Design and Analysis of Modified UWB Mono-Cone Antenna for WBAN Applications

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Abstract. A low-profile UWB antenna is presented in this paper for wireless body area network (WBAN) applications. The proposed antenna consists of a modified mono-cone structure by adding a semi-sphere on top of the mono-cone. A top-plate is added as overhead to the proposed antenna. This plate leads to a height reduction when compared to conventional mono-cone antennas. In this paper, the effect of ground plane dimensions, effect of top-plate dimensions, effect of the supporting legs and effect of the total height of the antenna is studied to get a better insight into the working of the radiating structure. The antenna operates in the frequency range of 4.1 GHz to 10.1GHz with return loss less than -10dB. The bandwidth of the proposed antenna is 6 GHz. The frequency domain results are obtained by simulating the design using Ansoft HFSS. The voltage standing wave ratio is less than 2 within the frequency range of the proposed antenna design. The influence of the human proximity on the antenna was simulated by placing the proposed antenna over a human body model.

1. Introduction
In the wireless communication systems development, new wireless devices and systems are developed to meet the demands of multimedia applications. In today's wireless world, multifrequency and multimode devices particularly wireless body area networks (WBANs) demands antennas. These antennas need to have high gain, small physical size, broad bandwidth, versatility etc. Since the 1970s, UWB radio technology is widely developed for wireless applications. UWB radio systems transmit and receive short time pulses without any carrier or modulated short pulses with carrier. In UWB systems almost no interference is produced. The power level transmitted is almost at the noise level of the systems using the same spectrum. It makes the system possible to share the spectrum and space with other established technologies like Wi-Fi and WLAN [1]. Research on UWB antennas and their design and analysis got great attention among the antenna research community [2]. Also, Recently researchers have showed huge response on UWB antenna designs exclusively for the WBAN applications [3].

WBAN requires omni-directional radiation pattern thus biconical antennas [4] can be used. It gives a 360 coverage in azimuthal plane and particular coverage in elevation plane. Thickening the arm of the bicone structure results in wide bandwidth but the efficiency is poor at lower end frequency. The
overall height of a bicone antenna is 11.3mm. Thus a low profile shorted dipole antenna [5] is considered which consists of top-loading biconical antenna with shorted posts to improve the radiation bandwidth. The height is 15.1mm due to presence of balanced feeds. Balanced feeds are required as the functionality is disturbed in bicone antenna. In order to reduce the antenna height mono-cone antennas are considered. A compact button antenna is discussed in [6] where a cylinder is added to improve the total bandwidth and the electrical length increases with radius of cone. The radius required is large for more resonances with only cone, thus cylinder structure is used to reduce the diameter with a total height of 16.5mm. A bevel structure is used for broadband impedance matching in [7] where a planar monopole antenna is considered for body proximity applications. When the operating frequency increases, the bandwidth and radiation efficiency are affected. A compact UWB antenna for on-body applications with total height of 10mm [8] is omni-directional but when placed parallel to human body, efficiency is reduced. The E-field polarization must be normal to body to improve on-body propagation (i.e) vertical polarization is required for WBAN. To overcome drawback of planar monopole antenna, a PICA structure is used. In a planar cone antenna, there is large group delay variation which causes distortion in pulse shape. This affects the fidelity factor of antenna performance. In [9] a CPW fed tapered slot antenna (TSA) is designed. A reversed T-match dipole antenna with a ground plane is proposed in [10]. In planar metal-plate monopole antenna, the bandwidth is enhanced by using many techniques like offset feeding from the centre of the structure, top loading the structure with circular disk, folding the planar structure into 3-D and using a bevel structure [11]. This antenna has a very large height of 40 mm and unsymmetrical radiation pattern due to offset in the feeding structure. Flat transfer function amplitude and linear phase over the frequency band is desired [12].

In [13], PIFA is designed by modifying a monopole into a T-shaped structure to improve the bandwidth at high frequency. Top loading the antenna increases the lower frequency bandwidth. A typical slot antenna structure with an added reflector reduces the effect of radiation on human body [14]. A coplanar waveguide fed aperture coupled patch antenna [15] mounted on a finite sized ground plane with reflector to provide field cancellation in arbitrary directions. The antenna can introduce difficulties in packaging, or cause coupling to components. A modified mono-cone antenna [16] has a total height of 8.5mm with omni-directional radiation pattern and suitable transfer characteristics. The proposed antenna has smallest height when compared to the existing works, and also omni-directional in H-plane. The proposed antenna is simulated by placing it on human body model as discussed in the existing works and found that the proximity effects is very minimum.

2. Proposed antenna design
In this work, a low-profile UWB antenna based on conventional mono-cone antenna is designed by considering low coupling into human body, perpendicular polarization, low height and omnidirectional in H-plane for efficient on-body communications. The mono-cone is modified by adding a semi-sphere on its top to reduce the height and covering by a radiator plate supported by two legs to further enhance its -10dB impedance bandwidth. The radiator top-plate as a capacitive load enhances the lower frequency performance and mono-cone for higher frequencies. The proposed antenna has a low height of 5.8mm with a ground plane of size 30mmx30mm. The antenna design is shown in figure 1(a) and (b) and the antenna specifications are given in Table 1.
Fig. 1 Proposed Antenna Design (a) Top view (b) Side view.

Table 1 Antenna design specifications.

| Parameters | a  | b  | c  | d  | e  | f  | g  | h  | i  | j  | k  | l  | m  | n  | 0  |
|------------|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|
| Values in  | 30 | 20 | 16 | 10 | 4  | 4  | 2  | 6.75| 5.8 | 14.25| 2.5 | 10.4| 0.5 | 3.05| 0.25|
| mm         |    |    |    |    |    |    |    |    |    |     |    |    |    |    |    |

From the figure 1(a) and (b), and antenna design specifications given in Table 1, it can be inferred that the size is very compact when compared to the existing works in the literature survey.

3. Simulation results and discussion

The performance of the proposed antenna is analyzed with their geometrical parameters like top-cross-plate radiator, ground-plane and supporting legs using Ansoft HFSS electromagnetic solver. The antenna structure is optimized to obtain values that give the desired UWB frequency range of operation which is required for WBAN applications. The S11 (dB) parameter which depicts the return loss is analyzed and shown in figure 2.

Fig. 2 Return loss plot of the proposed antenna.

From figure 2, it can be inferred that the frequency for which the antenna radiates effectively is from 4.1GHz to 10.1GHz, for S11<~10dB. Thus the bandwidth of operation is 6GHz. From the bandwidth obtained for the proposed antenna, it can be concluded that it operates in UWB range and can transmit large amount of data.
3.1. Parametric analysis

The effects of the design structure on the performance are studied to obtain a better insight about the physical behavior of the antenna by varying one parameter at a time. The performance of the proposed antenna is analyzed with top-plate dimensions, dimensions of the supporting legs, dimensions of ground plane, distance between the cone and top-plate. The proposed antenna is also analyzed with respect to radiation pattern in 2-D and 3-D, current distribution on the antenna surface and VSWR measure.

Effects of the supporting legs.

The antenna impedance bandwidth behavior is changed for the change in the dimensions of the legs. The length and breadth of the brass legs which are used for supporting the top-plate are varied and the effect of these parameters is analyzed. Figure 3 shows the reflection coefficient for the variation of these parameters.

From the above figure, 3, it is found that the optimum dimensions are 4mmx4mm. When the dimensions are increased the frequency of operation narrows down.

Effects of ground plane dimensions.

The induced surface current distributed on the antenna ground plane indicates that its dimensions affect the antenna reflection coefficient characteristic. In figure 4, the simulated results for different ground dimensions are shown.

Effects of the radiating top-plate.

The effect of top-cross-plate is studied by simulating the antenna design with truncated top-plate and a rectangular top-plate as proposed in this work. Results shown in figure 5 confirms that when the top-plate is truncated the lower and higher frequencies are attenuated more when compared to other frequencies which lie within the bandwidth of operation. This leads to higher value of group delay.
greater than 4ns. To achieve wider impedance bandwidth, without much transitions in the return loss plot the top-plate must not be truncated by cutting the corners of the radiating plate. It can be seen from figure 5 that the proposed antenna effectively radiates when compared to antenna with truncated top-plate.

![Graph](image1.png)

**Fig. 5 Effect of the radiating top-plate.**

Effect of the top-plate dimensions.

The effect of top-plate is studied by simulating the antenna design with various top-plate dimensions. Results shown in figure 6 confirm that the higher band (7–11 GHz) is obtained when the dimensions are 20mmx20mm.

![Graph](image2.png)

**Fig. 6 Effect of top-plate dimension.**

Effect of antenna height.

The height of antenna between the mono-cone and rectangular top-plate directly influences the antennas input impedance. The simulation results of this parameter effect on the antenna input reflection coefficient is given in figure 7. The increasing or decreasing of this parameter leads to slightly diminishing bandwidth.

![Graph](image3.png)

**Fig. 7 Effect of antenna height**

From figure 7, the value 5.8mm gives the maximum bandwidth of operation. Thus the proposed antenna height is 5.8mm, which is very compact and can be used for WBAN applications.
Analysis of radiation pattern and current distribution. The proposed design is validated in frequency domain and the radiation pattern is obtained as shown in figure 8. The E-field and H-field values are obtained and analyzed in figure 8 and figure 9 using 2-D and 3-D plots. The simulated radiation patterns for the proposed UWB antenna are depicted in figure 8(a), (b), (c) in 2-D view, in both E-plane and H-planes at 4GHz, 6.85 GHz and 10 GHz (E-plane is phi=0 plane and H-plane is theta=90 plane). The 3-D view of the E-plane radiation is depicted in figure 8(d), (e) and (f), for 4 GHz, 6.85 GHz and 10 GHz.

Fig. 8 Simulated 2-D & 3-D radiation pattern of the proposed antenna at (a) & (d) 4 GHz, (b) & (e) 6.85 GHz, (c) & (f) 10GHz.
It is observed from figure 8 that the antenna radiates omni-directionally in H-plane and has vertical polarization. The radiation properties are acceptable over the entire ultrawide bandwidth. From the figure 8, one can observe that the radiation properties are not almost same throughout the operating frequencies. Figure 9(a), (b) and (c) shows the current distribution on the antenna at 4 GHz (lower frequency), 6.85 GHz (middle frequency) and 10.6 GHz (higher frequency). From the current distribution pattern depicted in figure 9, it can be inferred that there is current distribution mainly on the top-plate and around the edges of the top-plate for figure 9(a). Also current distribution is found on the ground plane near the feed. The colors representing the current distribution varies in linear scale from dark blue (weak current) to green and red (strong current). When the frequency of operation is increased the current distribution is found only in the top plate, and thus the middle frequency is mainly due to the top-plate in figure 9(b). Thus proper dimension of the top-plate is required for attenuating the middle frequency ranges. In simulating the antenna at high frequencies the current is mainly concentrated in ground plane and also near the edges of legs and around the corners of the top-plate as shown in figure 9(c). When the top plate is truncated these current lines get disturbed and leads to lower return loss for upper and higher frequencies. Thus the top-plate is not truncated, which leads to a better smooth transition between the upper and lower end of frequencies. Figure 10 shows VSWR plot for the proposed UWB antenna. It can be inferred that the VSWR value is less than two for the entire bandwidth which is desirable for reliable transmission.
3.2. Analysis of UWB antenna characteristics

Figure 11 comprises two identical antennas, one for transmitting (Tx) and one for receiving (Rx), placed side-by-side with a large separation distance (40 cm). It is considered as far-field of each other to obtain system transfer function which relates the pulse to be transmitted and the pulse received, in the frequency domain. The magnitude and phase of the proposed UWB antenna are shown in figure 12 (a) and (b).
From Figure 12 (a) and (b), it is observed that magnitude varies smoothly and its phase is almost linear over the frequency range of interest. This is desirable to obtain almost constant group delay for the transmission and reception of nanoseconds pulses. The stability of magnitude of the reflection coefficient, radiation pattern, gain and polarization do not consider phase difference with which the wave arrives. The stability must be taken into account to reconstruct the pulse on reception. Group delay is the figure of merit for studying the phase behavior of the proposed antenna. An ideal UWB system would have a constant group delay so that the phase would vary linearly over frequency. When group delay is large it causes ringing, which limits the performance of the WBAN communication. The figure 13 shows the group delay plot.

It is inferred from Fig. 13 that the group delay is almost constant throughout the frequency of operation and the change is within 2ns.

3.3. Analysis of body effects of proposed antenna

The applications of UWB-WBAN antennas include operation of antenna in human proximity. Preliminary study of the influence of such scenarios on the antenna can be conducted by considering skin model with permittivity values as shown in Table 2. The reflection coefficient of the proposed antenna is simulated in human proximity situations as shown in figure 14.
Table 2 Dielectric properties of body model.

| Tissue | Relative Permittivity | Conductivity(S/m) | Loss tangent |
|--------|-----------------------|-------------------|--------------|
| Skin   | 33.82                 | 5.11              | 0.37         |
| Fat    | 4.82                  | 0.39              | 0.20         |
| Muscle | 45.46                 | 6.85              | 0.36         |

Fig. 14 Proposed antenna on body model.

Fig. 15 shows the return loss plot of the antenna on body model and without body model. It can be seen that the results of UWB antenna on body model does not vary very much when compared to the original results of the UWB antenna without body model.

Fig. 15 reveals that the antenna does not detune in on-body scenarios in spite of maximum expected influence of the body. The proposed antenna has minimum body effect because it possess vertical polarization.

4. Conclusion
A low-profile vertically-polarized UWB antenna is designed in this paper. The proposed antenna is simulated using Ansoft HFSS. The antenna consists of a modified mono-cone with a top-plate shorted to the ground using two supporting legs and has a small overall height of 5.8 mm. The effect of ground plane, top-plate, supporting legs and effect of the total height of the antenna are studied. Simulation results shows that the proposed antenna radiates from 4.1 to 10.1GHz, has omni-directional radiation properties in the H–plane and has VSWR less than 2. The transfer characteristics are analyzed and it is found that the proposed antenna is suitable for nano-second pulse transmission. The phase and magnitude of S21 is analyzed and group delay is less than 2ns and almost constant throughout the
operating frequency range. The antenna characteristics do not change in the proximity of the wearer. Thus these results indicate that the proposed antenna is a suitable candidate for WBAN applications.

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