger power density than UWB systems, they are therefore likely to fatally interfere with the operation of UWB systems. This necessitates an additional function from UWB systems to suppress such interfering signals. The conventional solution to

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eliminate or suppress the interfering signal, is by using a band reject filter in the front-end of the UWB system. However, since the filter is wavelength dependent, it will result in an increase of the physical size of the UWB system. To overcome this issue, UWB antenna with a band rejected function is required. UWB antennas with notch bands have been proposed using various techniques, some of which include using H-shaped conductor-backed plane [5], cutting two modified U-shaped slots on the patch [6], inserting two rod-shaped parasitic structures [7], embedding resonant cell in the microstrip feed-line [8], using a fractal tuning stub [9], utilizing a resonant patch [10] and using a MAM and genetic algorithm [11]. In [12] and [13], different configuration slots are shown to provide band-notched property at the WLAN band.

In [14], band-stop function is achieved by using a T-shaped coupled-parasitic element in the ground-plane. In [15]-[19], it is shown that one slot or parasitic element is sufficient to create a stop-band; however, this is contrary to [20] and [21], where multiple identical elements are employed to generate a single notch band in radiators. The shortcoming of these notch antennas is that the notch band is either shorter or wider than the bandwidth of the interference signal. This means that the interfering signal is either partially suppressed or completely suppressed along with some of the desired signal.

In [22], it is shown that excellent bandwidth performance can be achieved with a monopole circular patch antenna with a circular-shaped ring, used as a parasitic element and a slit in the ground-plane. However, this structure lacks in band-stop functionality. In [23], a printed monopole antenna is proposed using a circular patch enclosed in annular ring, to provide ultra-wide bandwidth coverage. However, the antenna's azimuthal radiation pattern is approximately omni-directional and in the elevation plane it resembles a figure eight. The antenna however exhibits nulls in the radiating patterns, which exceed 10 dB resulting from surface current variations with frequency. This antenna also lacks in band-stop functionality. A planar modified circular ring antenna for ultra-wideband applications with band notch performance was reported in [24]. It has a return-loss of 10 dB over the frequency range 3.1-10.6 GHz, except at the notch frequency band. The band-notched characteristic is achieved by introducing a tuning stub inside the ring monopole. The annular ring is mounted vertically on a circular ground-plane.

The structure is relatively complex to fabricate and its radiation pattern is essentially unidirectional.

In this paper, a UWB antenna is presented possessing a band-notch function. The antenna uses a patch consisting of an annular ring and etched on the reverse side of the same substrate is a parasitic ring element that determines the exact frequency of the notch-band. Unlike [22] and [23], the proposed antenna exhibits a band-notch function to eliminate interfering WLAN signals. Unlike [23], its radiation pattern is approximately omni-directional in both azimuthal and elevation planes. The proposed antenna is also much less complicated to fabricate than [24]. The structure of the proposed antenna was optimized using an available EM simulation tool and the antenna fabricated to verify its performance.

II. ANTENNA STRUCTURE

The proposed monopole antenna is composed of an annular ring which is fed through a 50 Ω microstrip line, whose width is 2.8 mm, as shown in Fig. 1. Etched on the reverse side of the same dielectric substrate and immediately behind the annular ring is a parasitic ring. Dimensions of the parasitic element determine the frequency of the notch band (i.e., 5-6 GHz). The ground-plane resembles the shape of a trapezoid to enhance the antenna's impedance bandwidth.

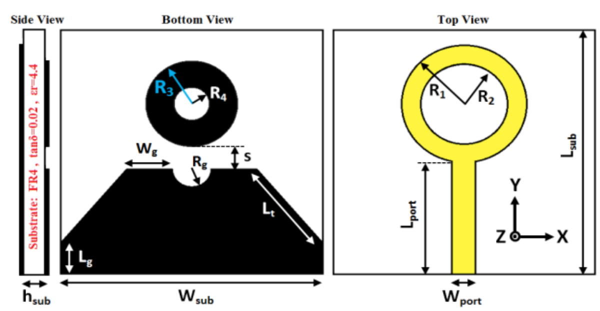


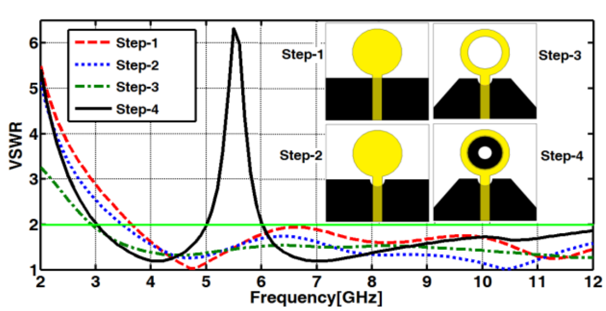
Fig. 1. Geometry of the proposed antenna.

The upper part of the ground-plane is defected with a semi-circular notch next to the annular ring, to further improve the impedance bandwidth. The antenna was fabricated on a low-cost commercially available substrate FR-4 with relative permittivity of 4.4, tanδ=0.02 and thickness of 1.6 mm. The antenna design is terminated with a 50 Ω SMA connector for signal reception/transmission. The optimal dimensions of the antenna, defined in Fig. 1, are given in Table 1.

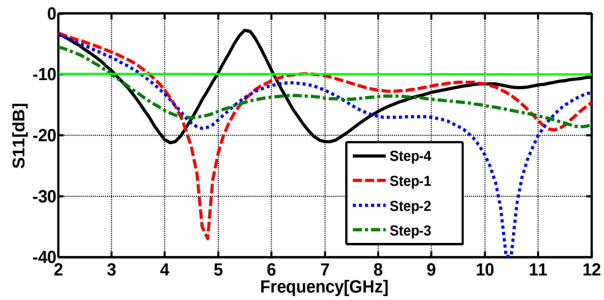
Table 1: Optimized antenna dimensions (unit: mm)

W_{sub}=30	R_1=7.2	L_t=11.7
L_{sub}=30	R_2=5	L_g=4
h_{sub}=1.6	R_3=5.3	W_g=5.3
W_{port}=2.78	R_4=2	R_g=2.2
L_{port}=13.9	S=2.5	

Figure 2 shows the four steps undertaken to realise the antenna. The first step includes only a circular radiating patch and a rectangular ground-plane; in the second step the ground-plane is defected with a semi-circular notch in the vicinity of the circular patch; in the third step the circular patch is converted to an annular ring and the ground-plane is tapered; in the final step a parasitic ring is added in the ground-plane and the ring is placed directly below the annular ring patch. Figure 2 shows the changes in the VSWR and return-loss performance for the various modifications made to realise the antenna. The proposed antenna corresponding to the final step, exhibits an ultra-wideband impedance bandwidth between 3.06-12 GHz for VSWR≤2 and a band notch function that cover the WLAN band. The insertion of the parasitic ring creates a narrow band notch between approximately 5-6 GHz. This phenomenon can be understood using the Smith chart, plotted in Fig. 3. Embedding the parasitic element leads to capacitance enhancement between the parasitic element and the patch; thus, saving energy instead of propagating it to hence realize a stop band [25].



(a)



(b)

Fig. 2. (a) Simulated VSWR and (b) S11 characteristics for four steps used to create the proposed antenna structure.

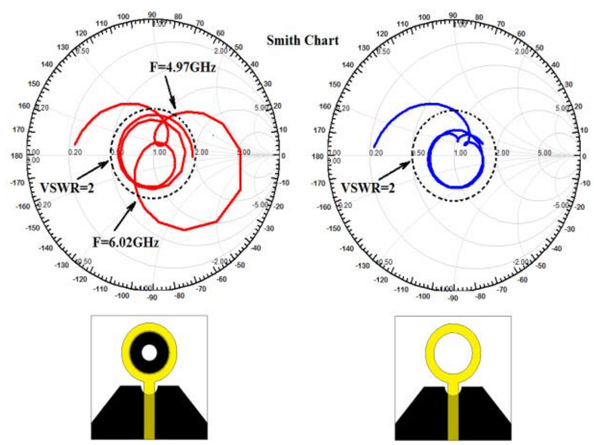


Fig. 3. Smith chart for the proposed antenna and antenna without parasitic element.

Finally, about the ground plane, it's understood that the radius of the semi-circular notch in the ground plane is important as it affects the impedance match of the antenna.

III. SIMULATION RESULTS AND MEASUREMENTS

In this section, the affect of the various antenna parameters on the performance of the band notched UWB antenna is investigated. Numerical and experimental results of the impedance bandwidth and radiation characteristics are presented and discussed. The parameters of the proposed antenna were studied by changing them systematically one at a time, while keeping all other parameters fixed.

Full-wave electromagnetic analysis was performed on the proposed antenna using Ansoft HFSS (ver 11.1) software.

As mentioned earlier, the band rejection property in the proposed antenna is achieved by printing a parasitic element in the shape of a ring on the reverse side of the substrate, which located immediately below the annular ring shaped patch. The operating frequency of the antenna and the bandwidth of the rejection band were achieved by carefully tuning the dimensions of the annular ring and the parasitic ring, respectively. From this study, it was found that the parasitic element behaves as resonator that is coupled with the annular ring to create a resonance band-stop function at f_r is given by [26]:

$$f_r = \frac{c}{2\pi R_3 \sqrt{\varepsilon_{eff}}} \tag{1}$$

That $2\pi R3$ is the outer circumference of the parasitic ring, ε_{eff} is the effective dielectric constant and c is the speed of light. Figure 4 shows the antenna's impedance bandwidth can be adjusted by varying the outer radius of the annular ring (R_1), which has a marginal effect on the center frequency of the notch and bandwidth. The outer radius (R_3) of the parasitic element significantly affects the center frequency of the notch, as shown in Fig. 5. The change in notch frequency is approximately 1 GHz for radius change from 5-6 mm. The ground-plane notch radius (R_g) affects the impedance bandwidth of the antenna, as shown in Fig. 6, as well as the VSWR magnitude of the notch. Analysis shows the inner radius (R_2) of patch and the gap (S) between the parasitic element and ground-plane play an important role in determining the sharpness and width of the stop-band response. Figure 7 shows the measured radiation patterns of the proposed antenna (co-polarization and cross-polarization) in the H-plane (x-z plane) and E-plane (y-z plane). It can be observed from this result that the radiation patterns in x-z and y-z plane are nearly omni-directional and bi-directional, respectively, at the frequencies of 5 GHz and 6.9 GHz. The measured and simulated gain of the proposed antenna over the antenna's operating bandwidth is shown in Fig. 8. The graph shows that the measured gain varies between 1.7-3.9 dBi, except in the notch band between 5-6 GHz where the signal is attenuated. The current density distribution over the proposed antenna at the center frequency of the notch (i.e., 5.5 GHz) is shown in Fig. 9. The current density is concentrated over the feedline, the ground-plane below the feedline and the parasitic ring. The current emanating from the parasitic element is in the opposite direction to the current flow in the patch. Photograph of the UWB antenna is shown in Fig. 10.

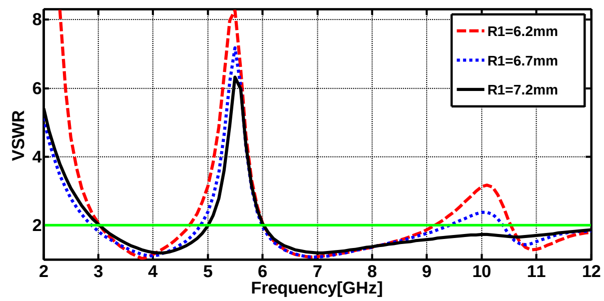


Fig. 4. Simulated VSWR response of the proposed UWB antenna as a function of annular ring's outer radius (R_1).

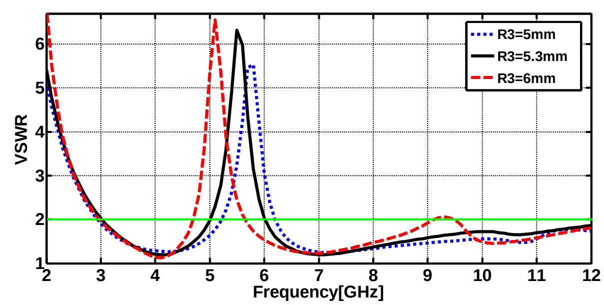


Fig. 5. Simulated VSWR characteristics of the proposed UWB antenna as a function of outer radius of the parasitic element (R_3).

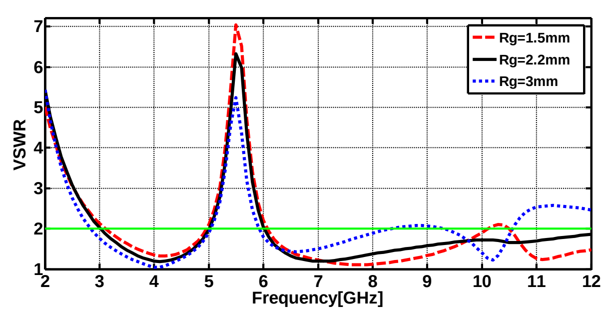


Fig. 6. Simulated VSWR response of the proposed UWB antenna as a function of ground-plane notch radius (R_g).

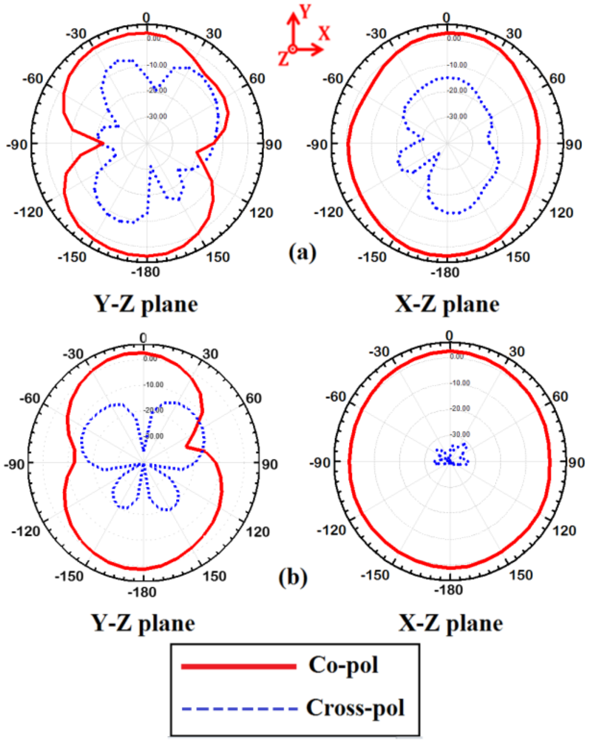


Fig. 7. Measured radiation patterns of the proposed antenna at: (a) 5 GHz and (b) 6.9 GHz.

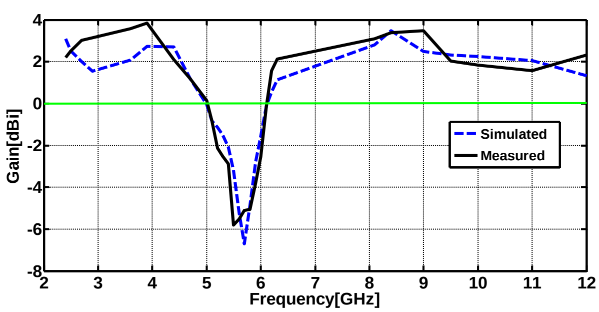


Fig. 8. Measured and simulated gain of the proposed antenna.

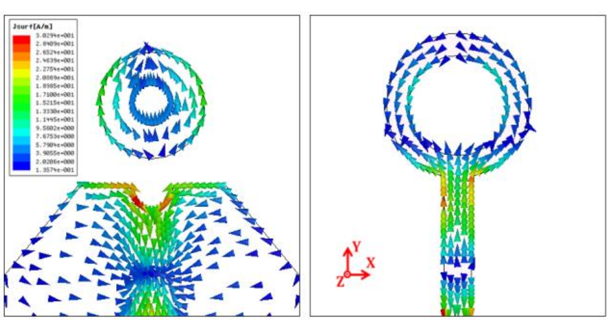


Fig. 9. Surface current distribution over the proposed antenna at 5.5 GHz.

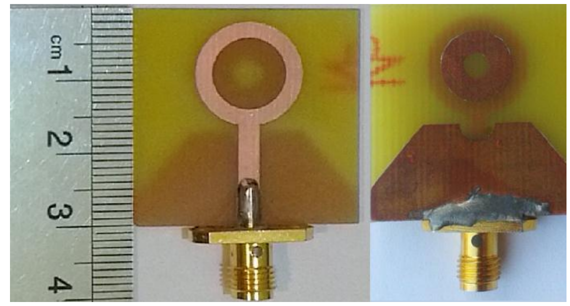


Fig. 10. Photograph of the fabricated antenna.

The measured and simulated reflection-coefficient of the proposed antenna that depicted in Fig. 11 not only verifies its performance up to12 GHz, but also shows a close correspondence between the measured and simulated curves.

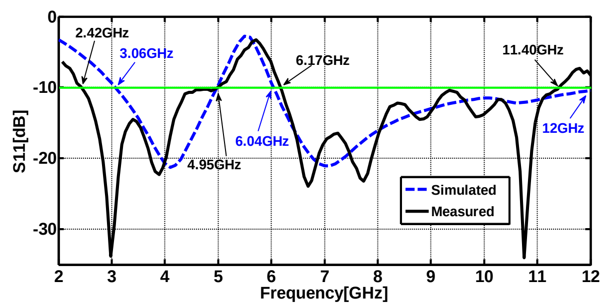


Fig. 11. Measured and simulated return-loss of the proposed antenna.

IV. CONCLUSION

A dual function monopole antenna is reported for UWB applications. The antenna has inherent band-notch characteristic necessary to filter out WLAN interference signals. The proposed antenna has advantages of low-cost, compact size and ease of fabrication. The measured results verify its excellent UWB response (2.42-11.4 GHz) with a prescribed WLAN rejection band and good radiation patterns across the entire UWB spectrum. These characteristics make the antenna a viable good candidate for UWB wireless applications.

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