Study of a Printed U-T shape Monopole Antenna For UWB Systems

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Abstract—this paper presents a study of a novel monopole antenna for ultra wide-band (UWB) applications. Printed on a dielectric substrate and fed by a 50Ω micro strip line, a planar U-T shape monopole has been demonstrated to provide an ultra wide band with 10 dB return loss bandwidth with satisfactory radiation properties. The parameters which affect the performance of the antenna in terms of its frequency domain characteristics are investigated. A good agreement is achieved between the simulation and the experiment. In addition, the time domain performance of the proposed antenna is also evaluated in simulations.

Index Terms—Circular disc monopole,U-T shape microstripline-fed, Printed antennas, ultra wideband (UWB).

I. INTRODUCTION

The Ultra-wideband (UWB) system covers the frequency range from 3.1-10.6 GHz, which based on narrow pulses to transmit data at extremely low power, and looks like random noise to most conventional radio systems. The UWB technology offers several advantages over conventional communications systems. For instance, there is no carrier frequency. Instead, UWB emits timed "pulses" of electromagnetic energy. Therefore transmitter and receiver hardware can be made very simple, which is necessary for the portable devices. There is a wide range of applications for UWB technology, which includes wireless communication systems, position and tracking, sensing and imaging, and radar. Antenna plays an essential task in UWB system, which is different from narrowband system. UWB systems transmit extremely narrow pulses on the order of 1ns or less resulting in bandwidths in excess of 1 GHz or more. Ultra-wideband (UWB) technology is emerging as a solution for IEEE 802.15.3a (TG3a) standard [2].The standardization of the UWB radio is ongoing under IEEE 802.15 WPAN High Rate Alternative PHY Task Group 3a (IEEE802.15.3a) and wireless personal area network (WPAN) is originated by the Bluetooth (IEEE802.15.1). IEEE802.15.3a is trying to establish the new standard of WPAN to drastically increase the data rate, which is a weak point of Bluetooth. Now IEEE802.15.3a considers the use of UWB, following the tentative regulation of FCC (Federal Communications Commission, USA), to achieve the bit rate of 110 Mb/s at 10 m and 200 Mb/s at 4 m. The paper is organized in the following sections. Section II describes the antenna design and the 10 dB return loss bandwidth obtained for an optimal design. Section III analyzes the characteristics of the antenna. Section IV presents the time domain performance of the antenna. Section V summarizes and concludes the study.

Fig.1. Geometry of the printed U-T shape monopole antenna.
lg=20.2mm only covers the section of the microstrip feed line

<table>
<thead>
<tr>
<th>Wsub</th>
<th>Lsub</th>
<th>Wp</th>
<th>Lp</th>
<th>Wg</th>
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<th>Wf</th>
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<tr>
<td>50</td>
<td>50</td>
<td>28</td>
<td>29</td>
<td>50</td>
<td>19.9</td>
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<td>Wr2</td>
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<td>Wr3</td>
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<td>R</td>
<td>r</td>
</tr>
<tr>
<td>28</td>
<td>3</td>
<td>8</td>
<td>16</td>
<td>8</td>
<td>16</td>
<td>13.5</td>
<td>8.25</td>
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Table 1: Dimensions (in mm) of designed UTMP UWB antenna

Lf is the length of the ground plane. h is the height of the feed gap between the feed point and the ground plane. The simulations are performed using the HFSS which use finite element method for electromagnetic computation [12]

III. ANTENNA CHARACTERISTICS

For U-T shape monopole antenna, the ground plane serves as an impedance matching circuit. Consequently, it tunes the input impedance and hence the 10 dB return loss bandwidth by changing the feed gap [12], [13]. Another two important design parameters that affect the antenna performance are the width of the ground plane Wg and the length of the ground plane Lg dimension of the disc. The effects of these two parameters can be well explained by investigating the current distributions of the antenna

A. Current Distributions

The simulated current distributions at different frequencies for the optimal design with Wsub=50mm, Lsub=50mm, Wt1=28mm, Ll1=3mm, Wa1=8mm, La1=16mm, Wa2=8, La2=16, Wl2=4mm, Ll2=29mm, r=8.25, R=13.5, Wf=3, Lf=20, Wg=50, Lg=19mm, and are presented in Fig. 3. Fig. 3(a) shows the current pattern near the first resonance at 3 GHz. The current pattern near the second resonance at 5 GHz is given in Fig. 3(b), indicating approximately a second order harmonic. Fig. 3(c) illustrates a more complicated current pattern at 7 GHz, corresponding to the third order harmonics shown in Fig. 3, the current is mainly distributed along the edge of the T shape patch, which indicates that the first resonant frequency is associated with the dimension of the U shape disc

A prototype of the proposed U-T shape monopole antenna with optimal Wsub=50mm, Lsub=50mm, Wt1=28mm, Ll1=3mm, Wa1=8mm, La1=16mm, Wa2=8, La2=16, Wl2=4mm, Ll2=29mm, r=8.25, R=13.5, Wf=3, Lf=20, Wg=50, Lg=19mm was fabricated and tested. Fig. 2 shows the simulated and the measured return loss curves. The measured 10 dB return loss bandwidth is from 2 to 12 GHz, while in simulation from 2 to 9.80 GHz. The measurement confirms the UWB characteristic of the U-T shape monopole antenna, as seen in the measured

B. The Effect of the Dimension of the ground plane

On the ground plane, the current is mainly distributed on the Upper edge along the y-direction. That means the portion of the ground plane close to the u shape acts as the part of the radiating structure. Consequently, the performance of the antenna is critically dependent on the width of the ground plane Wg [10], [11]. However, it also leads to a disadvantage, i.e., when this type of antenna is integrated with printed circuit board, the RF circuitry cannot be very close to the ground plane. Simulations have shown that when the length Lg of the Ground plane is more than 20.122 mm, the performance of the Antenna is almost independent of Lg.
different dimensions of the ground plane with their respective optimal designs (Lg=20.1mm, Wg=50mm, r=8.25mm, R=13.5mm, Lf=20mm, Wf=3mm, Lg=50mm, r=8.25mm, R=13.5mm, Lf=20mm, Wf=3mm, Lg=20mm, Wg=50mm, r=8.25mm, R=13.5mm, Lf=20mm, Wf=3mm, Lg=20.2mm, Wg=50mm, r=8.25mm, R=13.5mm, Lf=20mm, Wf=3mm, Lg=20mm, Wg=50mm, r=8.25mm, R=13.5mm, Lf=20mm, Wf=3mm, Lg=20mm, Wg=50mm, r=8.25mm, R=13.5mm, Lf=20mm, Wf=3mm, Lg=20mm, Wg=50mm, r=8.25mm, R=13.5mm, Lf=20mm, Wf=3mm, Lg=20mm, Wg=50mm, r=8.25mm, R=13.5mm, Lf=20mm, Wf=3mm).

Fig. 4. Simulated return loss curves for different dimensions of the ground Plane with the optimal designs.

Fig. 4 demonstrates that the first resonant frequency is determined by the diameter of the ground plane, which approximately corresponds to the quarter wavelength at this frequency. So the lower end frequency of the 10 dB return loss bandwidth of the antenna is directly related to the dimension of the ground plane.

C. The Effect of the Dimension of the U-T shape

Change in the ground plane dimension has indicated that the first resonant frequency is associated with the ground plane dimension. Actually, it is noticed in the simulations that the first resonance always occurs at around 3 GHz for different value of W and Lg. Furthermore, the smaller radius of the disc is 8.25 and bigger dimension of the disc is 13.5, which is very close to the quarter wavelength at the first resonant frequency which is around 20.1 mm Fig.5 presents the simulated return loss curves for different Dimensions of the U-T shape with their respective optimal design. Wsub=50mm, W1=28mm, L1=3mm, Wwa=8mm, Lwa=16mm, Ww2=8mm, Lw2=16mm, Wf=3mm, Lf=20mm, r=8.25, R13.5, Wg=50mm, Lg=199mm, r=10mm and r=11, other parameter keep constant. It is seen in Fig.5 that the first resonant frequency decreases with the increase of the radius of the u shape disc.

D. Radiation Patterns and Gain

Antenna radiation pattern demonstrates the radiation properties on antenna as a function of space coordinate. For a linearly polarized antenna, performance is often described in terms of the E and H -plane patterns. The radiation patterns have been simulated. The simulated normalized radiation patterns at 3, 5 and 7 GHz are plotted in Fig 6. The E -plane is defined as the plane containing the electric field vector and the directions of maximum radiation while the H -plane as the plane containing the magnetic field vector and the direction of maximum radiation. The x- z plane elevation plane with some particular azimuth angle φ is the principle E -plane while for the x- y plane azimuth plane with some particular elevation angle θ is the principle of H plane. Figure6 shows the simulated two-dimensional E and H-plane at three frequencies. In the E -plane, the value of azimuth angle φ of 0 and 90° while in H -plane, the value of elevation angle θ of 0° and 90° are taken into consideration.

Fig.6. Radiation patterns at 3, 5,7GHz.

The plot for radiation is utilized for three frequencies within pass band, which are 3 GHz at the lower bound, 5 GHz at the middle bound and 7 GHz at the upper bound. The simulated results of maximum gain in dBi of the designed antenna are as shown in Figures 6. The gain is simulated at the fix point on azimuth angle of φ at 0° and 90° and at different elevation angle of θ. It is observed that the gain pattern is not the same for all angle of φ. It is noticed that the H-plane pattern is omni directional at lower frequency (3 GHz) and is near omni-directional at higher frequencies (5 and 7 GHz), where the gain reduces 8 dB in the x -direction at 9 GHz. In general, the shapes of the H-plane patterns correspond well to the current patterns on the disc, as shown in Fig. 3 at different frequencies, respectively.
IV. TIME DOMAIN PERFORMANCE OF THE ANTENNA

Apart from the consideration of the 10 dB return loss bandwidth and radiation pattern, as studied in the previous Section,

Fig.7 Source pulse waveform with $a = 45$ ps

A good impulse response, i.e. time domain characteristic, is an essential requirement for an UWB antenna. The printed U-T shape monopole antenna has also been tested for its impulse response in the simulation In order to validate the efficiency of the antenna; the pulse base signal is excited with Gaussian pulse. It can be related to the dispersion of receive signal compared to transmitter signal. The time domain characteristics viz. group delay of the proposed antenna can be measured between two identical antennas placed at 0.3-0.4 m in the face-to-face orientations, using Vector Network Analyzer. As shown in Figure 9, the measured group delay is constant over the operating bands except over the 3-5 GHz band.

Table 2: performance summary of the U-T shape monopole printed UWB antenna (UTMPUA) Substratespecification R4, $\varepsilon_r=4.4$, $\tan\theta=0.02$, $H=1.6$mm

<table>
<thead>
<tr>
<th>PARAMETERS</th>
<th>U-T shape Monopole Printed UWB antenna</th>
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<tr>
<td>Dimension</td>
<td>$50\times50\times1.6$</td>
</tr>
<tr>
<td>Absolute Bandwidth(GHz)Below - 10dB</td>
<td>2-9.12</td>
</tr>
<tr>
<td>Maximum Fractional Bandwidth (%)</td>
<td>128</td>
</tr>
<tr>
<td>Notch Band</td>
<td>---------------------------</td>
</tr>
<tr>
<td>Returnloss,S11(dB)</td>
<td>-20.9dB at 2.4GHz and -19.6 dB at 4.7GHz</td>
</tr>
<tr>
<td>VSWR</td>
<td>1.3 at 2.4GHz and 1.4 at 4.7GHz</td>
</tr>
<tr>
<td>Peak gain</td>
<td>3.21</td>
</tr>
<tr>
<td>Accepted Power (watt)</td>
<td>0.9644</td>
</tr>
<tr>
<td>Radiated Power (watt)</td>
<td>0.8299</td>
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<tr>
<td>Incident Power (watt)</td>
<td>1</td>
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<tr>
<td>Radiation efficiency (%)</td>
<td>86</td>
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<tr>
<td>Antenna efficiency (%)</td>
<td>82.99</td>
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V. FABRICATION AND MEASUREMENTS

The antenna structure is fabricated on a printed circuit board (PCB) using Photolithography technique and tested. The fabricated antenna is shown in Figure 12. Below fig clearly show the process for S11 (dB) measurement which is for $L_g=45$mm. The measured results reasonably agree with simulated results, by changing the length of the ground plane different S11 values can be obtained. The proposed antenna performs good impedance matching over the UWB band.
ACKNOWLEDGMENT

The printed circular disc monopole antenna fed by microstrip line is investigated in this paper. It has been shown that the performance of the antenna in terms of its frequency domain characteristics is mostly dependent on the feed gap, the width of the ground plane and the dimension of the disc. The first resonant frequency is directly associated with the dimension of the circular disc because the current is mainly distributed along the edge of the disc. It is demonstrated numerically and experimentally that the proposed printed circular disc monopole can yield an ultra wide bandwidth, covering the FCC defined UWB frequency band. It is observed that the radiation patterns are nearly omni-directional over the entire 10 dB return loss bandwidth. Simulations have also indicated that the impulse response of the antenna has a slight ringing effect due to the mismatch between the antenna bandwidth and the pulse bandwidth, while the radiated spectrum can meet the FCC defined emission mask in the most part of the frequency range.

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