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# COMPACT ASYMMETRIC INVERTED CONE RING MONOPOLE ANTENNA FOR UWB APPLICATIONS

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**Abstract**—A new printed monopole antenna configuration, asymmetric inverted cone ring monopole antenna, is proposed. The proposed antenna which has the size of 23.6 mm × 40 mm, is fabricated on a low-cost FR4 substrate that has the relative permittivity ($\varepsilon_r$) of 4.4 and substrate thickness of 1.6 mm to operate in the UWB band (3.1 GHz to 10.6 GHz) released by Federal Communications Commission (FCC) in 2002. It gives an ultra-wide impedance bandwidth of VSWR $\leq 2$ from 2.9 GHz to 35 GHz (169.4%) for numerical result and from 3.1 GHz to 31.1 GHz (163.74%) for experimental result. Moreover, it exhibits omni-directional radiation patterns with acceptable gain across the whole operation band, which meets the requirements of UWB applications. The parameters which affect the performance of the antenna characteristics are investigated in this paper. The simulated results have a good agreement with the measured ones, and the proposed antenna shows that it is a very good candidate for UWB operations.

## 1. INTRODUCTION

After the Federal Communications Commission (FCC) allocated the bandwidth of 3.1 to 10.6 GHz for the unlicensed use of the ultra wideband (UWB) in February 2002, the UWB technology has been developed rapidly and become very popular among researchers and academicians [1]. Commercial UWB systems require small low-cost antennas with omni-directional radiation patterns, large bandwidth and non-dispersive behavior [2]. The designs of the UWB antennas have been challenge to the researchers. The planar monopole type antenna is widely used among the UWB antenna designs because of its wide operating bandwidth, simple structure, low cost, nearly omni-directional radiation patterns, etc. Several designs of planar monopole

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UWB antenna have been proposed [2–18]. In [6, 7], two small wideband planar monopole antennas with truncated ground plane and notches in the lower corner of the patches are proposed to achieve the maximum impedance bandwidth. Moreover, other strategies such as radiating patch with tapered steps [8, 9, 11] and wide-slot antenna with coplanar waveguide (CPW) feed line [10] are also proposed for large bandwidth. One of the UWB antenna types is the planar inverted cone antenna (PICA) proposed by Suh [15, 16]. The PICA is vertically mounted on a large ground plane and as a wide monopole antenna. Its bandwidth is impressive in view of its small size and mechanical simplicity. However, this type of planar inverted cone antenna is not the most suitable for portable communication systems due to the protruding part of PICA. The printed slot and CPW-fed planar inverted cone antenna are also proposed in [17, 18]. However, they are large in size and fail to retain its wide band matching when the size is reduced.

In this paper, a new UWB asymmetric inverted cone ring monopole antenna is introduced and optimized. By cutting the inverted cone slot of suitable dimension at the inverted cone patch, asymmetric inverted cone ring patch can be constructed for UWB applications. The tapered ground plane is used to enhance the performance of the antenna. Simulated and experimental results are presented to demonstrate the performance of the proposed antenna. It is found that the proposed antenna satisfied all the requirements for the UWB frequency band.

## 2. ANTENNA DESIGN AND CONFIGURATION

Figure 1(a) illustrates the geometry and configuration of the proposed asymmetric inverted cone ring monopole antenna. The proposed antenna is fabricated on the FR4 substrate with the relative permittivity ($\varepsilon_r$) of 4.4, loss tangent ($\tan\delta$) of 0.001 and substrate thickness of 1.6 mm. The proposed antenna is composed of a tapered partial finite ground plane, an inverted cone-shaped radiation patch with an inverted cone-shaped slot which form an asymmetric inverted cone ring and a 50 $\Omega$ microstrip feed line. The outer ring with radius, $R$ and inner ring with radius, $r$ are tangent at the bottom and forming the asymmetric inverted cone ring. The bottom gap between the outer and inner ring of the proposed antenna is zero. On the other side of the substrate, the partial ground plane is tapered at the top corner sides to get a better impedance matching. In order to match the resistance of radiating element with the microstrip feed line, a linear tapered section has been used to connect these two parts.

The simulation tool Ansoft High Frequency Structure Simulator

(HFSS) is used for performing the design and optimization process. The prototype is fabricated with FR4 substrate based on the optimized parameters and measured with the Agilent 8722ES Vector Network Analyzer. The photograph of the fabricated antenna is shown in

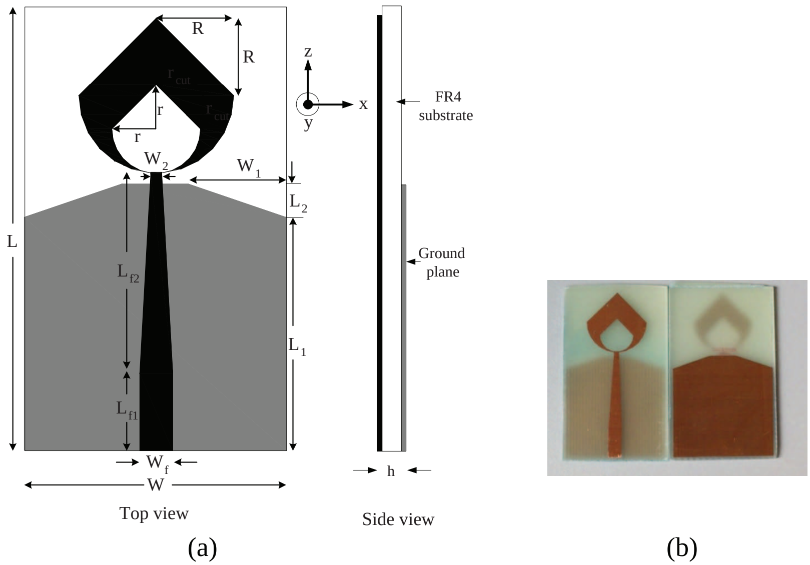


**Figure 1.** (a) Geometry of the proposed asymmetric inverted cone ring monopole antenna. (b) Photograph of the fabricated proposed antenna.

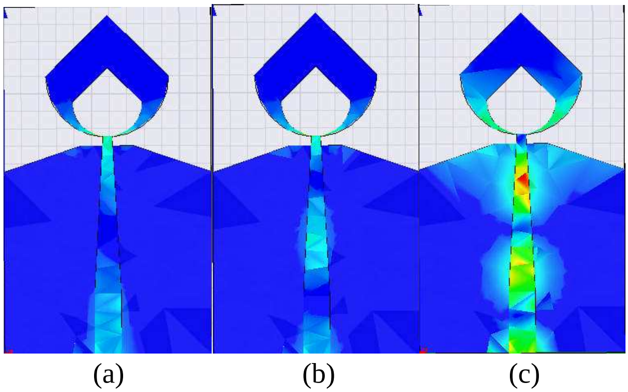


**Figure 2.** Simulated surface current distributions of the proposed antenna. (a) 3 GHz. (b) 6 GHz. (c) 8 GHz.

Figure 1(b). The asymmetric ring of radiating patch and the linear tapered transmission line are the key factors of the optimization process. In order to better understand of the antenna characteristics, the radius of inner ring ($r$), the upper transmission line width ($W_2$) and the bottom gap between the outer and inner rings are selected in the parametric study.

The simulated current distributions at 3, 6 and 8 GHz for the proposed antenna are illustrated in Figure 2 for better understanding of the radiation mechanism of the antenna. It can be seen that high strength of the current mainly radiates along the microstrip transmission line and lower edge of the radiating element. At high frequencies, the current distributed on the partial ground plane is mainly along the upper edge and acts like the parts of the radiating area.

Figure 3 illustrates the simulated return loss against frequency

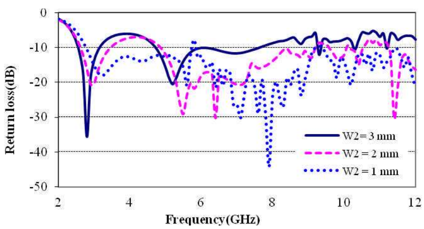


**Figure 3.** Simulated return loss against frequency for proposed antenna with various upper transmission line width ($W_2$).

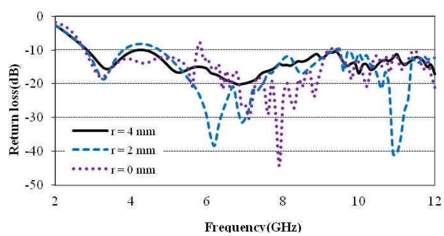


**Figure 4.** Simulated return loss against frequency for proposed antenna with various slot radius ($r$).

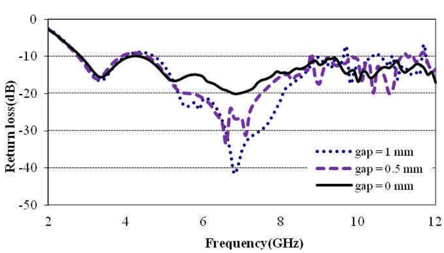


**Figure 5.** Simulated return loss against frequency for proposed antenna with various bottom gap between the outer and inner rings.

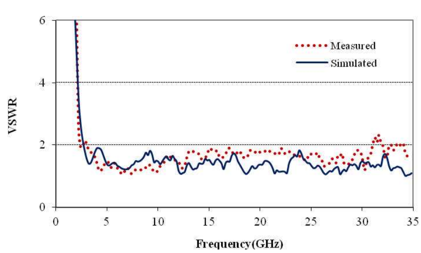


**Figure 6.** Simulated and measured VSWR characteristics against frequency for proposed antenna.

of proposed antenna with various upper transmission line widths ($W_2$). From the simulation results in Figure 3, it is found that the 10 dB impedance bandwidth increases as the upper transmission line width ($W_2$) decreases. The optimized width in the upper part of the transmission line is 1 mm. Simulated return loss curves with various slot radius ($r$) for proposed antenna are plotted in Figure 4. As the slot radius ($r$) increases, the impedance bandwidth also increases. The slot radius, $r = 0$ mm means that there is no slot in the patch. Figure 5 illustrates the simulated return loss against frequency for proposed antenna with various bottom gaps between the outer and inner rings. It is seen that the widest bandwidth can be achieved when gap = 0 mm, the inner ring and outer ring are tangent at the bottom.

## 3. RESULTS AND DISCUSSION

The final proposed antenna is achieved after the parametric study of several adjustments on parameters. The design parameters of the proposed antenna are given in Table 1.

Figure 6 illustrates the measured VSWR characteristics of the proposed antenna along with the simulated one. The simulated bandwidth is from 2.9 GHz to 35 GHz and the measured bandwidth is from 3.1 GHz to 31.1 GHz. The different between the simulated and measured values may be due to the fabrication accuracy, SMA connector to transmission line, which is not taken into account in

**Table 1.** Design parameters of the proposed antenna.

| Parameter | Value (mm) |
|---|---|
| $W$ | 23.6 |
| $L$ | 40 |
| $L_1$ | 21 |
| $W_1$ | 8.8 |
| $L_{f1}$ | 7 |
| $L_{f2}$ | 18.1 |
| $W_f$ | 3 |
| $W_2$ | 1 |
| $L_2$ | 3 |
| $R$ | 7 |
| $r$ | 4 |

the simulation results and the dielectric constant is not stable when the frequency increases. However, both simulated and measured bandwidths completely cover the whole UWB operation bandwidth (3.1 GHz to 10.6 GHz) released by FCC.

The radiation characteristic of the proposed antenna in the far-field has also been investigated. The simulated and measured radiation patterns of the proposed antenna at 3 GHz, 6 GHz, 7 GHz and 10 GHz

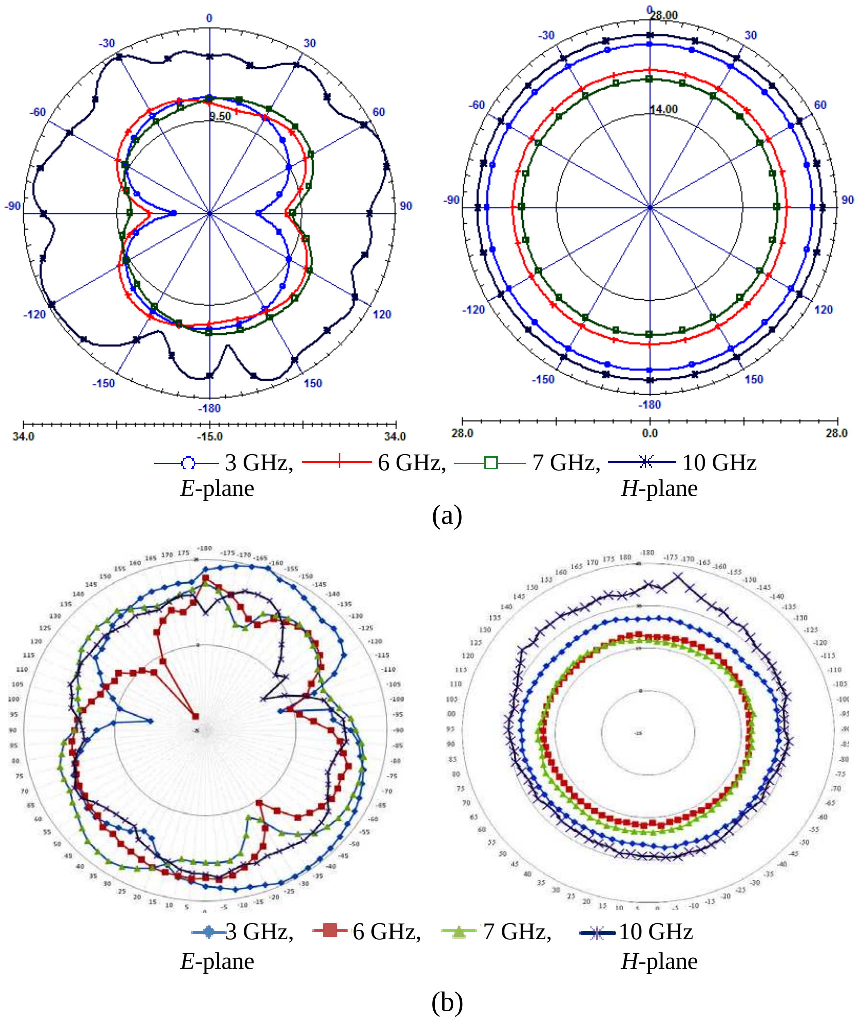


**Figure 7.** Radiation patterns at different frequencies, (a) simulated and (b) measured.

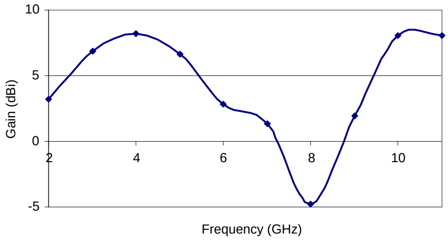


**Figure 8.** Simulated gain of the proposed antenna.

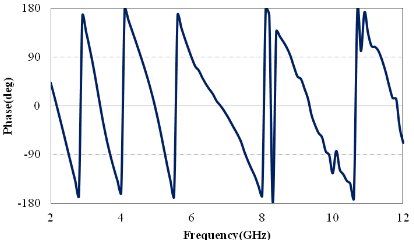


**Figure 9.** Phase response of the proposed antenna.

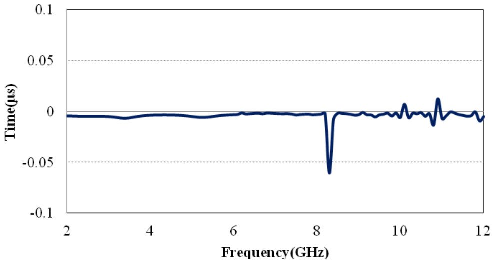


**Figure 10.** Group delay of the proposed antenna.

for E- and H-planes are illustrated in Fig. 7. From an overall view of these radiation patterns, the proposed antenna exhibits an omni-directional radiation patterns in H-plane for both simulated and measured results. In the E-plane, dipole-like radiation patterns at low frequencies and becomes more directional at higher frequencies Fig. 8 presents the simulated antenna-gain response of the proposed antenna. It can be seen that the gain is larger at the lower and higher frequencies and smaller between 7 GHz to 9 GHz. The impulse response is an important characteristic of the UWB antenna. Linear phase response or small group delay time of the UWB antenna shows a good impulse response. Figure 9 shows the phase response of the proposed antenna. The group delay is an important parameter of UWB antenna design and it represents the degree of direction of pulse signal. Figure 10 illustrates the group delay of the proposed antenna. It can be seen that the variation of group delay is less than 0.01 μs for the frequency range of 2 GHz to 8 GHz and less than 0.07 μs for the frequency range of 8 GHz to 12 GHz.

## 4. CONCLUSION

A compact low-cost UWB asymmetric inverted cone ring monopole antenna has been proposed in this paper. The proposed antenna has been simulated, fabricated and tested. The proposed antenna shows that the experimental results show agree well with the simulated results and can operate an ultra wide operation bandwidth covering the whole UWB range set by the FCC. The proposed antenna also maintains the omni-directional radiation patterns with acceptable gain, less variation in group delay and it is very suitable for UWB applications. The proposed antenna design is suitable with the low cost FR4 substrate for getting higher frequencies over 15GHz. The compact proposed antenna can easily be integrated with RF circuits for low cost manufacturing using the FR4 substrate.

## ACKNOWLEDGMENT

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