Time Domain and Qualitative Analysis of a Compact Asymmetrically Fed Circular UWB Antenna for WBAN Scenarios

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Abstract *– This article presents about the design, time domain analysis and qualitative analysis of a circular monopole Ultra Wideband (UWB) antenna for Wireless Body Area Networks (WBAN) applications. The size of the proposed antenna is 30 x 30 x 1 mm3. The proposed antenna provides Ultra wide bandwidth from 2 – 10 GHz and also complies with IEEE C95.3 safety standards. The simulated and measured results are close to each other with minimum deviations. To ensure proper and less distorted communication in real time scenarios, time domain analysis was done for free space, on body and off body conditions. The magnitude and phase of transmission coefficient (S21) were found to be consistent. The group delay was analyzed under free space, on &off body conditions whose variations are less than 0.5 ns in the entire UWB range. Fidelity factor was also analyzed for flat and bent conditions to ensure pulse similarity. Also to ensure the communication link quality, the obtained minimum path loss of 51.10 dB and maximum Received Signal Power of 0.17 dBm were found to be satisfactory warranting a good transmission and reception characteristics of the proposed antenna.*

Keywords*:* *Group delay, Link budget, Link margin, On/Off body, Ultra Wideband*

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1. INTRODUCTION

Because of the fast moving life style of the people, Bio telemetry is creating remarkable footprints. To implement proper bio telemetry, a proactive health management is required. Wireless Body Area Network has gained a keen attention because of the major role played by it in health care systems. This is because it finds its application in various sectors like Bio health care, Telemedicine, sports, multimedia applications [1] and indoor data transmission [2]. WBAN communications can classified into 3 types on the basis of placing the antenna in/on the body and the method of communication with other devices. One is in body communication, where communication is established between the antenna located inside the body and another antenna located outside but on the body surface. Next is the on-body communication where two or more devices placed on the surface of the human body communicates with each other. Lastly, the off- the device located on the human body surface and an outward device or a network located away from the surface of the human body at a certain distance. Antennas that are capable of supporting both on and off body communications are of primary importance [3].

To implement such a network with good performance, the Ultra Wideband technology will be highly suitable. Ultra Wideband (UWB) antennas shall be one of the right candidates because of the advantages like compactness, low profile, large bandwidth, high data rate, low power consumption, less penetrating effects. Announcement from Federal Communication Commission (FCC) for utilizing the frequency range 3.1 – 10.6

GHz has led to such advantages. Though UWB antennas offer certain advantages, they also suffer from certain kind of short falls. Since UWB communications use short pulses with less time duration for transmission and reception, there are possibilities for those pulses being distorted easily.

Hence analyzing the transmission characteristics (time domain analysis) of an UWB antenna in terms of transmission coefficient, group delay, fidelity factor becomes inevitable to ensure good performance of UWB antennas [4].

Several UWB antennas have been used for WBAN applications, a few recent of such works are listed in the literature. Though the antennas reported in [5-13] satisfy the bandwidth and gain requirement requirements of UWB, not any parameters related to time domain analysis such as group delay, fidelity factor, path loss were analyzed. This becomes a major drawback where the UWB communication system may become less reliable. Most of the antennas reported are larger in dimensions which is also a major disadvantage in WBAN scenarios.

Also, most of the antennas support either on body communication or off body communication but not the both.

In the works reported from [14-17], group delay was analyzed under free space conditions. In [18], group delay was analyzed for free space, on body and off body conditions and comments were presented for the three conditions. The works reported in [19-22] have analyzed the transmission coefficient and group delay but it is done only under free space conditions. Fidelity analysis was done in the works [23-26] only under two conditions namely face to face and side to side, but not for face to side and side to face conditions.

In all of the above works done, the analysis was done only under free space condition. But in actual WBAN or wearable scenarios, communication shall happen in on body and off body scenarios also.

Hence, keeping in mind the requirements of an efficient antenna for WBAN and coming to know the short falls prevailing, a compact UWB antenna with ultra-wide bandwidth, good gain supporting both on and off body communications is proposed in this work. Also, to furnish the need of real time WBAN scenario and analyze the system's transmission performance, time domain analysis was carried out for free space, on body and off body conditions. Fidelity analysis is done in normal and bent conditions with four different configurations. Quality analysis was also done by analyzing the Received Signal power or Received Signal Strength (RSS) for free space, on body and off body conditions. The effects of the parameters that affect the RSS are also studied and the results are presented.

The manuscript is organized with the antenna design methodology in chapter II, achieved results in chapter III, followed by Time domain and qualitative analysis in chapter IV and V respectively.

2. ANTENNA DESIGN

This section focuses on the proposed UWB Antenna design. The entire design of the antenna shown in Fig. 1 is considered for further analysis. The substrate used is ROGERS 4003C whose dielectric constant is 3.5 & loss tangent is 0.0027. The total foot print of the antenna is 30x30x1 mm3. All the dimensions are given in Table 1.

The antenna is fed by a 50Ω micro strip line. The stage to stage evolution of the antenna design is depicted in Fig. 2 and the corresponding effects in the resonance characteristics in terms of return loss (S11) is depicted in Fig. 3. The basic shape of the proposed antenna is a circular patch. To design the circular patch antenna, the required radius was estimated using the conventional design equations in [27] which are represented in equations 1 and 2.

$$a = \frac{F}{\sqrt{1 + \frac{2h\left(\ln\left(\frac{\pi F}{2h}\right)\right) + 1.7726}{\epsilon \pi F}}} \quad (1)$$

$$F = \frac{8.791 \times 10^{9}}{\sqrt{\varepsilon_r}\, f_r} \quad (2)$$

Where,

- a-radius of the patch
- h-thickness of the substrate
- f_r-resonant frequency
- ε_r-dielectric constant of the substrate
- F-a constant

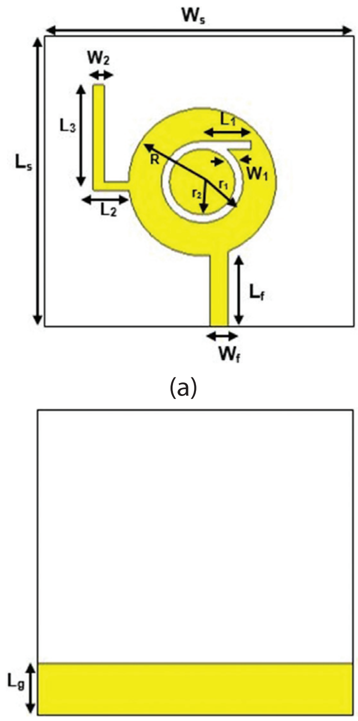


Fig. 1. Proposed antenna, (a) front view, (b) back view

The circular patch antenna designed in stage 1 resonates at 4.2 GHz with some additional harmonics at higher frequencies. In stage 2, a ring shaped slot is introduced slot is introduced in the patch to alter the current path and supress the higher order harmonics. The additional capacitive coupling introduced by the slot between the either sides of the slot help to supress the unnecessary higher order resonances.

Table 1. Antenna Dimensions

Sl. No.	Dimensional parameter	Dimension name	Value (mm)
1.	W_s	Substrate width	30
2.	L_s	Substrate length	30
3.	R	Patch radius	9
4.	R_1	Radius of outer ring	6
5.	R_2	Radius of inner ring	5
6.	W_1	Width of ring slot	1
7.	W_2	Width of stub	1
8.	L_1	Length of slot	6
9.	L_2	Length of horizontal stub	4.5
10.	L_3	Length of vertical stub	12
11.	L_g	Length of ground plane	6.3
12.	L_f	Length of feed	10
13.	W_f	Width of feed	2

The outer radius of the ring slot was obtained using the following relation [18].

$$a_{slot} = \frac{7.15}{\sqrt{\varepsilon_r} f_r} \tag{3}$$

The inner radius was chosen in such a way to maintain better impedance matching and fixed to be 5mm. Once the higher order harmonics are supressed, now to improve the antenna's resonance at lower band, in stage 3, a horizontal slot was combined with the ring shaped slot due to which two resonances were created, one at 3.5 and the other at 3.7 GHz. But the S_{11} values appear very close to the threshold level of -10 dB. Hence to improve the S_{11}, the impedance matching has to be improved. In this notion, the feed location was placed asymmetrically which is the stage 4 and the S11 was improved to -19 dB from -11 dB. In stage 5, a horizontal stub is introduced in the patch to increase the electrical length of the antenna which in turn will increase the bandwidth. Seeking further improvement in bandwidth, another vertical stub was combined with the horizontal stub as it increases the inductance, which will improve the bandwidth at higher frequencies. The stub length was calculated using equations 4 and 5 as per the suggestions in [28]

$$f_r = \frac{c}{\sqrt{\varepsilon_r} 4 l_e} \tag{4}$$

Where *fr* is the frequency, ε_r is the permittivity, l_e is the effective length which is given by

$$l_e = l_{stub} + \frac{0.4 l_{stub}}{\sqrt{\varepsilon_r}} \tag{5}$$

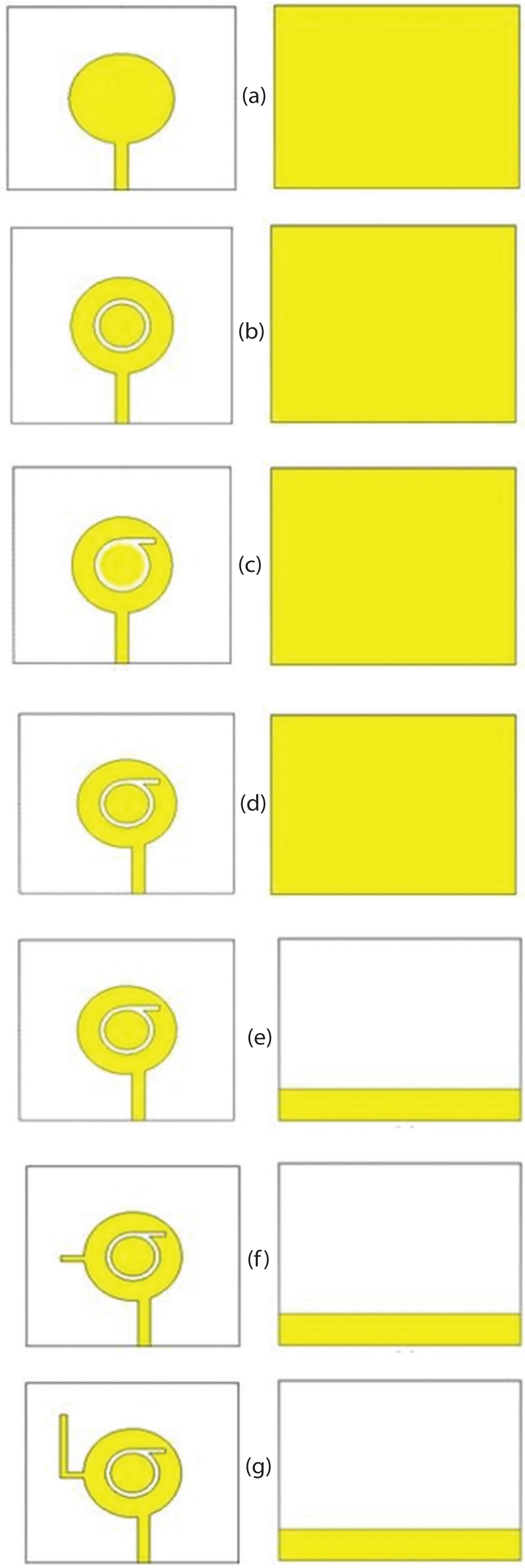


Fig. 2. Various stages of antenna design, (a) stage 1, (b) stage 2, (c) stage 3, (d) stage 4, (e) stage 5, (f) stage 6, (g) stage 7

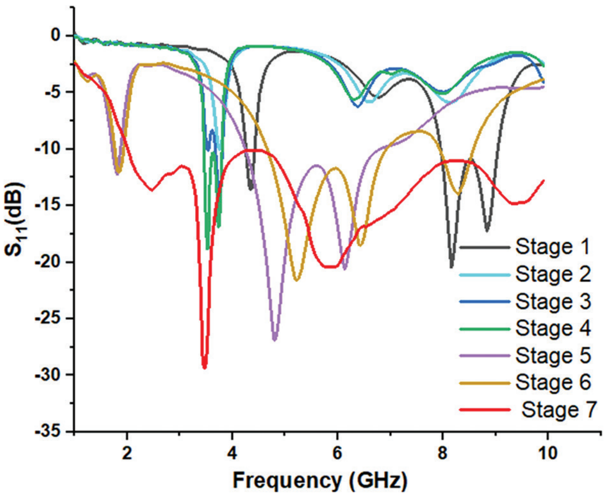


Fig. 3. S_{11} of various stages of antenna design

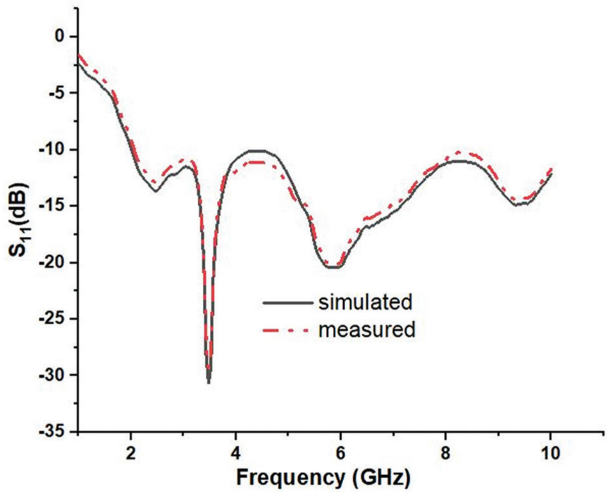


Fig. 5. S_{11} of the proposed antenna – Simulated and Measured

Initially, for a frequency of 10 GHz, the effective length was calculated using equation 4 and using that the stub length (lstub) was calculated using 5. But still the Ultra wide bandwidth of 7.5 GHz (3.1 – 10.6 GHz) was not achieved. Hence the length of the ground plane was reduced then to achieve UWB bandwidth. The reduced length of the ground plane was calculated using the following relation in equation 6.

$$L_{partial} = \frac{C}{1.45 f \sqrt{\varepsilon}} \tag{6}$$

Reducing the ground plane length results in a reduced Q factor which increases the bandwidth as per the relations given in equation 7 [28]

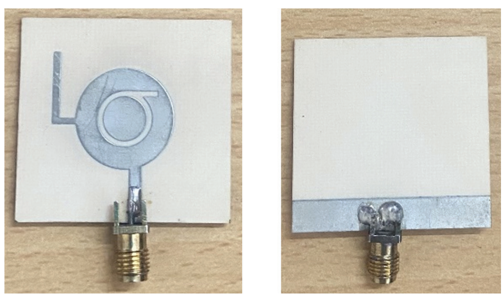
$$Bandwidth = \frac{f_r}{Q} \tag{7}$$

3. RESULTS AND DISCUSSION

The authors have focused on the analysis of basic results like S_{11}, bandwidth, gain etc. in brief while the time domain & qualitative analysis of the antenna were made in depth thereby justifying the manuscript title.

a) Return loss (S_{11}) and Bandwidth

The fabricated prototype is shown in Fig. 4. The simulated and measured S_{11} of the proposed antenna is shown in the Fig. 5.



(a) (b)

Fig. 4. Fabricated antenna, (a) front view, (b) back view

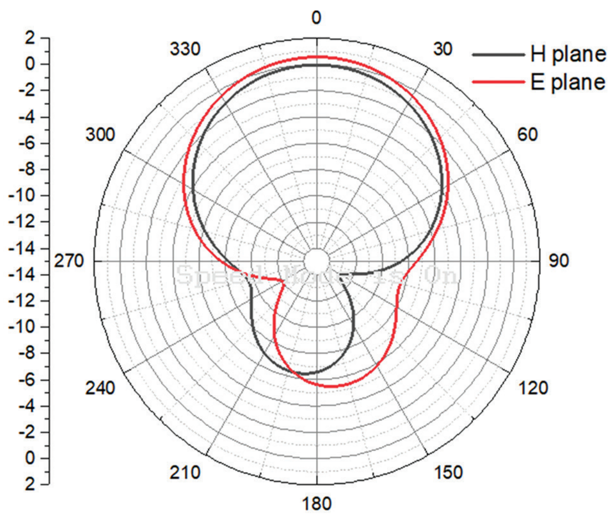
It is seen from the graph that the simulated and measured results agree well with each other with minimum deviations which are due to fabrication errors. The S_{11} of the antenna are -13 dB, -32 dB, -21dB and -14 dB at 2.4, 3.5, 5.8 and 9.3 GHz respectively. The absolute bandwidth of the antenna is 8 GHz ranging from 2-10 GHz.

b) Radiation pattern

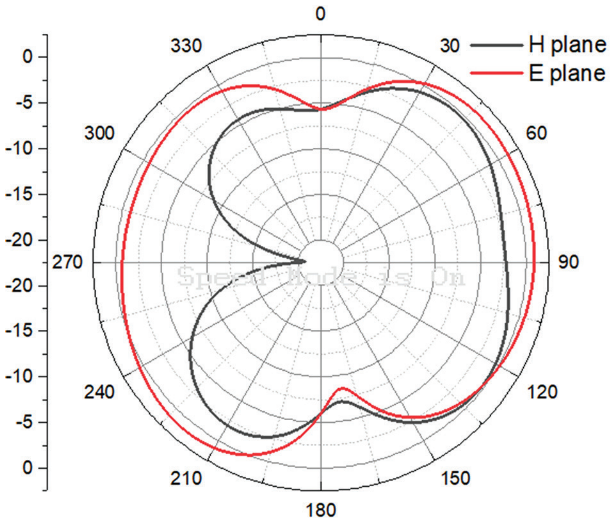
The measured radiation pattern of the antenna is depicted in Fig. 6. The antenna provides omnidirectional pattern at 5.8 GHz facilitating on body applications and directional pattern perpendicular to the ground at 2.4 GHz facilitating off body communication. Thus it supports both on and off body applications.

c) Gain

The measured gain of the antenna reported is shown in Fig. 7. The antenna affords the gain of 1.85 dB, 3.13 dB, 3.36 dB and 5.95 dB at 2.4, 3.5, 5.8 and 9.3 GHz respectively with a peak gain of 6.61 dB at 7 GHz. From the measured gain values, the calculated measured efficiencies are 86%, 89%, 92%, 94% at the respective frequencies.



(a)



(b)

Fig. 6. Radiation Pattern of proposed antenna (a) at 2.4 GHz (b) at 5.8 GHz

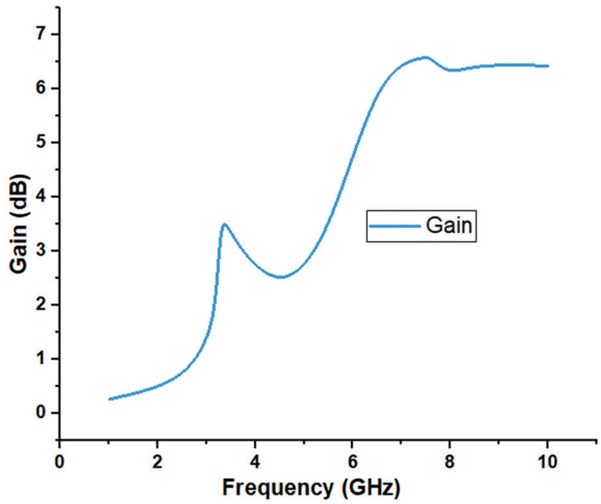


Fig. 7. Measured gain of the proposed antenna

d) SAR

The Specific Absorption Rate (SAR) of the proposed antenna is calculated in the presence of a three layered human tissue model whose setup is shown in the Fig. 8 [21]. The simulated SAR values are 0.579 W/Kg and 0.498 W/Kg at 2.4 and 5.8 GHz respectively. These values are much lower than the prescribed value of 1.6 W/Kg as per IEEE C95.3 standards which makes the proposed antenna more suitable for WBAN based applications.

e) Deformation analysis

Antennas deployed in real time WBAN scenarios undergo deformation in the form of bending. Hence, a bending based deformation analysis is done to study the antenna behaviour. The sample images of the bent antenna are shown in Fig. 10. Two orientations namely x and y orientations were considered for bending. The corresponding resonance behavior is depicted in the Fig. 11. From the results of y bend, it is observed that only the S_{11} values change from -30 dB to -25 and -22 dB. This change is because of the change in the impedance of the antenna's feed while bending it symmetrically. Still the antenna's S_{11} remains below -10 dB which the standard value for reference.

On analyzing the x bend results, there is slight shift of resonances. Nevertheless, the shift in resonance occurs only within the band of operation of the proposed antenna (2-10 GHz) and hence the results remain unaffected due to bending.

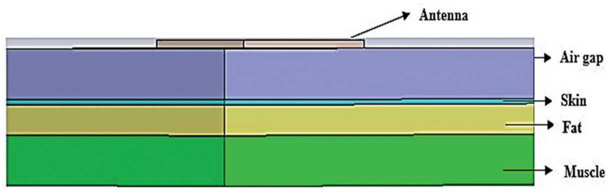


Fig. 8. SAR simulation setup of the proposed antenna

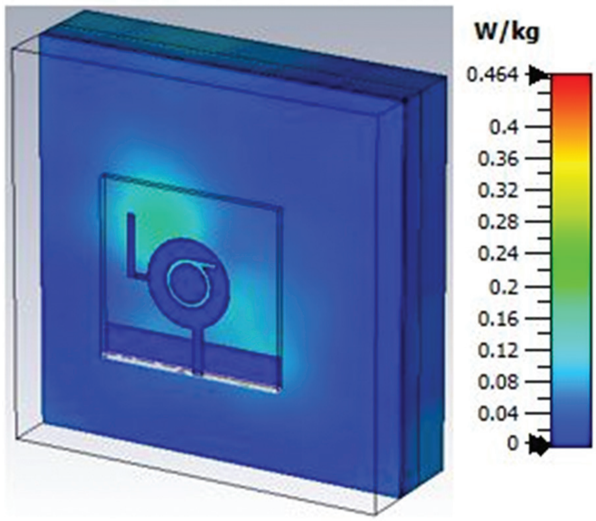
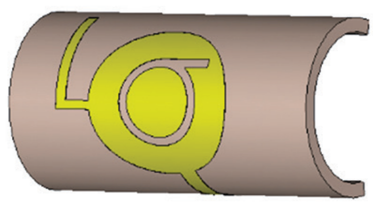


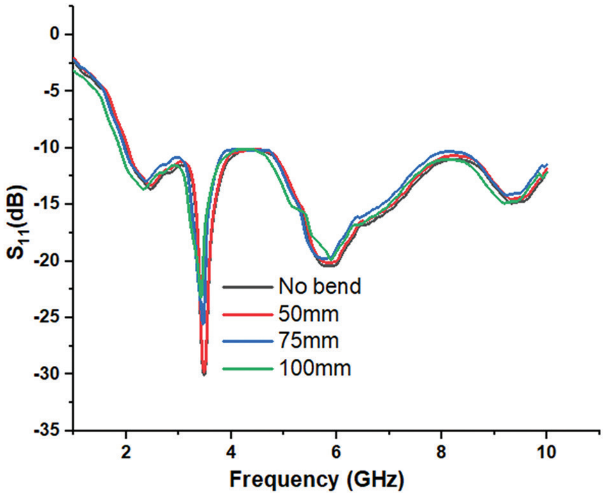
Fig. 9. SAR simulation of the proposed antenna

(a)

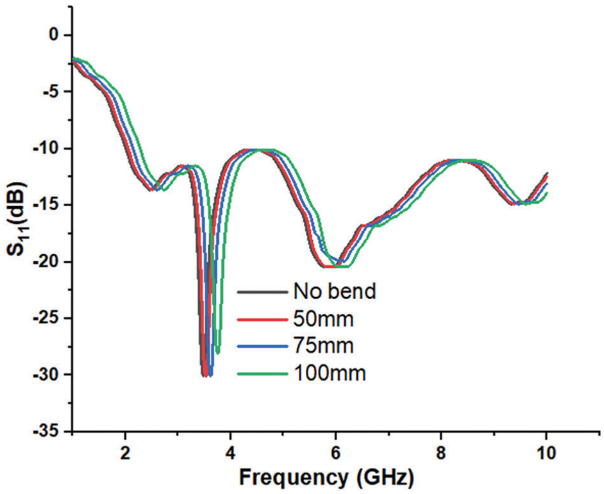


(b)

Fig. 10. Antenna bending (a) y bend (b) x bend



(a)



(b)

Fig. 11. Antenna bending results (a) y bend (b) x bend

From the bending results, it can be concluded that, the performance of the antenna undergoes only acceptable minimum change due to deformation which proves the proposed design's robustness.

4. TIME DOMAIN ANALYSI

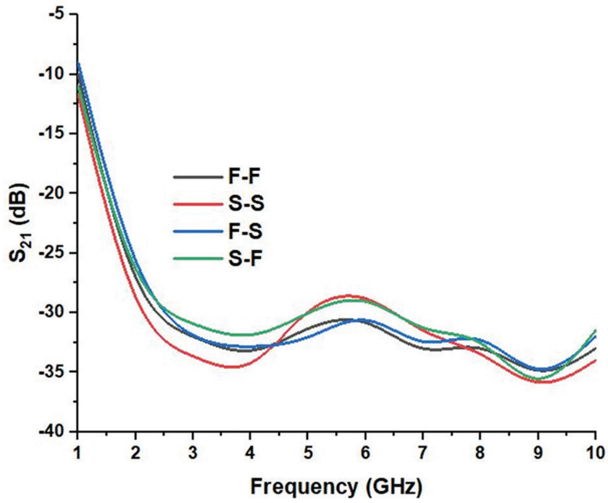
All the required results such as Reflection Coefficient, Bandwidth, Gain, Radiation Pattern, Efficiency, SAR were found to be satisfactory. Hence, the transient analysis alone is concentrated in depth in this section. Data transfer in UWB systems happens in the form of pulses which are of short duration and so there could be distortions in the communication. This can be verified by analyzing the system transfer function in terms of transmission coefficient S_{21}.

a) Free space condition

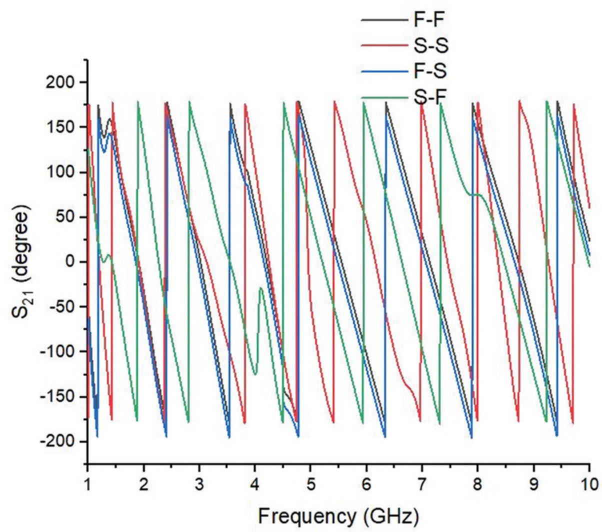
The measurement set up for evaluating the magnitude and phase of the system function S_{21} is presented in the Fig. 12 and the corresponding results are presented in Fig. 13. Four kinds of setups were used for analysis namely face to face (F-F), side to side (S-S), face to side (F-S) and side to face (S-F). These four scenarios shall be encountered in real time cases and hence they were chosen.

Fig. 15 a shows the magnitude of S_{21} and 15 b shows the phase of S_{21}. A communication with less distortion is attested by the minimum fluctuations in magnitude of S_{21} and linear phase variations in S_{21}.

Fig. 12. Free space measurement set up



(a)



(b)

Fig. 13. Free space Transmission response (S_{21}) performance under various setups (a) Magnitude of S_{21} (b) Phase of S_{21}

It can be seen that, the magnitude of S_{21} is almost consistent for all the cases and the variations in phase response is linear. This shows that the antenna performs well under free space conditions. However, a noticeable decrease in magnitude occurs between 1 and 2 GHz. Since the desired operational frequency range of the antenna is 2-10 GHz, it may not be taken into account.

b) On body condition

In WBAN scenarios, communication mainly exists between two nodes placed on the body surface. This scenario is on body scenario where the antenna is placed on the body surface with a suitable separation, preferably clothing [19]. Hence it is very much obligatory to study the performance of the antenna under this scenario. To make this study elaborate, two real time transmission scenarios were chosen which are Line of Sight (LOS) and Non – Line of Sight (NLOS). Antenna locations on the human body were chosen accordingly.

To establish LOS communication, two case studies were chosen. In the first case, one antenna which acts as the transmitting antenna is placed on the chest of the human body and the other antenna is placed on the abdomen of the same human. In the second case, one antenna is placed in the same chest location while the other is placed in the front portion of the arm (arm front).

Fig.14. Measurement set up for on body communication (same body)

To establish NLOS communication, two case studies were chosen. In the first case, one antenna is placed on the chest of the human body and the other antenna is placed on the back of the same human. In the second case, one antenna is placed in the same chest location while the other is placed in the back portion of the thighs (thighs back). All these measurement setups are shown in the Fig. 14.

The obtained S21 characteristics is depicted in Fig. 15. On observing figure 15 a, it can be seen that there is a slight variation in the magnitude and phase of S_{21} in chest to back and chest to thighs back cases. This is because change in magnitude occurs as both the antennas are placed facing opposite to each other. Also the presence of human body in between both the antennas influences the transmission and reception behavior.

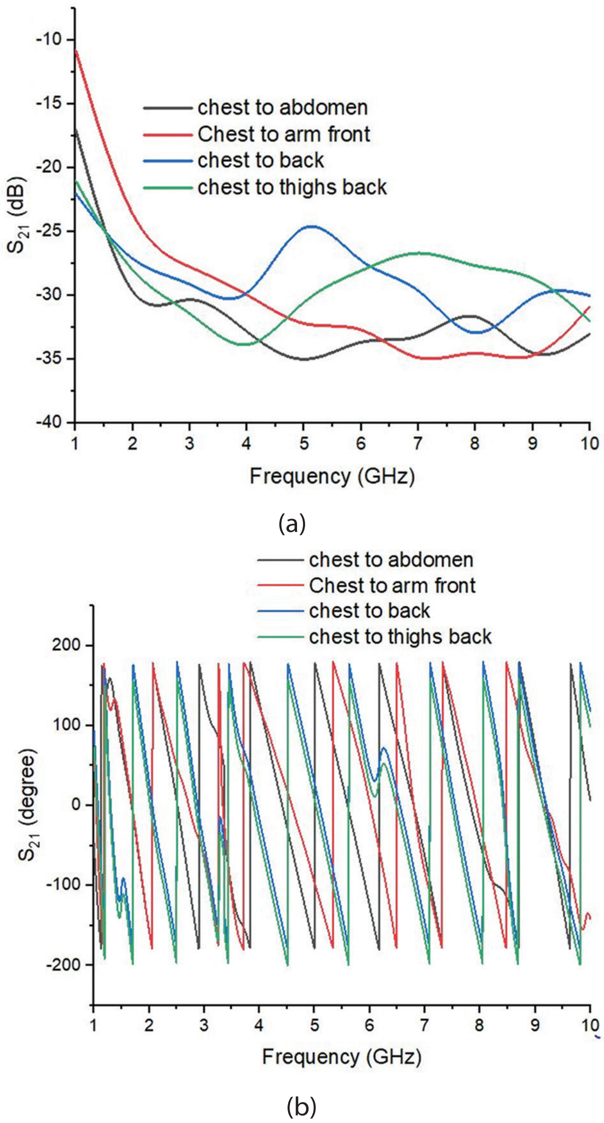


Fig. 15. On body Transmission response (S_{21}) under various setups (a) Magnitude of S_{21} (b) Phase of S_{21}

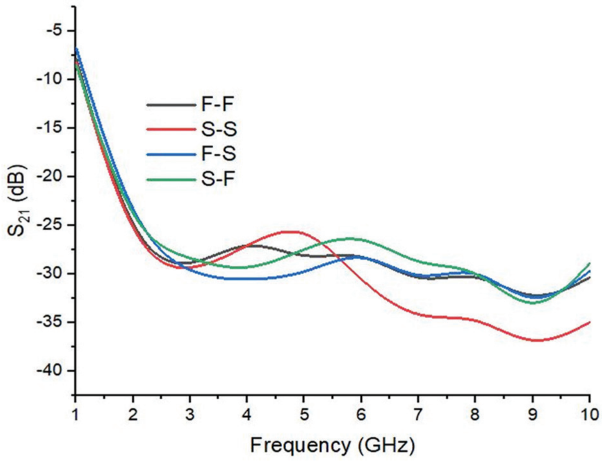
c) Off body condition

In off body condition, communication happens between the antenna in one human body to another antenna in another human body proximity or any other location. To encounter this scenario, one antenna is placed in the chest of one human volunteer while the other antenna is placed in the chest of another human volunteer of nearly same physic. Also to mimic real time scenarios, four real time cases such as F-F, S-S, F-S, S-F were also considered and the results were studied.

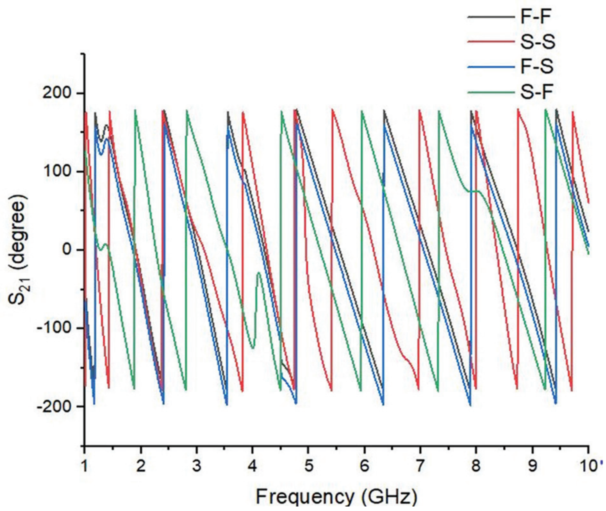
The measurement setup for off body condition is shown in the Fig. 16. The corresponding results are shown in the Fig. 17.

From the results, is can be understood that the magnitude and phase response of the proposed antenna are consistent and linear for F-F, S-S, F-S and S-F scenarios. So the proposed antenna exhibits acceptable transmission and reception characteristics under free space, on body and off body conditions.

Fig. 16. Measurement set up for off body communication (different bodies)



(a)



(b)

Fig. 17. Off body Transmission response (S_{21}) under various setups (a) Magnitude of S_{21} (b) Phase of S_{21}

d) Group Delay

To validate the phase distortions, a parameter called group delay is to be examined. It represents the distortion in phase response alone.

The group delay is given by the expression below.

$$T_g = \frac{-d\varphi}{d\omega} \tag{8}$$

Where φ is the phase factor and ω is the angular frequency. The group delay measurement was carried out with the measurement setups that were similar to the ones already depicted in Figs. 12, 14 and 16.

For free space and off body scenarios, group delay was measured for four cases F-F, S-S, F-S, S-F. The results are shown in the Figs. 18 and 19. From the figure it is seen that the group delay of the antenna under all the four cases are flat with variations being within the 0.5 ns.

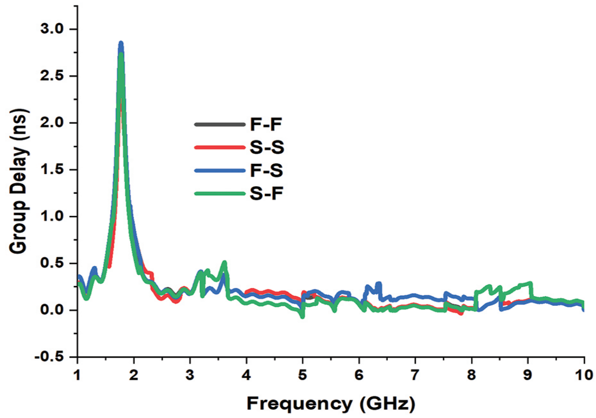


Fig. 18. Group delay (free space)

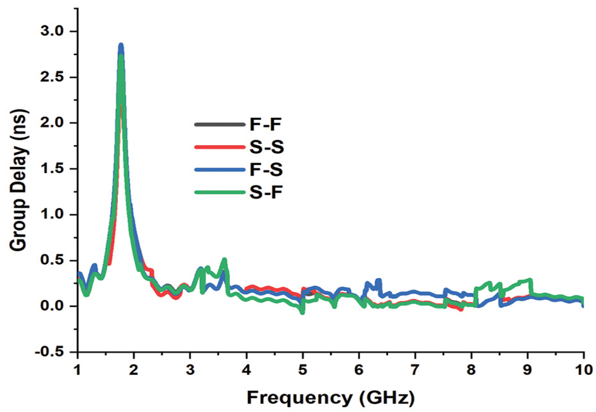


Fig. 19. Group delay (off body)

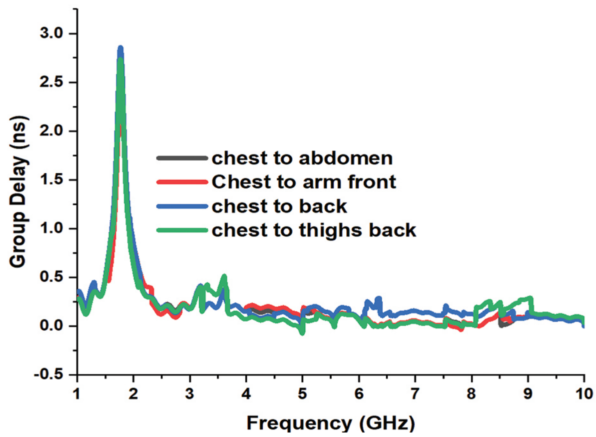


Fig. 20. Group delay (on body)

A flat response is found in all the cases which ensures minimum phase distortions. Some variations in the group delay is seen from 1.6 GHz to 1.9 GHz. But it may not be given more attention as it is not in the operational frequency range. The measured group delay of the antenna for on body scenario is shown below in Fig. 20. The group delay shows good results with flat response.

e) Fidelity Analysis

While establishing communication in UWB systems, the shape of the UWB pulses has to be preserved from the period of transmission to reception. Analyzing this pulse preserving capability is said to be fidelity analysis. The analysis term is called as fidelity factor (FF).

The expression used to evaluate the FF is as follows

$$FF = max \int_{-\infty}^{\infty} T_s\,(t)\, R_s\,(t+\,\tau)\,dt \qquad (9)$$

To find out the FF of the proposed antenna, one antenna is used as a transmitter antenna and another as a receiving one. Fidelity factor was analyzed for four cases as already mentioned namely F-F, S-S, F-S and S-F. The transmitted and received signals were collected and applied in equation 4 for all the four cases. The obtained FFs are tabulated in Table 2.

Table 2. FF for Various Cases

Cases	F-F	S-S	F-S	S-F
FF (flat)	0.912	0.916	0.902	0.906
FF (x-bent)	0.853	0.863	0.852	0.866
FF (y-bent)	0.889	0.875	0.895	0.883

Also to analyze the fidelity performance in various angles of receiver, instead of using a similar antenna or another kind of antennas as receiver, field probes were setup with various angular separation. Analysis is also done for both flat, bent and on body conditions.

This simulation setup was developed using CST microwave studio and is shown in the Fig. 21 and the results are shown in Table 3.

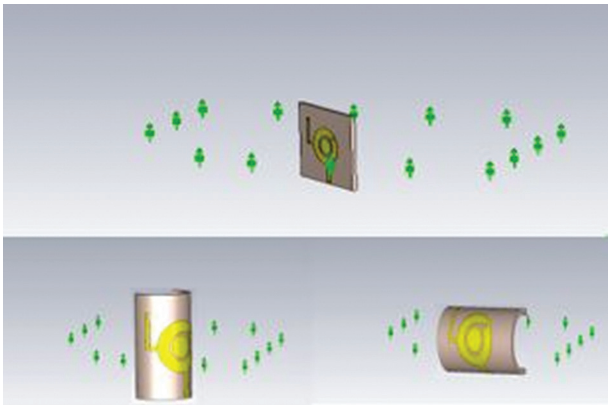


Fig. 21. Simulation set up for fidelity analysis

Table 3. FF for Various Angles

Angular separation (in degrees)	30	60	90	120	150	180
FF (flat)	0.92	0.91	0.91	0.91	0.90	0.90
FF (x-bent)	0.83	0.83	0.82	0.81	0.80	0.79
FF (y-bent)	0.83	0.82	0.81	0.81	0.81	0.79

A good correlation between the transmitted and received pulse exists if the FF value is equal or above 0.5 [29]. Looking into the values of FF in both table 2 and table 3, all the FF values are above 0.5 which ensures good correlation between the transmitted and received pulses.

5. QUALITATIVE ANALYSIS

To study the quality of the transmitted & received signal and also the proposed antenna, framing the link budget using the proposed device shall be certainly required. The link budget represents the received signal strength (RSS) of the antenna. With the conditions of acceptable impedance and polarization matching, the expression to evaluate the measured RSS is as follows [30].

$$P_{rx}\,(dBm) = P_{tx}(dBm) +\; G_{tx}\,(dB) +\; G_{rx}(dB) - P_L\,(dB) \qquad (10)$$

Where, P_{tx} is the transmitted power, P_{rx} is the received power, G_{tx} is the transmitter antenna gain, G_{rx} is the receiver antenna gain, P_L is the path loss. The measured path loss of the antenna is calculated using the expression as follows [30]

$$P_L = -10\log\left(\frac{G_{tx}G_{rx}\lambda^2}{(4\pi d)^2}\right) \qquad (11)$$

Where, d is the distance between the transmitter and receiver and λ is the operating wavelength. The path loss and in turn the received power is calculated for free space, on body and off body conditions at varying distances and the results were studied.

For on body condition, the transmitter and receiver antennas were placed on the chest and belly locations with a measured separating distance of 200 mm (20 cm). This represents the LOS case. For NLOS case, the receiver antenna was placed at the same separating distance but exactly at the back portion to the belly. Similar to this, the P_L was calculated for free space and off body conditions. While evaluating P_L for off body condition, on body gain of the transmitter antenna and the free space gain of the receiving antenna was considered which resembles the off body case. For free space P_L, the free space gain was considered for both the antennas.

All the path loss values are tabulated in table 4. With the obtained P_L values the link budget was analyzed by calculating the received power according equation 10 at two target frequencies 2.45 and 5.8 GHz. The transmitted power of the antenna is chosen to be 27 dBm as per the suggestions in [31]. The obtained received signal power is tabulated in Table 5.

Table 4. Path Loss

Frequency (GHz)	PL (dB) for 100 mm			
	Free space	On body		Off body
		LOS	NLOS	
2.45	31.15	32.69	33.20	31.92
5.8	36.04	36.70	37.12	36.38
Frequency (GHz)	**PL (dB) for 200 mm**			
	Free space	**On body**		**Off body**
		LOS	**NLOS**	
2.45	45.02	46.55	47.02	45.79
5.8	49.93	50.56	51.10	50.24

Table 5. Received Signal Power

Frequency (GHz)	Prx (dBm) for 100 mm			
	Free space	On body		Off body
		LOS	NLOS	
2.45	0.17	-1.69	-2.20	-0.76
5.8	-1.04	-1.95	-2.37	-1.5
Frequency (GHz)	**Prx (dBm) for 200 mm**			
	Free space	**On body**		**Off body**
		LOS	**NLOS**	
2.45	-13.70	-15.55	-16.02	-14.63
5.8	-14.93	-15.81	-16.35	-15.36

Based on this received signal power, the communication link margin (LM) is calculated as [32]

$$LM\ (dB) = P_a - P_r \tag{12}$$

Where, P_a and P_r are the available and required power levels.

LM is the difference between the available power and required power. The available power level is given by

$$P_a = P_{rx} - N_0 \tag{13}$$

The required power level is given by

$$P_r = \frac{E_b}{N_0} + 10log_{10}(B_r) - G_c + G_d \tag{14}$$

The parameters in equations (13) & (14) are adhered with the methods and values in [32] and P_{rx} is taken from equation (10).

In order make a justified comparison with the available literatures, the distance between the transmitting and receiving antenna is taken to be 5m which was also considered for calculations in [33-36]. For this distance, the calculated LM under free space condition is 60 dB. This LM is comparatively better than the LM in [33-36].

A comparison of the proposed antenna's performance is shown in the Table 6.

On comparing with the existing works, the proposed antenna is lesser in size than [20, 23, 24, 32], more in gain than [30, 23-25, 32-35], higher in bandwidth than [25, 35], lesser in group delay than [20,24,25]. Also, better performance in terms of communication link budget is achieved on comparing with the link budget in [33-36] which is a notable feature of the antenna.

Table 6. Performance Comparison

Reference	Size (mm3)	Peak Gain (dB)	Bandwidth (GHz)	Group delay (ns)	Minimum Path Loss	Link margin (dB)
[20]	24 x 28 x 1.6	4.08	8.37	Up to 10 ns	NA	NA
[23]	51.5 x 31 x 1.6	5.97	10.39	up to 0.5 ns	NA	NA
[24]	35.9 x 29.8 x 1.6	6.5	9.2	up to 4 ns	NA	NA
[25]	12.5 x 12.5 x 1 mm^3	4.12	7.7	up to 4 ns	NA	NA
[26]	42 x 40 x 1.6	4.1	8.9	0.5	60	NA
[32]	36 x 36 x 9.5	6.4	NA	NA	96	-105
[33]	14.8 x 21.7 x 0.254	2.15	12.6	NA	NS	12.24
[34]	15 x 15 x 1.27	-31.4	0.261	NA	NS	20
[35]	26 x 11 x 1	-36	NA	NA	NS	6.89
[36]	10 x 10 x 1.27	-21	NA	NA	NS	50
Proposed	**30 x 30 x 1**	**6.61**	**8**	**0.5**	**109**	**60**

*NA – Not Analyzed, NS – Not Specified

6. CONCLUSION

The design, time domain and qualitative analysis of a dual mode UWB antenna has been discussed in this paper. The proposed antenna was able to provide 8 GHz bandwidth with sufficient gain and less SAR. Free space and body centric measurements were carried out for analyzing the parameters like the magnitude and phase of the transmission coefficient, group delay with various scenarios. The magnitude of transmission coefficient is almost constant and change in phase is also linear with slight variations in the NLOS case alone. The group delay of the antenna is also constant with less variations which ensures reduced amount of distortion in the desired operational range. Fidelity factor was calculated under flat and bent conditions for various cases and angles whose values are good enough to preserve the pulse during transmission and reception. Analysis of Link budget and Link margin ensured proper and quality communication link. Thus the proposed antenna's compliance with WBAN and UWB requirements makes it to be a promising candidate suitable for UWB based WBAN applications.

COMPETING INTERESTS

The authors declare hereby that there are no competing interests in publishing the paper in any form.

DATA AVAILABILITY STATEMENT

Data sharing is not applicable as no data sets were generated

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