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Research paper

A Single Notch Semi-Circle UWB Antenna with Partial Ground Plane

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Abstract

This work presents an ultra-wideband (UWB) antenna with single notch band characteristics. The proposed antenna is composed on a simple, low loss and compact planar commercially available Rogers RT/Duroid 5870 substrate. The antenna is designed with a modified semi-circular radiating patch on one side and modified partial ground plane on the other side of double layer substrate. The semicircular patch is modified by etching a circular slot which assist to achieve the stop band at 4 GHz C band frequency range. The ground structure and the substrate materials are optimized to achieve desired performance of proposed antenna prototype. The proposed antenna prototype is designed, fabricated and measured. The measured results display that the prototyped antenna has achieved impedance bandwidths of 13.5 GHz (1.5 to 15 GHz) with a single frequency band-stop performance of 3.58 – 4.92 GHz. The optimized antenna offers higher gain, almost stable radiation patterns and adequate radiation efficiency over the operating bandwidth.

Keywords: *gain enhancement; notch band antenna; partial ground plane; Ultra-wideband;*

1. Introduction

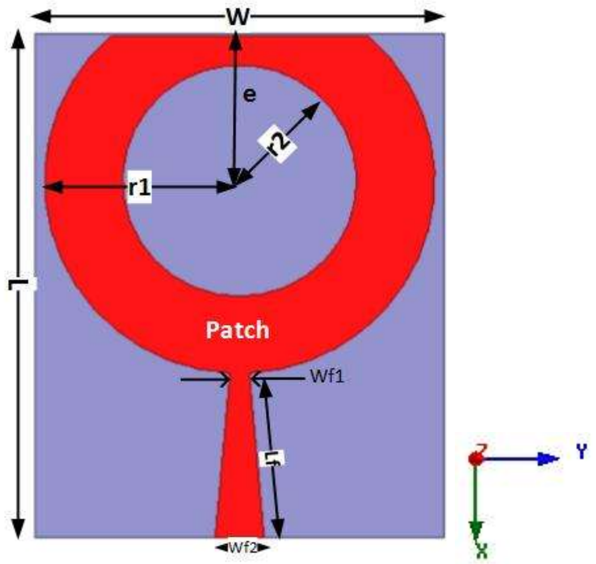
Ultra-wideband (UWB) has become an extraordinary technology in last few decades with the development of high sped communication. With the allocation of frequency spectrum of 3.1 – 10.6 GHz with wide bandwidth and low power consumption, high data transmission rate, low cost and easy to fabricate, low interference and low complexity made the UWB technology an interesting research phenomena for both academic and industrial point of view [1-3]. So the UWB antenna should be compact in design, high gain, low profile and stable radiation characteristics to fulfill the requirement of UWB standard. After the allocation of UWB band by The Federal Communication Commission (FCC) several researchers have already proposed a number of monopole UWB antenna for wireless application [4-6]. Though the researchers have attraction to work on UWB but there remains a number of challenges like wideband antenna, cost effective and compact size antennas for UWB based wireless communication application. UWB has recently used in numerous applications due to its distinctive characteristics like wireless personal area network (WPAN), real time transmission of audio and video with higher quality, high-speed wireless USB connectivity for PCs and its Short-distance peripherals, in radar systems, for positioning and tracking with higher degree of accuracy, microwave imaging system to detect malignant tissues inside the human body [7-10]. There are several types of antennas have been designed and proposed for UWB applications. Among them, the planner antennas are capable to reduce the antenna dimension with the increasing of antenna gain.

With the increasing demand of electrically small multi technology devices, antenna size reduction plays a significant role in wireless communication world. Antenna miniaturization is remained an extensive topic of interest for communications engineers, especially the requirement of small form factor devices for space applications. Microstrip patch antenna is a good candidate for UWB application, particularly portable devices. Due to scarcity of the bandwidth spectrum UWB band application become very popular for various applications. The antenna size reduction is a vital factor for such portable small radar that uses short distance. There are several miniaturization approaches introduced to design and analyze the electrically small antennas. Using high permittivity ceramic material substrate for antenna miniaturization is exceptionally prevalent compared to other techniques [11-13]. Different approaches have already been recommended to design UWB antennas with band-notch characteristics [14-18]. For example, a compact planar slot antenna with a notched band at 5.5 GHz is recommended [14] for UWB applications. Two symmetrical parasitic slits are imprinted in the slot of the ground plane to create the wanted notch band. In [15], a printed UWB antenna was prototyped on a 32×28 mm^2 FR4 dielectric substrate by putting two C-shaped slots and a U-shaped slot into the patch to achieve the dual notched bands centered at 3.5 and 5.5 GHz. In [16], a planar antenna with standard band-notched characteristics was offered to generate a notch frequency band of 5.12-6.08 GHz. A technique to enhance the bandwidth of a microstrip-fed planar monopole antenna has been proposed [17]. The monopole antenna fed by a 50Ω microstrip feed line is fabricated on the FR4 substrate. To improve the bandwidth, the top side of the partial ground plane has been modified to form a saw tooth-shape and by this modification it is found that, the bandwidth is enhanced by 43.6% compared the initial design. The proposed antenna is easy to be integrated with microwave circuitry for low manufacturing cost.

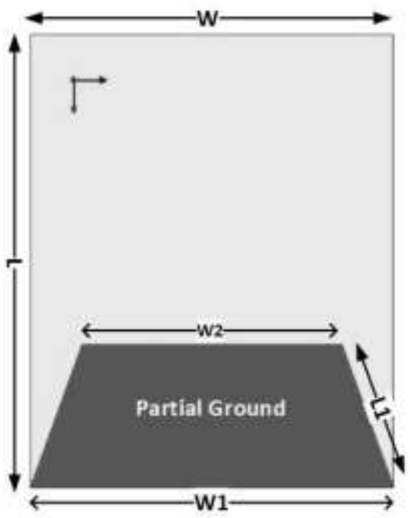
In this study, a microstrip feed line simple patch antenna of size 42 (W) × 52.25 (L) mm^2 with UWB band functionality is presented. The antenna also performs C band notch characteristics. By applying partial ground plane with small gap between semicircle patch and trapezoid ground plane the proposed antenna exhibits initially broadband characteristics. To achieve the band notch properties, a circular slot with radius r_2 is etched out. The antenna achieved impedance bandwidths are 13.5 GHz (1.5 – 15 GHz) except rejecting the spectrum of C-band (3.48 to 4.92 GHz) with resonant frequency of 2.9, 9 and 13.5 GHz respectively. The antenna geometric information, parametric investigations, simulations and experimental data are critically analyzed and discoursed in the following section.

2. Antenna Layout

The geometric structure of proposed single notch monopole UWB antenna is illustrated in figure 1. The overall size of proposed prototype is 52.25 mm ×42 mm. The low cost commercially available Rogers RT/Duiroid 5870 substrate is used for antenna fabrication. The antenna has partial semicircular radiating patch on the front side of the substrate and a partial ground plane of trapezoid shape on the other side of substrate. The monopole partial circle with maximum radius r_1 and the width e along the partial edge of the circle. The tapered microstrip feedline is used to feed the antenna on middle position of ground plane. The band notch characteristics are achieved by incorporating a circular slot with radius r_2 from the main radiating circular patch. The band notch characteristics are controlled by changing the size of circle and the impedance matching network is controlled by the ground plane. A 50Ω SMA connector is connected to the tapered microstrip feedline. The overall dimension of antenna is $L\ mm \times W\ mm \times h\ mm$. The area of trapezoid ground-plane is $\frac{1}{2} \times L_1 \times (W + W_2)\, mm^2$. Table 1 summarized the optimized design parameters of proposed antenna.



(a)



(b)

Fig. 1: The geometric layout of proposed design (a) Front side (patch) (b) Back layer.

Table 1: Optimized Dimension of the proposed antenna (all in mm)

Parameter	Value	Parameter	Value	Parameter	Value
W	42	W2	30	r1	20
Wf1	1.97	L	52.25	r2	12
Wf2	5	L1	17.56	e	15.25
W1= W	42	lf	17.09	h	1.575

In practice, the most commonly quoted parameter for antennas is S_{11}. S_{11} represent how much power reflected of the antenna. The performances of proposed antenna for various geometric layout in-terms-of reflection co-efficient (S_{11}) is presented in fig. 2. Wihtout notch the antenna covers the full band from 1.5 GHz to 15 GHz. From the figure it is clearly shows that the designed antenna offers UWB band of bandwidths 13.5 GHz (1.5 GHz – 15 GHz) except rejecting the spectrum of C-band (3.48 to 4.92 GHz) with the resonant modes at 1.7, 5 and 12.5 GHz respectively. The proposed prototype has realised the desired resonance frequencies due to the pull-out of different slots and extension of radiating patch. The practical requirements of notched frequency bands can easily be achieved and controlled by adjusting the sizes and locations of the resonating elements**.** Effect of length of ground plane to the return loss (S11) against frequency bands of the proposed antenna is presented in figure 3. An optimized ground plane of width W_1=42 mm, W_2=30 mm and *L1*=17. 56 mm long are proposed for the slotted antenna.

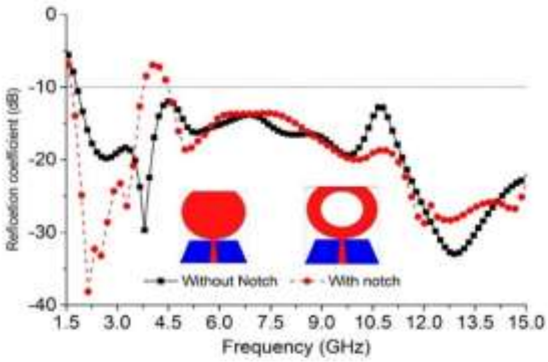


Fig. 2: Comparative reflection coefficient of proposed prototype without and with notch

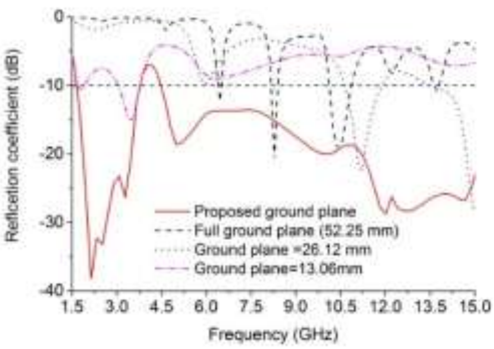


Fig. 3: Effect of length of ground plane to the return loss (S_{11}) of the proposed antenna.

An extensive study also been done for different dielectric materials substrate on the reflection coefficient. The comparison is presented in fig 4. The analysis would assist to explore the effects of dissimilar substrate materials to the impedance bandwidth. The used substrate materials are the Ceramic Thermoset Polymer Composite (ε_r = 6.3, tan δ = 0.0023), the Ceramic–PTFE (ε_r = 10.2, tan δ = 0.0023), the Glass-PTFE (ε_r = 2.33, tan δ = 0.0009), the Epoxy Resin Fiberglass (ε_r = 3.5, tan δ = 0.0018) and the Taconic (ε_r = 3.5, tan δ = 0.0018). From the study it is stated that the glass–PTFE composite material substrate provides wider bandwidth and lower return loss value for the proposed antenna geometry. Because of the higher relative permittivity (dielectric constant ε_r = 2.33), low dielectric loss (0.0009) and tight dielectric constant, glass–PTFE composite material offers better performance compared to other four substrate materials.

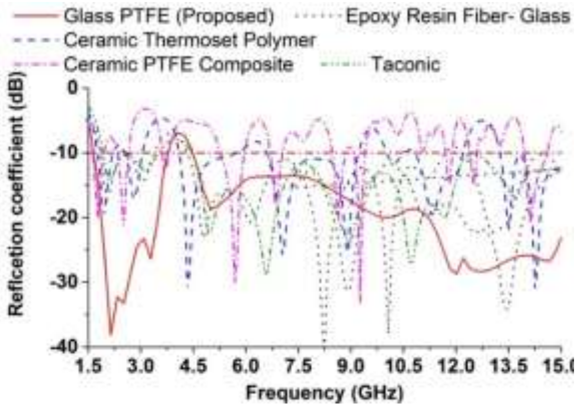
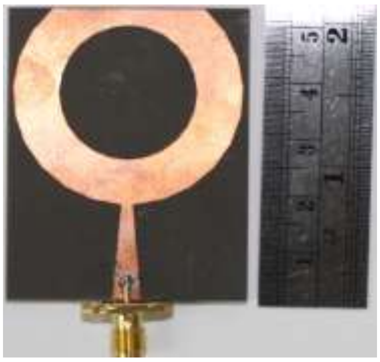


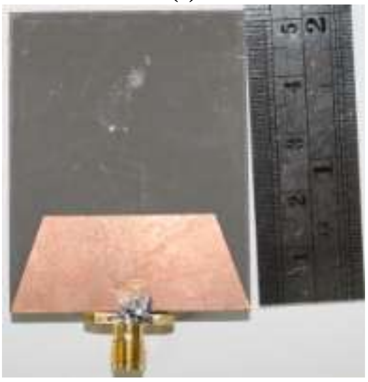
Fig. 4: Effect of different substrate materials to the reflection co-efficient.

3. Results and discussion

The fabricated photograph of the optimized antenna prototype (top and bottom view) is shown in Figure 5. The antenna prototype was measured using the Agilent E8362C Vector Network Analyzer (VNA) and UKM StarLab (Satimo near field). The measured and simulated reflection co-efficient of the proposed antenna against the frequency is presented in figure 6. The notch band is slightly shifted downward in measurement. This is so due to the fabrication tolerances of feed point and the influence feeding cable along with temperature and environmental effects. The simulated result shows that the proposed design covers the bandwidth from 1.5 GHz - 15 GHz and attained the notch characteristics from 3.81- 4.51 GHz in HFSS and in CST, it reject 3.58 GHz - 4.92 GHz. In measurement, it notched the 3.58 – 4.38 GHz C band. There have a small difference between simulation and measured result due to the fabrication tolerances and temperature effect. To understand the notch characteristics phenomenon, the simulated surface current distribution at notch band (4 GHz) and new resonance (10 GHz) are presented in figure 7. According to the figure 7(c), at notch point, the current flows are more dominant around the notch structures.



(a)



(b)

Fig. 5: The fabricated prototype of proposed UWB band notched antenna: (a) Front layer (b) Back layer

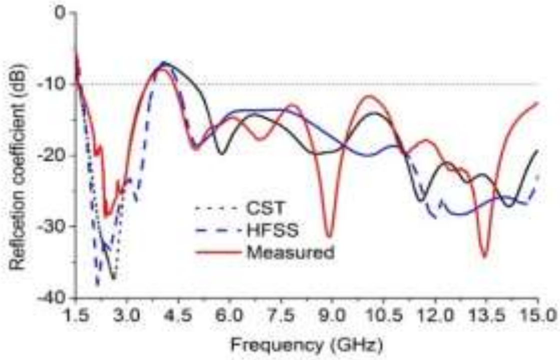
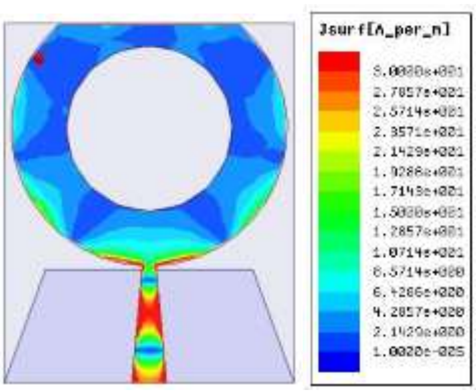
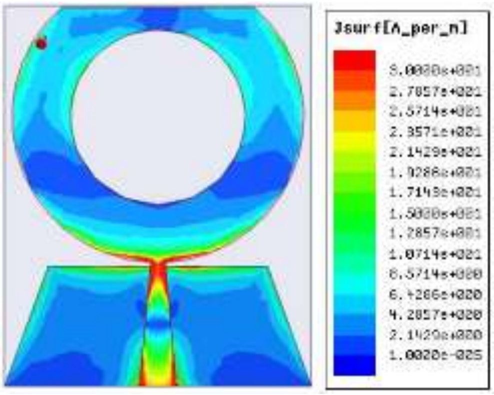


Fig. 6: The measured and simulated reflection co-efficient of proposed prototype.



(a)



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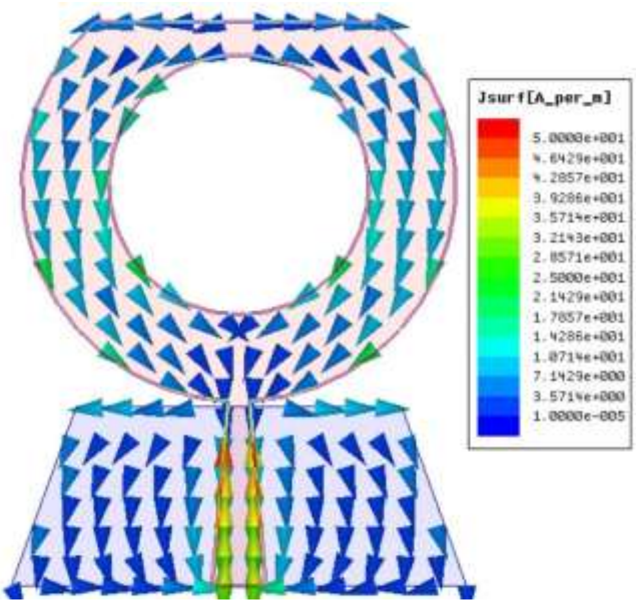
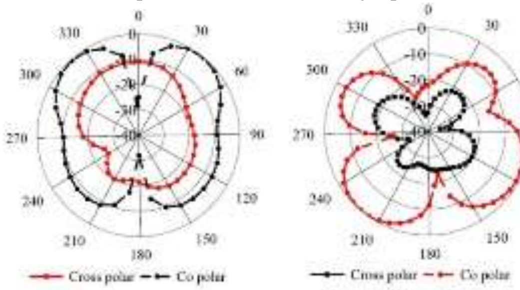


(c)

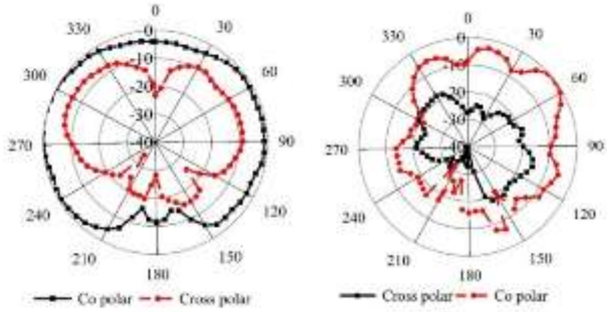
Fig. 7: The surface current distribution of proposed antenna at different frequency (a) 4.5 GHz (b) 10.0 GHz c) 3.25 GHz

The measured radiation pattern in both cross and co-polarization of the fabricated antenna at frequencies 4.5 and 10 GHz in two principal planes *xz*-(H) and *is-yz* (E) are depicted in fig. 8. From the figure it can be concluded that the radiation patterns of anticipated antenna in *xz* plane (H plane) exhibit nearly omnidirectional for two frequencies. Due to the loading of asymmetrical circular slot on the radiating patch and the reduced trapezoidal ground plane, the co-polarization effects are higher than the cross-polarization. In higher frequency the radiation deteriorates slightly due to the existence of higher order current mode. Figure 9 demonstrated the measure and simulated realized gain over frequency of projected antenna. From the graph it is clearly perceived that the proposed antenna has achieved maximum gains of 6.75 dBi with average gain of more than 4.3 dBi across the operating band. One of the most important parameters for antenna performance description is radiation efficiency. Figure.10 presents the measured and simulated radiation efficiencies of the prototyped antenna. Radiation efficiencies of the designed antenna at the operating frequencies are more than 80 %. Therefore, minimum power is required for data transmission. The prototyped antenna performance is compared with the existing antennas in the literature in terms of dimension and single notch-band characteristics is presented in Table 2:

xz-plane *yz*-plane



(a) 4.5 GHz



(b) 10 GHz

Fig. 8: The measured radiation pattern at different frequencies for both co-polarization and cross-polarization (a) 4.5 GHz (b) 10 GHz

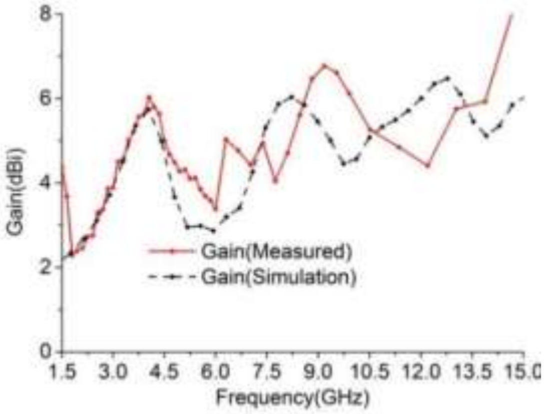


Fig. 9: The measured and simulated realized gain of proposed prototype

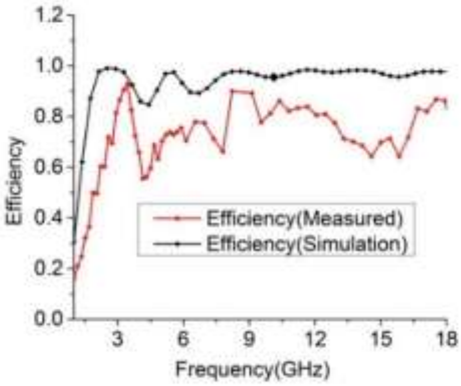


Fig. 10: Measured and simulated radiation efficiency of proposed prototype.

Table 2: Comparison of the proposed prototype with some existing antenna

Band-Notch Antennas	Dimensions (mm^2)	Bandwidth (GHz)	Notched Band (GHz)
Dual Band-Notch UWB Slot Antenna [13]	22× 24	3.04 - 10.88	3.5 – 3.95
Tapered slot antenna [10]	50×50	2.4 - 11.2	4.6 – 6.2
Compact Monopole Antenna [12]	35×30	3.05 - 11.15	5.12 – 6.08
Proposed	52×42	1.5 - 15	3.58-4.92

4. Conclusion

In this manuscript, a compact monopole printed UWB antenna with single notch characteristics has been proposed. The band notch characteristic is gained by incorporating a circular slot on the semi-circular disk. The fabrication antenna has frequency band 1.5 – 15 GHz with the rejection band around 3.58 – 4.92 GHz. Current distribution and radiation pattern are also presented in this work. The proposed antenna has a simple configuration, smaller in size and large operating characteristics. The optimized antenna demonstrates stable radiation properties, adequate gains across the operating frequency band and covers the sufficient impedance bandwidths which are appropriate to provide the services of L band, Wi-Fi, Bluetooth, ISM, LTE 2600 and different UWB applications.

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