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S JAYAKUMAR (sjayakumarece@gmail.com)
SSM Institute of Engineering and Technology
G. Mohanbabu
SSM Institute of Engineering and Technology

Research Article

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Low Profile Asymmetrical Slotted UWB Antenna for WBAN Applications

S. Jayakumar[1*] ,G. Mohanbabu[2]

sjayakumarece@gmail.com[1],shamyubabu@gmail.com[2]

Abstract— **In this article a low profile asymmetrical slotted Ultra Wide Band (UWB) antenna is proposed for Wireless Body Area Networks (WBANs) applications. The antenna was fabricated using Printed Circuit Boards (PCBs). An improved radiation pattern was obtained with an optimized patch shape of the antenna that broadens the bandwidth and lowers the antenna's profile. In frequency ranges from 2.50 GHz to 10.97 GHz simulation as well as measured results show that the reflection coefficient (S_{11}) of the antenna is below -10 dB and increased impedance bandwidth of 126%. Furthermore, the impact of the proposed antenna has a negligible effect on the human membrane. The low-profile UWB antenna's time-domain behavior is investigated, and the results show that it is capable of transmitting and receiving pulse signals.**

Keywords— Impedance bandwidth; low profile; reduced ground plane; UWB antenna; WBAN

I. INTRODUCTION

WBAN is a rapidly growing technology that fascinated many researchers owing to its real time applications in health care monitoring, army, and sports etc., The prerequisite of user-friendly, Cost-effective low power multifunctional WBAN systems is directed to develop UWB Technology. The WBAN system needed an antenna to transmit the signals from the WBAN to medical devices for real-time monitoring of the patient. The Ultra-wideband antenna (UWB) has unlicensed bandwidth coverage of 3.1 GHz-10.6 GHz that is allowed by the FCC [1].

*Correspondence:sjayakumarece@gmail.com,
Department of ECE, SSM Institute of Engineering and Technology, Dindigul,Tamilnadu, India

UWB technology has a high data rate across a short communication range [2], Compactness, minimal mutual coupling between the human membrane and the antenna with low backward radiation, tailored time and frequency characteristics,

higher radiation efficiency with wide bandwidth, and good impedance matching are essential requirements for WBAN system applications.

An antenna on the human body plays an essential role in the operation of the WBAN system. However, antenna design should take into account the antenna's impact on the human body. So the UWB antenna having vertical polarization is desirable for the WBAN system. Initially, Microstrip Patch Antennas were presented, but they only partially met the above requirements, hence several strategies to improve antenna performance were introduced [3-5].

Patches on UWB antennas come in a variety of shapes, including rectangular, circular, square, elliptical, and triangular. Slotted ground systems are recommended to enhance bandwidth while minimizing the influence of the ground plane [6]. A reduced ground plane is another commonly used strategy for improving bandwidth in UWB antenna [7]. Textile antennas [8] are easily sewn on the cloth: however, it is more sensitive to moisture content. Full ground plane textile antennas are vulnerable to deformation. The geometry of a flexible UWB antenna [9] that has a full ground plane is complex, and the bandwidth of a monopole antenna with a microstrip feed could not cover the full UWB range of frequencies.

The proposed UWB antenna should be built with compactness to address the problems in the above literature. So In this article, Low Profile Asymmetrical Slotted UWB Antenna is Proposed, fabricated, and tested for problem specifications. The proposed UWB antenna has a physical dimension of 17.5mm X 30.0mm and covers a frequency range from 2.5GHz to 10.97 GHz which is suitable for WBAN applications.

II. ANTENNA STRUCTURE AND DESIGN

The proposed UWB antenna has a slotted elliptical-shaped asymmetrical slotted patch with the ground plane. Figure 1 depicts dimensions of the proposed UWB antenna. It is designed on FR4 substrate which has a thickness of 1.6mm, and a Slotted elliptical-shaped patch and Microstrip feed line having a length (l_f) of 8.3mm and width (W_f) of 2.3 mm is printed on the same surface of the FR4. The opposite side of FR4is partially grounded with a hexagonal slot under the feed line. The optimized dimensions are

$$W = 17.5mm, L = 30mm, w_p = 5.76mm, l_p = 9mm, l_{g1} = l_{g2} = 8.25$$
$$mm,\ l_{gs} = 13.5mm, W_{gs1} = 7mm,\ W_{gs2} = 4.5mm, l_{fs} = 1.54mm$$

The unique design of UWB antennas with the same outer dimension is depicted in Figure.2 (a), (b), (c), and (d). To choose a suitable antenna, the four antennas are simulated and compared. The reflection co-efficient (S_{11}) of four antennas are compared and the results are shown in Figure 2 (e). The results show that the proposed design is desirable for BAN applications.

This antenna design operates in the range of frequency between 2.5 GHz and 10.97 GHz which produces the reflection coefficients of -23 dB, -33 dB, and -20 dB, respectively at 3.6 GHz, 7.4 GHz, and 9.8 GHz frequencies. The length of the Ground Plane plays a vital part in wideband antenna design. At low frequencies, the current is more concentrated to achieve proper impedance matching.

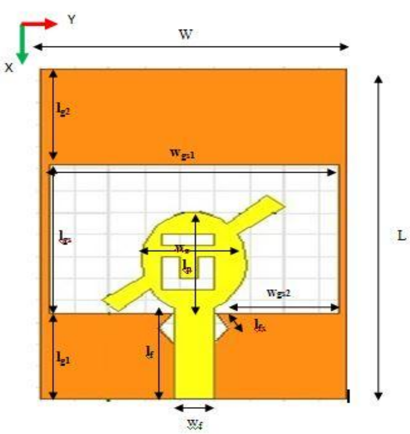
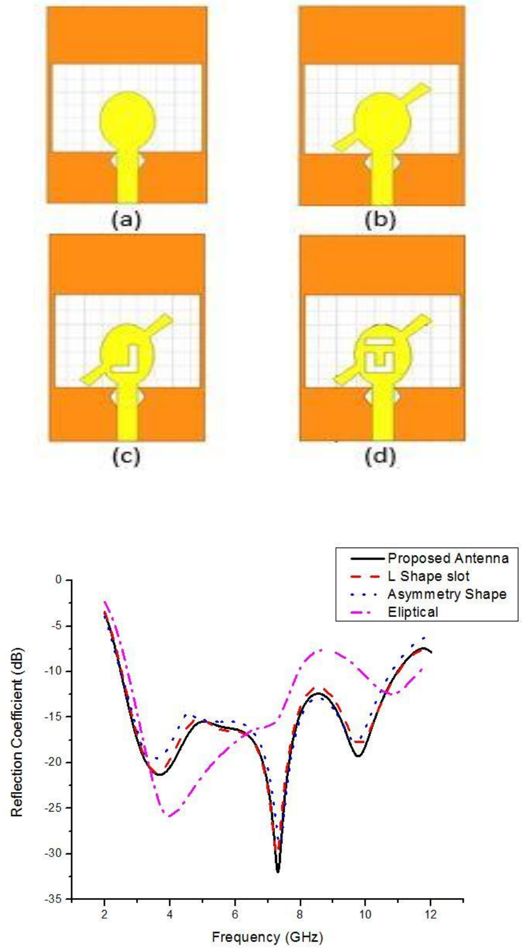


Figure.1 Proposed UWB Antenna dimensions



(e)

Figure.2 (a), (b), (c) and (d) are UWB antennas with same outer dimensions and Figure 2(e) is Reflection coefficient comparison of (a), (b), (c) and (d)

At symmetrical conditions current supplied by the feedline is distributed uniformly on the surface of the patch. If the antenna is an asymmetrical, the distribution of current is uneven over the patch because of the unbalanced current distribution, maximum radiation occurred at higher frequencies and the antenna's impedance bandwidth is enhanced. The slot in ground plane is specifically observed to play a significant role to increase the antenna bandwidth which is due to electromagnetic interaction in the slotted ground plane. The asymmetric patch design with offset feed plays a major role in maintaining proper impedance matching. As an effect of coupling between the asymmetrical radiating patch and slotted ground the lower and higher limit of resonance frequency is expanded. So the antenna’s impedance bandwidth is improved.

III. RESULTS AND DISCUSSION

The proposed UWB antenna is simulated by HFSS simulator and results are validated by using CST Simulator. In this session behavior of the antenna in both the time and frequency domains were examined. The proposed antenna prototype is fabricated as illustrated in Figure.3 (a) and 3 (b).

A. Frequency –Domain Behavior

The antenna performance in the frequency domain is analyzed in the section. The Simulation and Measured results of the reflection coefficient (S_{11}), radiation characteristics and VSWR are discussed. To investigate the human body effect fabricated antenna is tested on the surface of the human body and also in free space.

Reflection Coefficient (S_{11}) of proposed antenna simulated by Finite Element Method(FEM)based HFSS. In order to validate S11 of the antenna, the same design was simulated using CST simulator. The simulation result using the FEM solver reported a bandwidth of 2.5 to 10.97 GHz. whereas the impedance bandwidth by the finite difference transient solution ranged from 2.5 to 12GHz which is shown in figure 3(c).

The MS2037C VNA Master is utilized to take measurements of the antenna. The results of the antenna were plotted using Origin pro. The antenna is resonated at 3.6GHz, 7.4GHz, and 9.8GHz and spanned an impedance bandwidth of 2.50GHz to 10.97GHz during the measurement process which is shown in figure 3 (d). Almost all the results were uniform in the UWB frequency range and there was a small variation at some frequency. The small variation was caused by the antenna fabrication process.

Another reason could be substrate losses. The patch of the proposed antenna was asymmetric and had a slotted defective ground plane leads to reduce the antenna's size and the electric field distribution changed as the current flow was reduced. So that the bandwidth of the antenna is enhanced and impedance matching of antenna also improved.

Measurements of S11 on the body and free space are shown in Figure 3 (d). The results proved that the impact of the suggested design on the human body has a negligible effect. Moreover, the Measured results are slightly different from simulated results.

Figure 3(a)

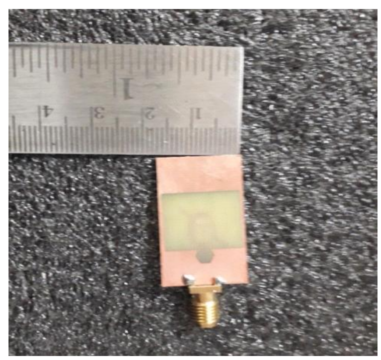


Figure 3(b)

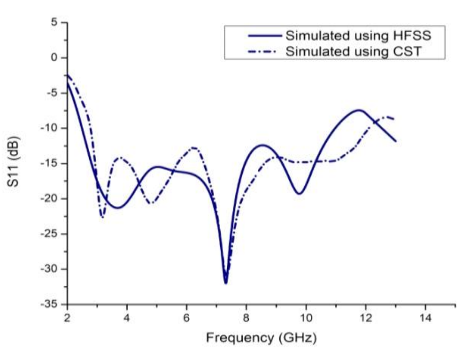


Figure 3(c)

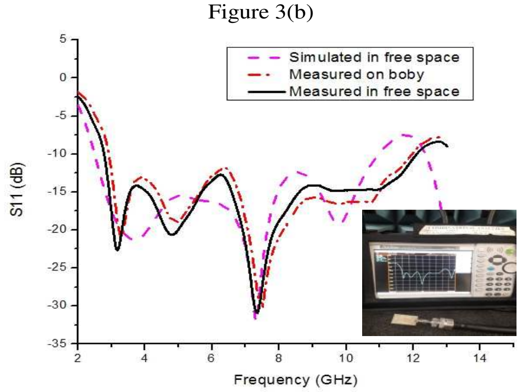
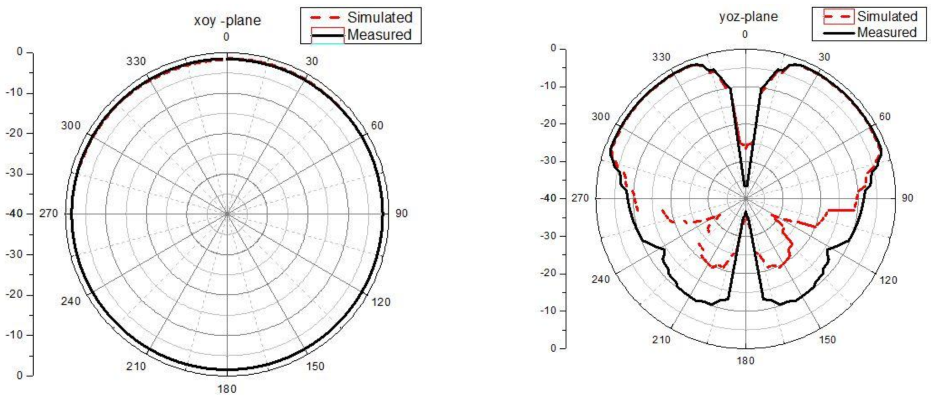
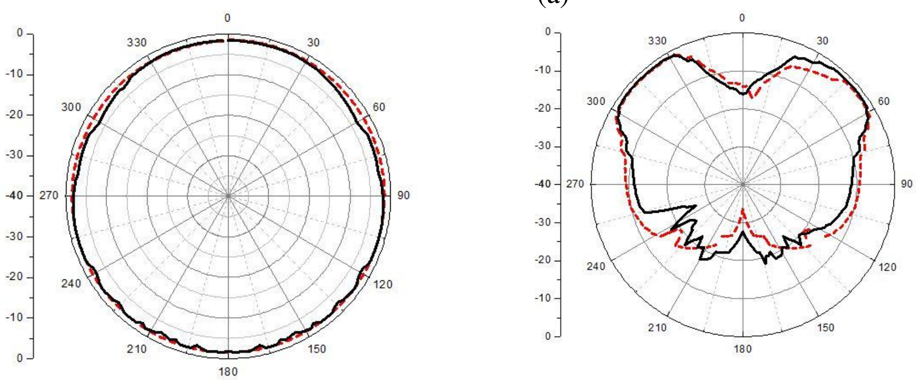


Figure 3(d)

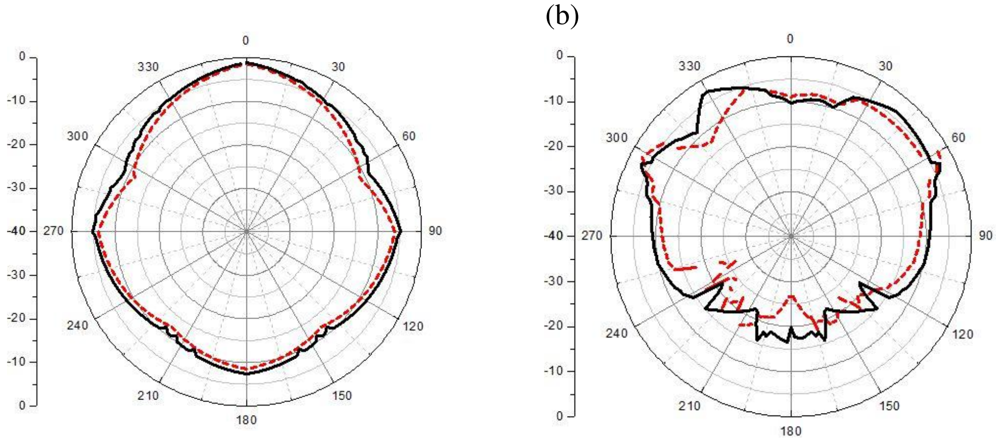
Figure 3(a) is Front view; Figure 3(b) is Rear view; Figure 3(c) is Simulation result of proposed antenna in HFSS and CST and Figure 3 (d) is Comparison of Simulated S_{11} with Measured S_{11} on the body and free space.



(a)



(b)



(c)

Figure.4 Radiation pattern for (a)3.6GHz (b) 7.6GHz (c) 9.8GHz

The radiation performance of the proposed design is analyzed by HFSS and CST tools. The far-field radiation pattern is measured in an anechoic chamber at 3.6 GHz, 7.4 GHz and 9.8 GHz. The simulated results and measured results in xoy-plane and yoz-plane at various frequencies are depicted in Figure 4.

The proposed antenna radiates Omni-directionally in the xoy plane (E Plane). The radiation pattern has some variation at high frequencies due to higher-order mode resonance. The proposed antenna's radiation performance is suitable for WBAN over the full UWB band.

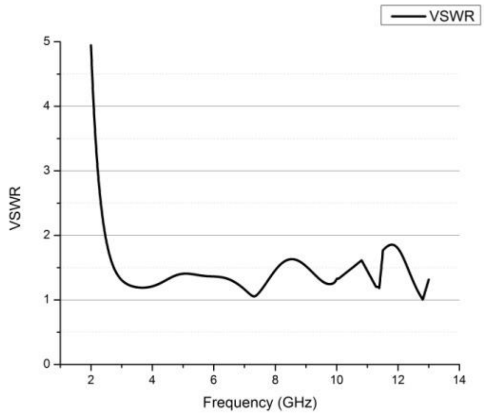


Figure 5(a)

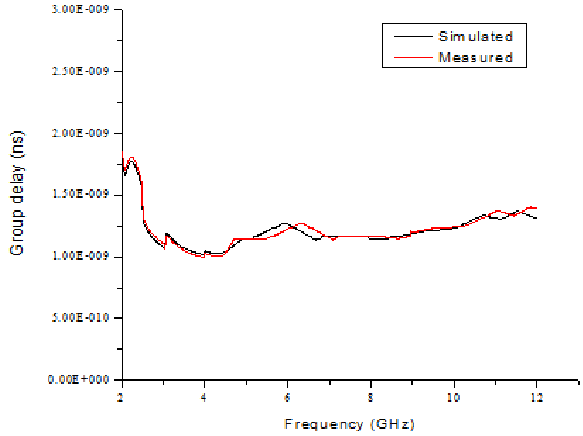


Figure 5(b)

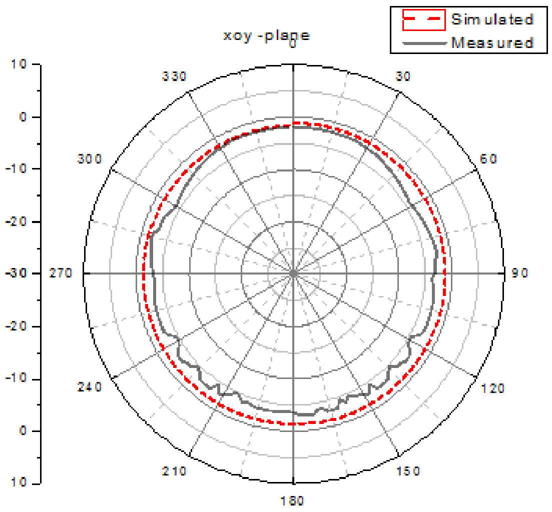


Figure 5(c)

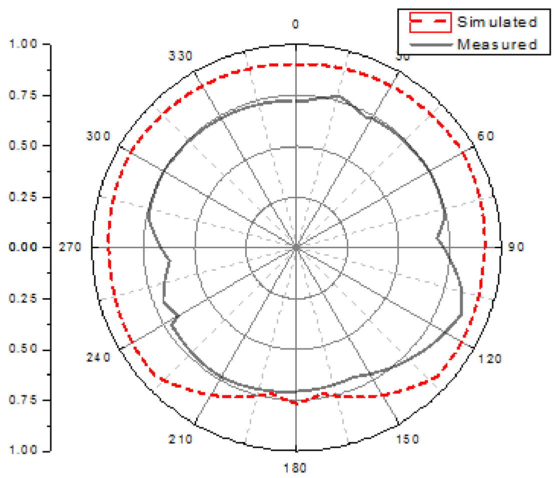


Figure 5(d)

Figure 5(a) VSWR Variation over UWB range, 5(b) Group Delay of the proposed antenna, 5(c) Simulated MRG and Measured MRG in xoy plane and 5(d) Fidelity Factor Variation

VSWR value is a numerical indicator and it is helpful to understand the status of impedance matching to which it is connected. A perfectly matched antenna has VSWR value of one. Figure 5(a) shows the VSWR Variation through the entire UWB Band. VSWR variations are acceptable over the UWB range.

B. Time domain characteristics

The performance of the antenna in the time domain is also essential to analyze. The behavior of antenna in the time domain can be understood with time domain parameters of Fidelity Factor, Group delay and Mean Realized Gain.

Mean Realized Gain (MRG) is an indicator to understand the radiation characteristics of the proposed UWB antenna in the UWB range .The MRG can be formulated as

$$MRG(r) = \frac{1}{BW_n}\int_{f_l}^{f_h} G_r(r,f)\,df$$

Figure 5 (c) depicts simulated and measured MRG over the UWB range of frequency from 2.5 to 10.97 GHz. MRG was obtained from 3dBi to 5dBi across UWB Band.

Group delay demonstrates time distortion behavior between two antennas. Two UWB antennas are set to face to face with a far-field distance of 120 mm. Figure. 5(b) shows the group delay of the proposed antenna. It is flat over the UWB range of frequencies with less variation of 0.3ns. Within UWB band the signal transmission is good without any distortion.

To understand the correlation between broadcast and received signals the fidelity factor of the antenna is helpful. It calculates the signal distortion induced by a two-antenna setup. The Fidelity Factor of Proposed antenna depicted in Figure 5 (d). The fidelity factor indicates excellent time-domain behavior at different azimuthal angles.

Table 1 Shows the Comparison of the Proposed Antenna with the Existing design. It shows that the Proposed design has an improved bandwidth with a compact size.

Table -1 Comparison of Proposed Antenna with Existing antenna

Reference	Operating Frequency Band(GHz)	Dimension (mm^2)	Radiation Pattern	Gain (dBi)
[5]	3.4-3.75 and 5.6-6	150*77	Directional	2-5
[6]	7.5-11.1	45*15	Omni	2.5
[7]	4.8-9.11	30*29	Omni	2-4
[8]	2.4	80*80	Directional	3
[9]	2.86-9.53	26*31	Omni	4
Proposed Antenna	2.5-10.97	17.5*30	Omni	3-5

IV. CONCLUSION

A UWB antenna with a unique shape of patch has been proposed for WBANs applications and it is fabricated and tested on the human membrane. This proposed antenna has benefits of both conventional and printed antennas and radiation performance is ideal for WBAN applications. The asymmetrical slotted patch with a diminished ground plane was introduced to broaden impedance bandwidth. The simulation results as well as measured results achieved 126 percent improvement in impedance bandwidth over the frequency ranges from 2.50 GHz to 10.97 GHz. The proposed UWB antenna has just a minor influence on human body. Behavior of the proposed UWB antenna in the time domain is evident in that it can transmit and receive pulse signals.

Declarations

Availability of data and materials

Data sharing not applicable to this article as no datasets were generated or analyzed during the current study.

Competing interests

The authors declare that they have no competing interests.

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Authors Contribution

SJ performed simulation and analyzed the results.GM validated the results drafted the manuscript.

Authors Information

S. Jayakumar[1], [1,]Department of ECE, SSM Institute of Engineering and Technology, Dindigul, Tamilnadu, India.
sjayakumarece@gmail.com,
G. Mohanbabu[2], [2,]Department of ECE, SSM Institute of Engineering and Technology, Dindigul, Tamilnadu, India.
shamyubabu@gmail.com,

List of Abbreviations

UWB-Ultra Wide Band; WBANs-Wireless Body Area Networks; PCBs- Printed Circuit Boards;

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Figure Title and Legend

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