Indian Journal of Pure & Applied Physics
Vol. 62, October 2024, pp. 884-896
DOI: 10.56042/ijpap.v62i10.11933

A Novel UWB Planar Antenna for Biomedical Applications based on CB - CPW Technique

Munna Khan[a], Lily Kumari[a,b] & Zahreeuddin[a]

[a]Department of Electrical Engineering, Jamia Millia Islamia, New Delhi, 110 025, India

[b]Electronics and Communication Engineering, Dronacharya Group of Institutions, Greater Noida U.P 201 306, India

Received 20 June 2024; accepted 4 September 2024

This paper presents, an Ultra-Wide Band CB-CPW based planar antenna design for biomedical applications. The proposed low-profile antenna boasts a compact size, measuring 66 × 52 × 1.57 mm^3. Here, a comparative analysis is performed of designed antenna with and without the CB-CPW technique. The designed antenna operates at resonance frequencies of 1.9 GHz and 5.37 GHz. It exhibits significant bandwidth from 1.6 to 6GHz. The gain of designed antenna is 2.8 dBi and 4.8 dBi at 2.45 GHz and 5.78 GHz respectively. Here, the designed UWB planar antenna is simulated using CST MWS and the results are verified experimentally. The antenna with CB-CPW technique demonstrates efficiency of 88.2% at 2.45 GHz and 78% at 5.8 GHz. The designed antenna is simulated with body phantom and also against the structural deformation (Bending).The antenna simulated and the experimental results demonstrate the efficacious performance of the designed antenna, even when subjected to structural deformation like bending. SAR analysis of the designed antenna has been simulated with HUGO human body model of VOXEL family using CST MWS software. Moreover, designed antenna indicate a significant low specific absorption rate (SAR) value with in the IEEE and FCC guidelines. The proposed antenna has low profile, compact size, low SAR, negligible backward radiation, broad bandwidth and high gain, position it as an excellent choice for BAN biomedical applications.

Keywords: Planar antenna; ISM (Industrial Scientific and Medical) Band; SAR (Specific absorption rate); Biomedical Antenna; MBAN (Medical Body Area Network); WBAN(Wireless body area network); Human Body Phantom; CB-CPW(Conductor Backed- Coplanar Waveguide); UWB(Ultra -Wide Band)

1 Introduction

Over the last few years, BAN (Body Area Network) has seen substantial growth alongside advancements in communication systems. These networks support a wide range of applications, such as personalized healthcare, patient health monitoring systems, relief and rescue operations, war field survival treatment, wireless medical data transmission and wearable gaming systems[1-3]. Body Area Networks (BAN) have been becoming a boon, especially for continuous health monitoring of Kids or elderly patients. The wearable devices are playing a key role in this, without hampering their today life activities[4,5]. Various frequency spectrum has been assigned to facilitate the commercialization of BAN communication systems, including the MICS spectrum (402-405 MHz), ISM band (2.40-2.48 GHz), WBAN(5.75-5.85 GHz) and Ultra-Wide Band. The FCC specified frequency band 2.4-2.48 GHz and 5.75-5.85 GHz for Medical Body Area Network and Wireless Body Network applications respectively worldwide. To ensure optimal performance, antenna used in BAN applications must meet specific criteria: it should be small sized, low profile, robust, easy to wear, and lightweight. It has been observed, the performance of designed antenna deteriorates significantly when it operates in close proximity to the human body[6,7]. This degradation occurs because the body's near-field coupling affects the surface currents of the antenna. Consequently, impacting the antenna's input impedance matching. When dealing with narrow-band operation, the immediacy with human body can significantly affect, a on body antenna. This proximity induces a shift in the antenna's resonance frequency, causing a mismatch at the desired frequency and resulting in substantial decrease in overall efficiency.

Implementing a biomedical antenna that combines high efficiency with attributes such as a low-profile, conformal shape, and lightweight design poses a considerable challenge[7,8]. Moreover, it is crucial to consider the impact of biomedical antennas on the

Corresponding author: (E-mail: lilygupta14dec@gmail.com)

body phantom, particularly with regard to maintaining the maximum allowable SAR (Specific Absorption Rate), which is set at 1.6 W/Kg for biomedical applications[3]. Numerous antenna configurations have been investigated as potential contenders for wearable applications. These include fractal-based antennas inverted-F planar antennas[5], monopole patch antennas[6], magneto-electric dipoles[9], cavity-backed antennas[10,11] and stacked microstrip planar antennas[12]. Some CPW technique-based antenna designs have large dimensions and lower bandwidth, not suitable for biomedical applications[17-19]. Along with this, CPW based antenna have been studied such as bow-tie antenna with AMC design for RFID application which, resonates at 5.8 GHz[20]. Another author presented CB-CPW based antenna for WLAN, RFID and WiMAX application of band width 4.83-8.17 GHz[25]. The research findings suggest that biomedical antennas need to be compact in size to enable their integration into biomedical devices seamlessly[13,14]. Non-planar antennas, which are typically larger, heavier, and bulkier, are impractical for use in biomedical equipment or devices[15,16]. Patch antennas offer numerous advantages, including simple fabrication, a compact and low-profile design, which render them well-suited for biomedical applications[16,17]. One of the fundamental requirements for a biomedical antenna is that it should be compact, have a low profile, be easy to fabricate and integrate, and have a low SAR value (<1.6 W/kg) without comprising the antenna performance. While the microstrip patch antenna meets many of these criteria but it suffers from the drawback of narrow bandwidth[17,18]. Initially, microstrip line patch antenna was designed with ground structure at the bottom and patch design at the top. The observed bandwidth of simulated antenna is very narrow and resonating at frequency is at 2.45 GHz ISM frequency. To overcome this limitation, the CB-CPW technique has been incorporated[10-13]. The CPW technique in antennas refers to the use of coplanar waveguides as the transmission in antenna designs. Coplanar waveguides are a type of transmission line where the signal conductor, ground plane, and any other conductors are all on the same plane[28-30]. The CPW technique has various advantages that its seamless integration with other microwave components and its signal transmission ability is better than that of microstrip antenna. CPW technique incorporate broad band feature in antenna and can also transmit odd and even modes for better antenna flexibility[25]. The author in[26] proposed a CPW fed monopole dual band antenna for Wi-Fi, WLAN and WiMAX antenna with a peak gain of 3.38dB. This paper presents an UWB CB-CPW based antenna for BAN (both MBAN and WBAN) applications. As, the proposed antenna has broad bandwidth can be used for other applications such as Mobile Communication, Wireless Communication System, Bluetooth, Zigbee, WiMAX (Worldwide Interoperability for Microwave Access). Further, proposed antenna is simulated with body phantom and against structural deformation in order to justify its validity for biomedical applications. The UWB antenna has provided promising the results in all condition (in free space, with bending condition, with HUGO body phantom and experimental).The proposed UWB biomedical antenna is designed for both MBAN and WBAN(2.45 GHz and 5.78 GHz ISM band) applications. The designed UWB antenna supports the broad bandwidth ranging from 1.6 GHz to 6 GHz. The intended antenna is simulated in free space and with body phantom using CST MWS[14]. This paper introduces a small rectangular patch antenna featuring perpendicular slots with CB-CPW technique, specially implemented for BAN applications.This paper is outlined as follows, in Section 2 theoretical analysis of designed antenna, evolution of antenna design, structural designing aspects of intended antenna and effect of CB-CPW technique on antenna parameters were discussed. In section 3, illustrates the parametric analysis to optimize the antenna performance. Further, this section also includes bending analysis and SAR analysis for the justification of proposed antenna application in biomedical field. The analysis is presented for the simulated antenna in two scenarios: antenna without CB-CPW technique, antenna with CB-CPW technique and designed antenna with human body phantom. The antenna performance in free space and as well as placed on body phantom is explored. Section 4, includes the comparative analysis of simulated and the fabricated results. Section 5 concludes the results and findings of this paper.

2 Antenna Design

2.1 Designed Antenna Theoretical Analysis

The CB-CPW technique provides the effective generation of resonance phenomenon to the achieve broadband width. This technique combines the both the benefits effective transmission due to CPW technique and effective heat dissipation and robust mechanical strength. CB-CPW based antenna ground structure (refer Fig. 1(a)) [25]. Here, the resonance phenomenon is generated by the CB-CPW technique. In this case of cavity model, two ground structures at the both ends and one at back end form a two-patch resonator, a magnetic wall is present around it. Within the structure, the signal at the middle passes through the space (G) on the both side and couples the EM wave to both resonating cavities. This produces the resonance frequency for the designed antenna. The characteristic impedance is represented by Z and input impedance by Zi in transmission line.[25] Operating frequency and impedance of CPW technique are given by Eq. (1) and (2) respectively

$$f_{pq} = c/(2\sqrt{\varepsilon_r})\,[(p/w_4)^2+(q/L_w)^2]^{0.5} \quad \ldots(1)$$

$$Z=\sqrt{\frac{L}{C}} \quad \ldots(2)$$

where,
f_{pq} = Resonant frequency
z = Impedance
c = speed of light

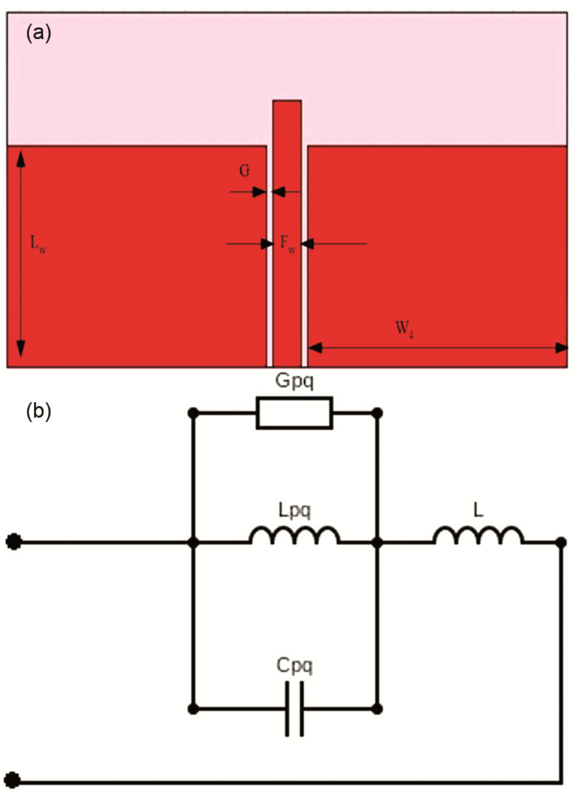

Fig. 1 — (a) CB-CPW ground structure, (b) — Top Equivalent circuit of CB-CPW ground structure[25]

ε_r = Relative permeability of the material
P_q= Resonant mode factors
L_w = Length of CPW ground
W_4 = Width of CPW ground
L = Distributed inductance
C = distributed capacitance

Microstrip line antenna CPW ground structure and simplified network mode is studied, shown in Fig. 1(a & b) respectively[25]. The input impedance is given by Eq. (3)

$$Z_i = 1/[(1/R_{pq})+j((\omega C_{pq}) - 1/(\omega L_{pq}))] \quad \ldots(3)$$

Z_i is the input impedance and $R_{pq} = 1/G_{pq}$
And, $\omega_{pq} = 1/\sqrt{L_{pq}C_{pq}}$,

$$Q = 2\omega_{pq}[(C_{pq}V^2/2)/V^2 R_{pq}] \quad \ldots(4)$$

$$Q = R_{pq}/\sqrt{(L_{pq}/C_{pq})}$$

Eq. (3) can be written as

$$Zi = R_{pq}/(1+jQG) \quad \ldots(5)$$

The characteristic impedance of feedline is R_{pq} reflection coefficient is given by Eq. (6)

$$|\Gamma| = |(Zi - R_{pq})/(Zi + R_{pq})| \quad \ldots(6)$$

After that,

$$(\rho+1)/(\rho-1) = 1/|\Gamma| \quad \ldots(7)$$

$$G = (f/f_{pq}) - (f_{pq}/f) = \pm(\rho-1)/(Q\sqrt{\rho}) \quad \ldots(8)$$

Where ρ is the VSWR and f_H and f_L are indicated by the positive and negative sign respectively.

$$\text{Bandwidth} = [(f_H - f_L)/f_{pq}]\times 100\% = [(\rho-1)/Q\sqrt{\rho}]\times 100\% \quad \ldots(9)$$

2.2 Antenna evolution

The proposed CB-CPW antenna is essentially a modified version of the rectangular microstrip antenna. Initially, the rectangular structure has been implemented on the Roger substrate of 1.57 mm backed with plane ground. The major drawback of this microstrip line patch antenna is its narrow bandwidth.

To get rid of this problem, here a CB-CPW technique has been implemented. The evolution of the proposed antenna includes 1-5 iterations is shown in Fig. 2. The return loss $|S_{11}|$ of iteration 1-5 is shown in Fig. 3.

In iteration 1, rectangular patch antenna was designed with plane ground at the back. The proposed

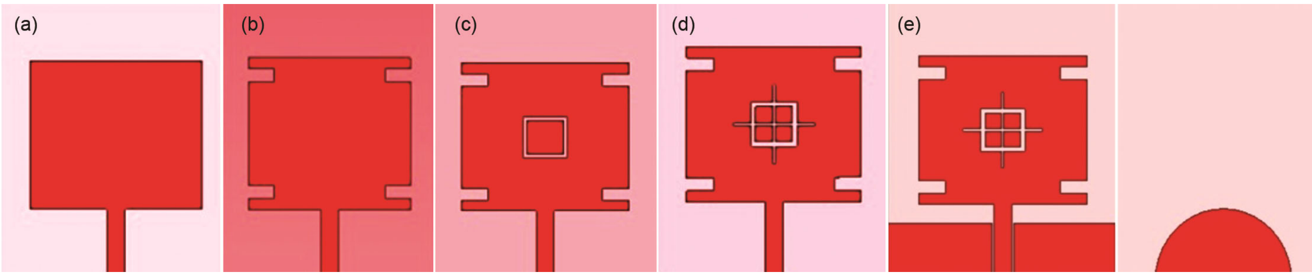

Fig. 2 — Evolution steps of designed biomedical planar antenna (a) Iteration 1 (b) Iteration 2 (c) Iteration 3 (d) Iteration 4 (e) Iteration 5

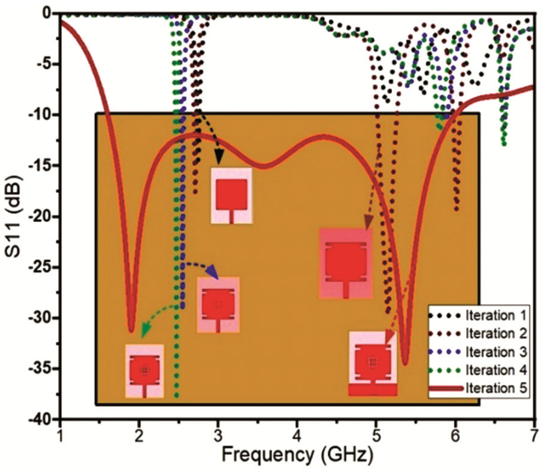

Fig. 3 — Parametric analysis of $|S_{11}|$ for iteration 1-5 of designed antenna

antenna in iteration 1, is operating at the frequency 2.71GHz which does not lie in the desired biomedical frequency range. It also suffers from the drawback of narrow bandwidth. During the iteration 2, four slots are grooved at the specific positions and resulting into multiband antenna design (2.7 GHZ, 5.1GHz and 6.0 GHz).The intended antenna resonating frequencies are still not operating in biomedical frequency range. In iteration 3, a square ring structure is incorporated in the design at the center of patch, as a result designed antenna resonating frequency deviates towards the lower frequency range (210 MHz) and starts operating in biomedical frequency range (MBAN). In next iteration, two perpendicular slots have been placed at the center of the ring and still a plane ground structure at the bottom. This design structure has been suffering from narrow band with problem. To avoid this, CB-CPW technique is implemented in iteration 5, antenna design resulting in ultrawide antenna design with bandwidth range from 1.6 GHz to 6 GHz. Now, the designed antenna has ultrawide bandwidth and suitable for wide range of applications including biomedical applications (both MBAN and WBAN).

2.3 Antenna Structure

The proposed antenna design is modified version of rectangular patch antenna. Having four slots positioned at all four sides, as well as a central ring. Additionally, there are perpendicular slots within the center of the ring. The intended antenna is based on CB-CPW technique which broader bandwidth. Fig. 4(a-c) depict the top view, side view and antenna with HUGO body phantom respectively.The designed antenna is simulated on a semi-flexible material, RT/duroid 5880, characterized by a dielectric constant (εr) of 2.2 and a loss tangent (tanδ) of 0.0004. The overall dimensions of the antenna are 52 mm in width, 66 mm in length, and 1.57 mm in thickness (or 0.54 λ × 0.42λ × 0.012 λ), where λ denotes the wavelength of the resonating frequency. The introduction of slots in the main radiator, which serve to improve the antenna gain and aid in achieving impedance matching within the required frequency band. In this design, a square ring with a side(s) of 2mm is etched out from the patch and perpendicular slots of dimension 0.5mm×18mm is incorporated at the centre of the ring. The inclusion of CB-CPW technique in the design result in broad bandwidth (1.6 to 6 GHz). The patch antenna is positioned 2mm above the body phantom to reduce the antenna backward radiation to the human body. The implemented antenna is placed over a (100 × 100) mm^2 HUGO body phantom for SAR analysis (see Fig.4(c)). It consists of three layers: skin, fat, and muscle representing the human body model. Parameters such as dielectric permittivity, thickness, conductivity, and density values for each layer of the human phantom are elaborated (see Table 1). Table 2 provides comparison of proposed antenna with previously published work in context of Gain, bandwidth and antenna size, as these are key parameters for the biomedical antenna[19-26]. Intended antenna's surface current density (J_{surf}) distribution without CB-CPW and with CB-CPW are in free space shown in Fig. 5.

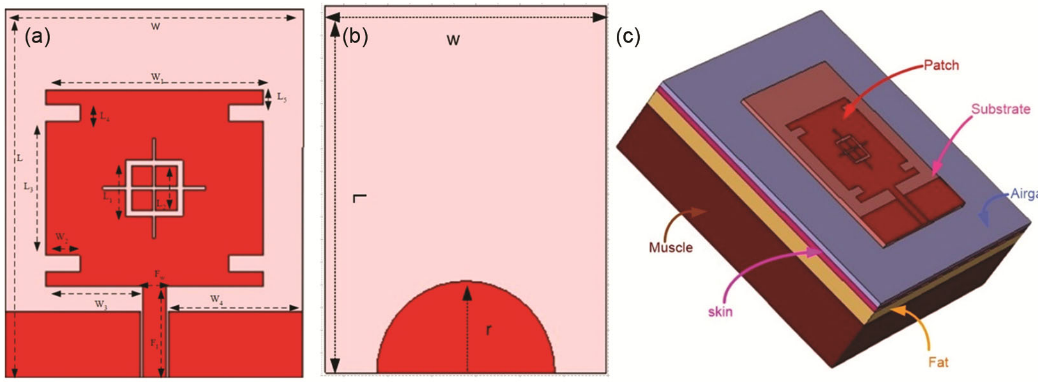

Fig. 4 — Simulated intended antenna design (a) Antenna top view (b) Antenna bottom view (c) Designed antenna placed on human body model [all dimensions are in mm (L=66, W=52, L_1 =10, L_2 =8, L_3 =24, L_4 =3, L_5 =2.5, W_1 =38, W_2 =6, W_3 =17,W_4 = 23.5, F_w = 4, L_w= 12, F_l=16.5,G=0.5)

Table 1 — Properties of Human Body Phantom layers and Dimensions

Body phantom layers	Relative Permitivity (ε_r)	Density (Kg/m^3)	Electric Conductivity (S/m)	Thickness (mm)
Skin	38.1	1001	1.43	2
Fat	10.8	900	0.26	6
Muscle	52.8	1006	1.74	20

Table 2 — Comparison of previous work with proposed work

Ref.	Technique used	BW (GHz)	Gain (dBi)	Antenna Size (mm^3)
[19]	Textile antenna	2.1-2.6	2	17054
[21]	EBG	5.6-6.15	2.5	3430
[22]	CPW	1.81-3.83	1.5-2.5	7800
[23]	CPW	1.73-3.11	4 2	9144
[24]	CPW	1.5-2.5	2.5-3.4	7840
[26]	CPW	2.36-2.45 3.2-6.29	3.38	20×35(mm^2)
[27]	CPW	1.8-2.9	4.7	$0.37\lambda \times 0.37\lambda \times 0.007\lambda$
Proposed	CB-CPW	1.6-6	2.8, 4.8	5388

3 Parametric Analysis

The optimized antenna parameters have been determined through parametric analysis for the proposed antenna design. In this context, parametric analysis has been conducted on following key aspects of the proposed antenna design: feedline length width (F_w), square ring on the patch structure, Slot width(W_2), length of CPW ground structure (L_w), Semi circle conductor radius(r) and bending analysis. SAR analysis of the designed antenna is also performed to conform its suitability for biomedical applications. The main aim of parametric analysis is to get the optimized results of different parameters. To optimize the value, return loss analysis for various

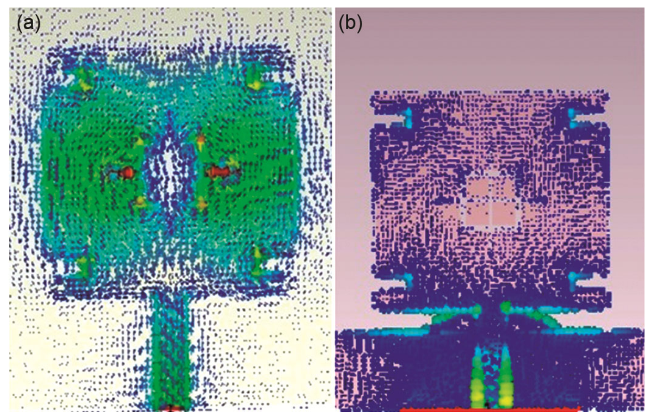

Fig. 5 — (a) Intended antenna 's Surface current Density (J_{surf}) without CB-CPW technique, (b) with CB-CPW technique

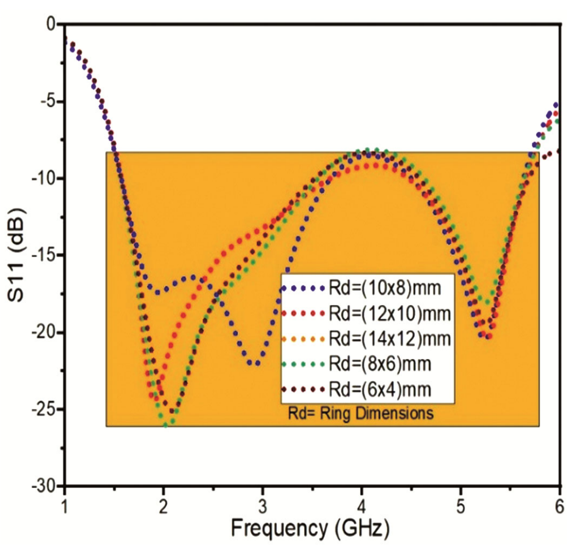

Fig. 6 — Simulated return loss $|S_{11}|$ of intended antenna on variation of feedline width (Fw)

feed line width value (F_w= 2 mm, 3 mm, 4 mm, 5 mm and 6 mm)are performed and depicted in Fig. 6. It is observed that when F_w=5 mm and 6 mm, the designed antenna is operating out of biomedical spectrum. Further, F_w=2mm case is considered, it is observed that antenna is operating in dual frequency band(2.239 GHz and 4.56 GHz) but exhibiting the lesser band width than F_w = 4 mm. At F_w = 3mm, antenna is showing good band width agreement, but in other analysis, it is observed that antenna performance degrades. Through the analysis it has been determined that the antenna has maximum band width at F_w = 4 mm. The intended antenna has shown broad bandwidth (1.6-6GHz) at F_w= 4 mm, resonating at1.9 GHz and 5.3 GHz. The optimum signal transmission occurs when the input matches with 50Ω.It is evident that the input resistance at feed lengthF_l = 16.50 mm intersects the 50Ω line within the MBAN and WBAN spectrum (refer Fig. 6). The configuration involves, a square ring (Rd=2mm)at the center of the patch antenna(see Fig. 7). A thorough parametric analysis is performed to identify the optimal ring position for the proposed antenna. The analysis has been carried at different ring positions *i.e*. Rd = (6×4) mm, Rd = (8×6)mm, Rd=(10×8)mm, Rd=(12×10)mm and Rd=(14×8)mm are conducted. This parametric analysis, showcasing the influence of varying the position of 2 mm square ring on the antenna's resonance frequency. After the analysis the Rd=(10×8)mm has been chosen for the proposed antenna design because it provides broader bandwidth compare to other values. The Return loss $|S_{11}|$ analysis for different ring positions, depicted in Fig. 7.

Now, the parametric analysis has done on the slot width W_2 to get the optimized result of antenna parameters. The various dimensions of slot width have been considered W_2=4mm, W_2=5mm, W_2=6mm, W_2=7mm and W_2=8mm. Now, the parametric Analysis in context of reflection coefficient has been performed on the slot width of the designed antenna (see Fig. 8). It is observed that for W_2 =7mm, and W_2 =8mm the bandwidth is covering 2.45 GHz (MBAN) frequency spectrum but not the other WBAN frequency band (5.8 GHz). The slot width W_2 =6mm antenna bandwidth covering both the both MBAN (2.45 GHz) and WBAN (5.8 GHz) applications and showing better impedance matching than the positions W_2 = 4 mm and W_2 = 5 mm. It is observed that slot width size W_2 =6 mm suitable for this antenna design. This systematic examination is crucial for pinpointing the most suitable position that ensures the antenna resonates precisely within the required BAN frequency band. Further, moving towards the other parametric analysis on the semicircular conductor and the length of CBW ground (see Fig. 9 & 10). To optimize the antenna results, analysis is performed on various radius r =6.5 mm, r = 9mm, r = 12.5 mm, r = 14 mm and r =16.5 mm. After analysis, it is observed that the radius of semicircle (r) = 16.5 mm is the most suitable position for intended antenna design as it provides the maximum bandwidth. Therefore, radius of semicircle (r) = 16.5 mm is considered as the suitable for the proposed antenna design. Other than this case, antenna has been exhibiting narrow bandwidth. Now the parametric

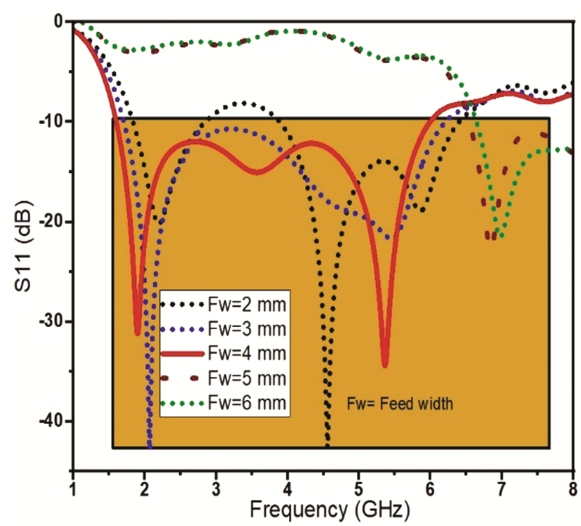

Fig. 7 — Simulated Return loss $|S_{11}|$ of designed antenna on variation of ring dimensions (R_d)

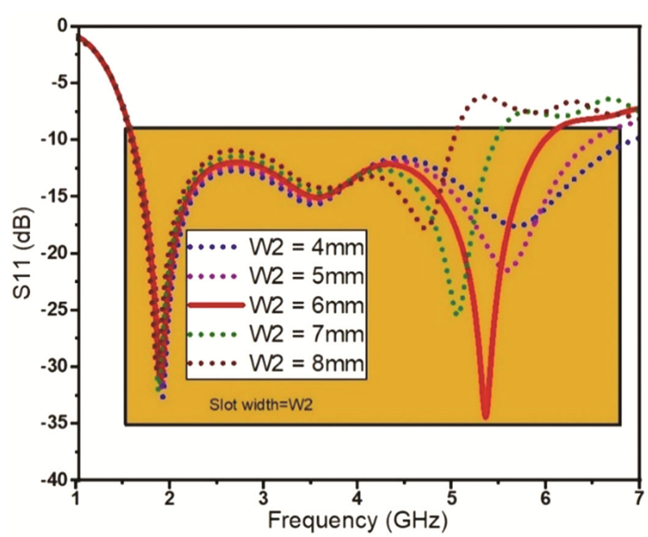

Fig. 8 — Parametric analysis of intended antenna reflection coefficient $|S_{11}|$ of slot width (W_2)

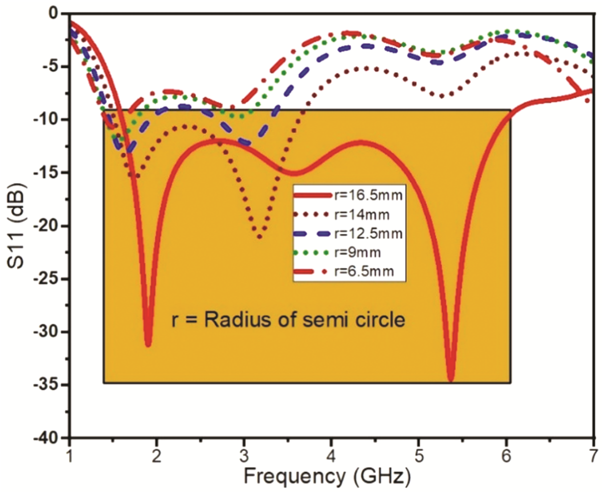

Fig. 9 — Parametric analysis of backed semicircle of intended antenna with CB-CPW technique

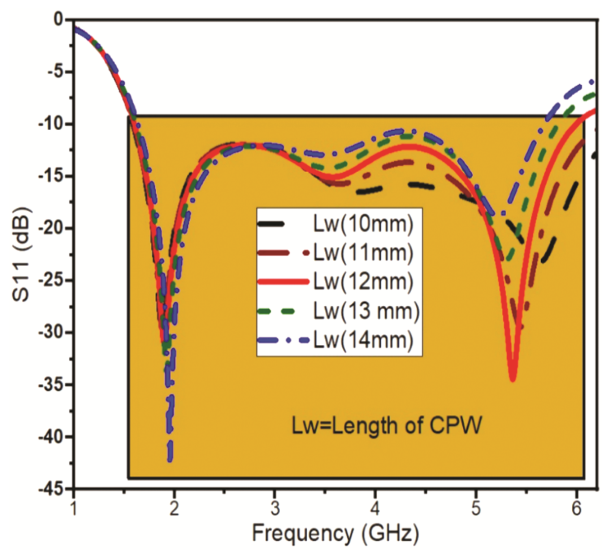

Fig. 10 — Parametric analysis on length of CPW ground structure of proposed antenna with CB-CPW technique

analysis is done on the length of CPW ground (L_w=10 mm, L_w=11 mm, L_w=12 mm, L_w=13 mm and L_w=14 mm).It is concluded that the best suitable position is L_w=12 mm for the intended antenna design refer (Fig. 10).The square ring of dimension 2mm is at the center (L_1=8 mm L_2=10 mm). To enhance the antenna's gain, two perpendicular slots have been integrated into the design. Subsequent analysis focused on optimizing the dimensions of these slots reveals a noteworthy improvement in gain.

3.1 SAR Analysis

In the biomedical antenna design phase, it is important to conduct SAR analysis to follow the safety limits regulatory standards set by the organizations such as the FCC and CNIR. According to these agencies, the SAR must not exceed 2 W/kg averaged over 10 g and should be kept below 1.6 W/kg averaged over 1 g of human tissues.18,19 To carry out SAR analysis, the multi-layer human body phantom has been employed (see Fig. 4(c)). The body phantom includes three layers muscle, fat, and skin arranged from bottom to top. SAR is the important parameter for biomedical antenna designing, as it helps to determine the amount of electromagnetic radiation by absorbed by the human body. The FCC and CNIR has set the safety guidelines for SAR value. It should be less than 1.6W/Kg to avoid the harmful human body.

Here, HUGO body model from VOXEL family (CST MWS) has been chosen for human body phantom. The phantom dimensions (thickness) and layer (Skin, Muscle and Fat) comprehensive information on key parameters are elaborated in Table 1. The Value of SAR (Specific Absorption Rate) is very small for UWB patch antenna and also within the limits of IEEE and FCC guidelines. It means that the backward EM radiation from the antenna to human body is not affecting the human body tissues. The intended antenna is placed 2mm above the human body to reduce the effect of EM radiation from antenna to human body. It can be easily concluded that the designed antenna is suitable for the biomedical applications as the SAR value lie in range specified by FCC, IEEE and CNIR. The SAR value is 0.728 W/Kg for 1g of human body tissue.

3.2 Bending Analysis

In bending analysis, the antenna design is bend as the cylinder surface and its performance are investigated. The bending is can be done in both x and y directions. Here, the bending is performed in x direction for two conditions first, antenna with plane ground and second, with CB-CPW technique (refer Fig. 11(a) & 12(a)).Various bending radii (R) in the x-direction have chosen to assess the designed antenna's return loss ($|S_{11}|$). For the analysis of antenna performance under bending condition, antenna structure is bend like cylindrical shape.The reflection coefficient $|S_{11}|$ of antenna under various bending scenarios along the x-axis (see Fig. 11(b)) was examined. It is evident that there is a shift in the resonant frequency in case antenna with plane ground. In this case the narrow bandwidth observed and plane ground structure has been modified with

CB-CPW technique.Consider the second case, antenna with CB-CPW has been bent like cylinder of different radii (Cr)(see Fig. 12(a)).The reflection coefficient analysis of various cylinder radii(Cr) of proposed antenna with CB-CPW is depicted in Fig. 12(b). The antenna demonstrates consistent performance in both bending and without bending scenarios at the ISM bands (2.45 GHz and 5.8 GHz). The study concludes that the designed antenna with CB-CPW is suitable for biomedical applications.

4 Results and Discussion

The intended antenna underwent simulation with optimization of various design parameters, proving its suitability for BAN applications. The UWB antenna is designed for MBAN and WBAN biomedical applications. Initially, the antenna has been designed backed plane ground (without CB-CPW technique) which suffers from the narrow bandwidth issue. To avoid this problem, CB-CPW technique has been implemented in the designed antenna. The resultant antenna is UWB planar antenna for BAN application. The two crucial aspects of analysis for biomedical antenna are SAR and bending analysis. It is necessary to analyse the antenna performance, when it is placed on curved surface (resemblance with human arm). Bending analysis are performed on both design of antenna without and with CB-CPW shown in Fig. 11(a) & Fig. 12(a) respectively. The reflection coefficient $|S_{11}|$ of antenna is showing stable performance during bending of antenna in x-direction. Bending analysis is performed by varying cylinder

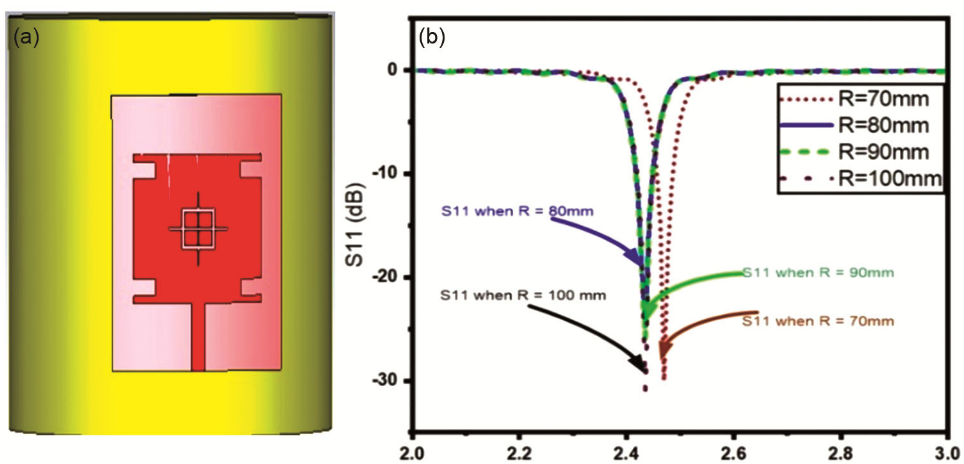

Fig. 11 — (a) Designed antenna without CB-CPW mounted on cylindrical surface for bending analysis without CB-CPW, (b) Return loss $|S_{11}|$ for bending Analysis

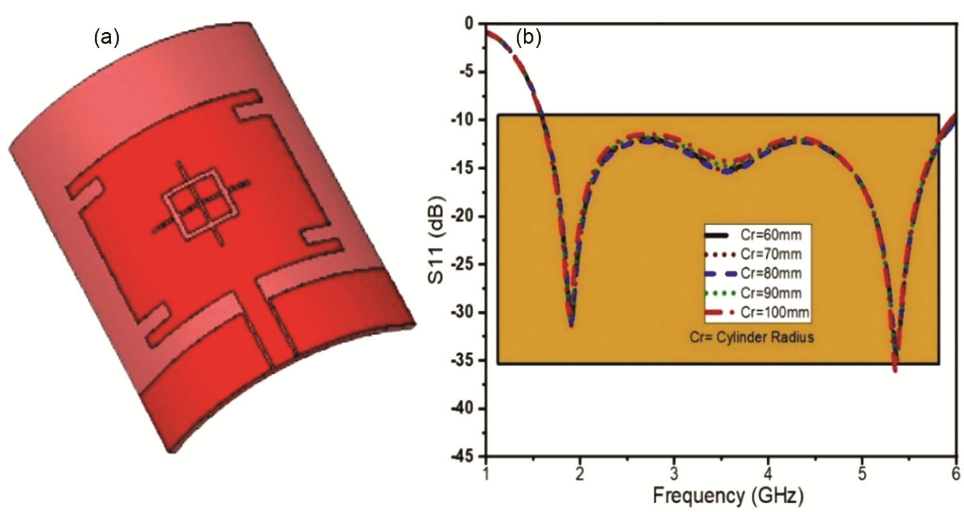

Fig. 12 — (a) Designed antenna with CB-CPW mounted on cylindrical surface for bending analysis, (b) Return loss $|S_{11}|$ for bending Analysis

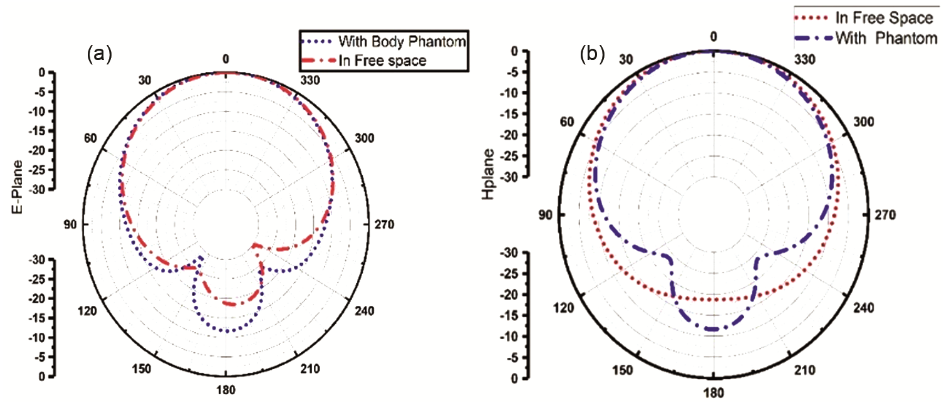

Fig. 13 — Simulated (a) E –plane (b) H -plane of the designed antenna without CB-CPW technique (i) free space (ii) on human body phantom

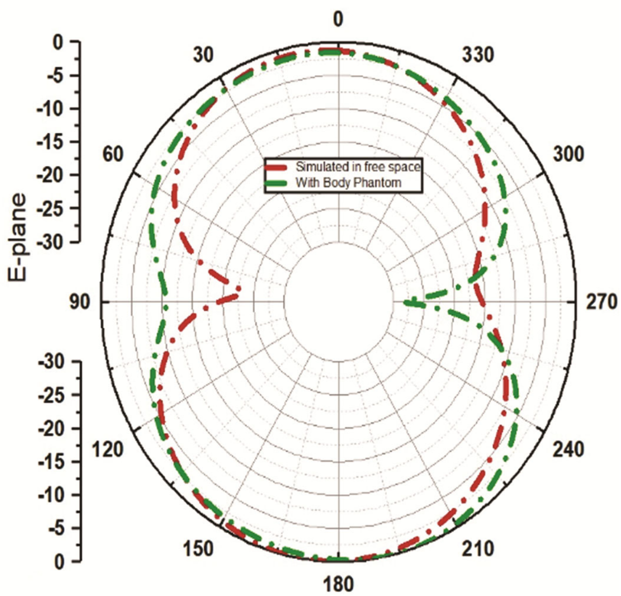

Fig. 14 — Simulated E-Plane results of intended UWB planar antenna (with CB-CPW technique) in free space and with body phantom at 2.45 GHz

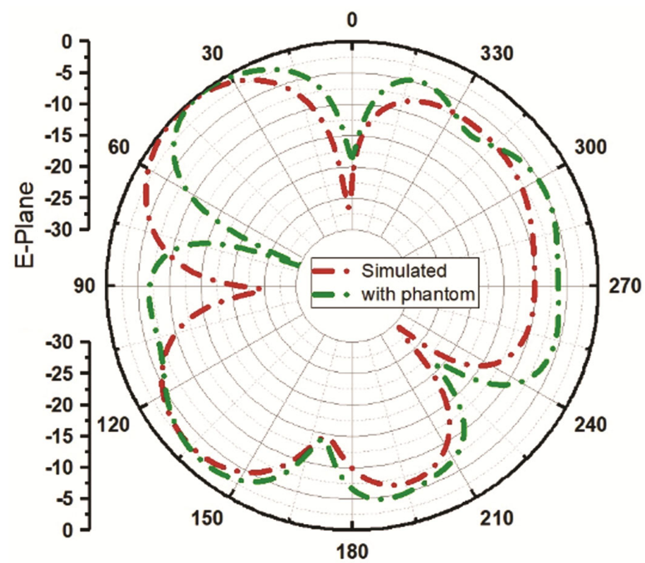

Fig. 15 — Simulated E-plane results of designed UWB planar antenna (a) free space and (b) with body phantom (with CB-CPW technique) at 5.8 GHz

radius (Cr) (Cr = 60 mm, 70 mm, 80 mm, 90 mm and 100mm) and results are shown in Fig. 12(a). The reflection coefficients ($|S_{11}|$) values for various bending scenarios along the x-axis show negligible variation in resonating frequency (See Fig 12(b)). It is concluded that antenna performance will not be affected, when it is placed on curved surface like human arm. The antenna maintains robust performance even under deformation conditions, such as bending. For SAR analysis, the antenna is placed over the human body (refer Fig. 4(c)). The properties of the human body phantom layer and their dimensions are mentioned in Table 1. To assess the effectiveness of the proposed antenna, a comparison is conducted with prior research endeavours (see Table 2).The SAR value (0.728 W/Kg) is within safety limits specified by the IEEE and FCC. The E-plane and H-Plane curve of designed antenna without CB-CPW were depicted in Fig. 13(a & b) respectively. The simulated E-plane curve and H-plane curve of implemented antenna with CW-CPW technique are shown in Fig. 14-16. The E-plane and H-plane curves are simulated in free space and with human body phantom.

The top and bottom view of the fabricated UWB antenna is depicted in Fig. 17. Experimental setup of proposed antenna measurement of proposed antenna is shown in in Fig. 18-21.

The return loss ($|S_{11}|$) of simulated and experimentally measured UWB antenna was depicted in Fig. 22. The fabricated antenna shows the almost similar bandwidth as that of the simulated UWB planar antenna. The simulated bandwidth is (1.6-6 GHz) The simulated antenna resonating at 1.9GHz and 5.37GHz whereas in fabricated antenna resonance frequency at 2.2 GHz and 5.30 GHz. The reflection coefficient ($|S_{11}|$) of fabricated antenna at 2.2 GHz and 5.30GHz are -46.3dB and - 44.7dB respectively. In comparison to simulated antenna, a shift of 0.3 GHz frequency is observed at first resonance frequency and 0.08 GHz shift at second resonating frequency. The designed UWB patch antenna has percentage bandwidth of 115%.The simulated gain of the antenna is 2.8 dBi, while the experimentally measured gain is 2.73 dBi at 2.45 GHz. At 5.8 GHz, the simulated gain is 4.8 dBi, and the fabricated antenna gain is 4.7dBi (see Fig. 23). The slight reduction in gain and efficiency is due to the influence of surface currents and the loading effect of the human body.It is analyzed that gain, almost consistent at 2.45 GHz and 5.8 GHz for simulated and fabricated antenna. The proposed antenna exhibits a simulated radiation efficiency of 88.2% at 2.45 GHz and 78% at 5.8 GHz.

The fabricated antenna shows a radiation efficiency of 83.6% at 2.45 GHz and 74.5% at 5.8 GHz (refer Fig. 24).

It is observed that the antenna performance showing good agreement for both the cases. The antenna demonstrates insensitivity to its usage in close propinquity to the body phantom the intended planar antenna frequency of 2.45 GHz and 5.8GHz. The E-Plane curve for UWB antenna at 2.45 GHz and 5.8 GHz are presented in Fig. 25 & 26.

Considerably less backward radiation makes it suitable for biomedical application. Specific Absorption Rate (SAR) is one of the important parameters for the on body biomedical antenna and should satisfy the IEEE and FCC The SAR value for proposed antenna is very small (0.728 W/Kg), emphasizing its safety for both on-body and off-body applications.

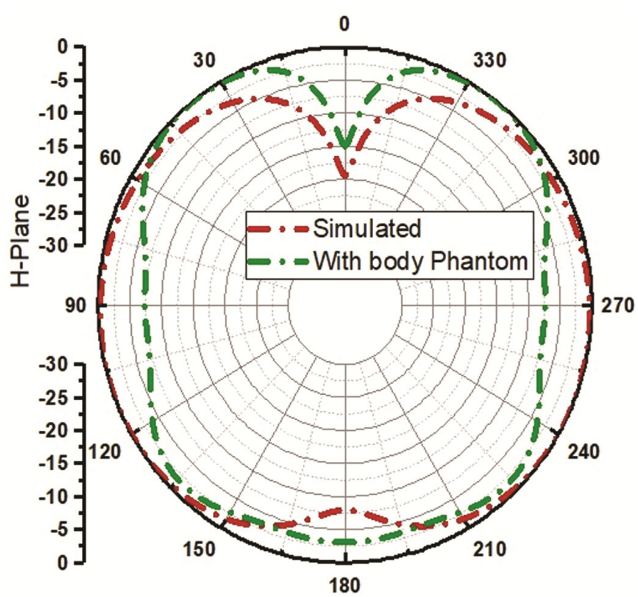

Fig. 16 — Simulated H-plane results of designed UWB planar antenna (a) free space and (b) with body phantom (with CB-CPW technique)

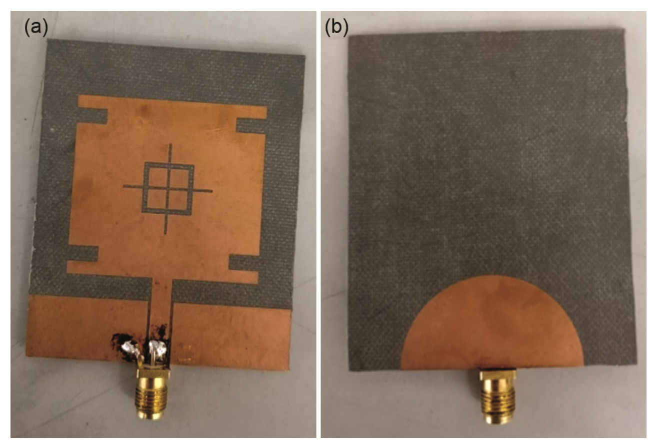

Fig. 17 — (a-b) Top and bottom view of fabricated UWB antenna for biomedical applications

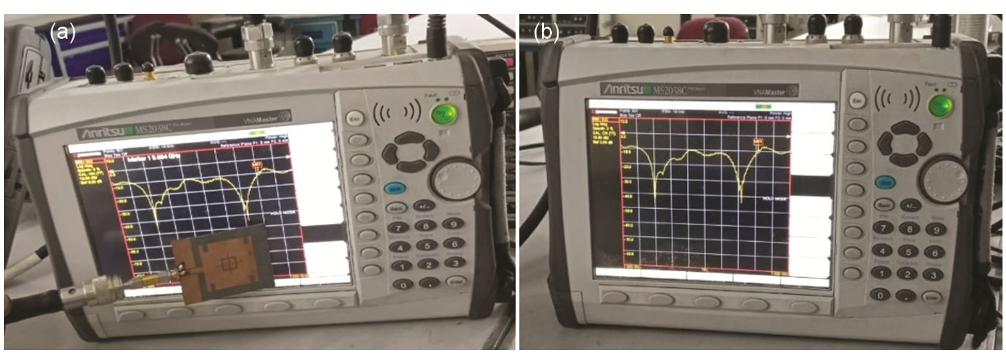

Fig. 18 — (a-b) Measurement of Return loss $|S_{11}|$ for intended antenna

Fig. 19 — Experimental setup of transmitting and receiving designed antenna in anechoic chamber

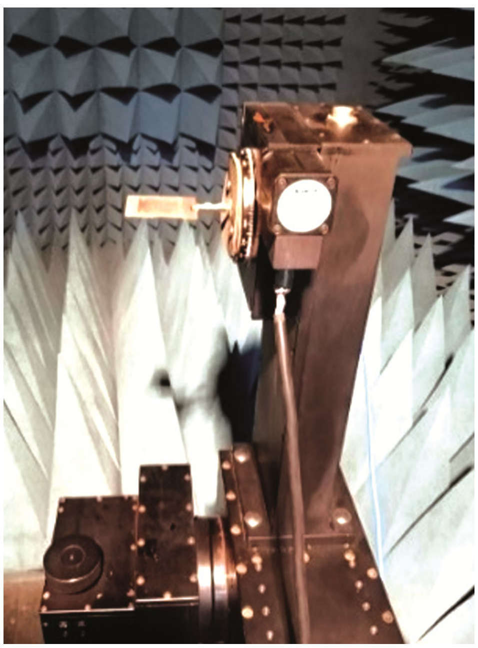

Fig. 20 — Experimental setup for designed antenna parameter measurement

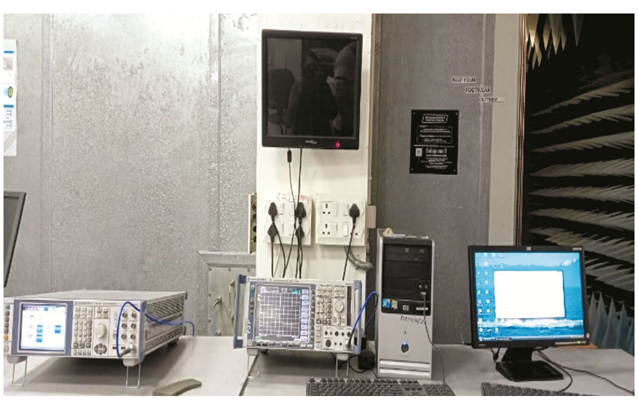

Fig. 21 — Experimental setup for antenna parameter measurement

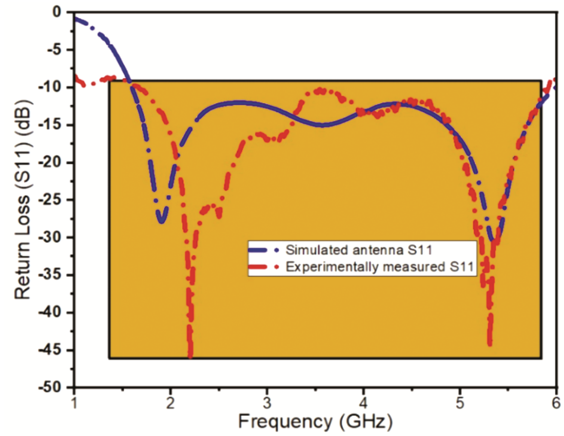

Fig. 22 — Analysis of simulated return loss with experimentally measured of designed antenna

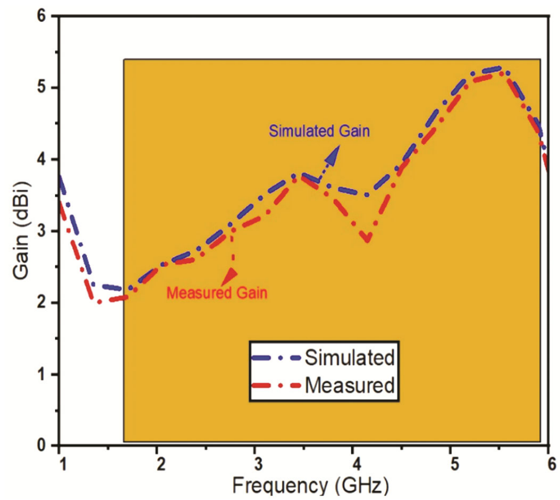

Fig. 23 — Analysis of simulated Gain (dBi) with experimentally measured of designed antenna

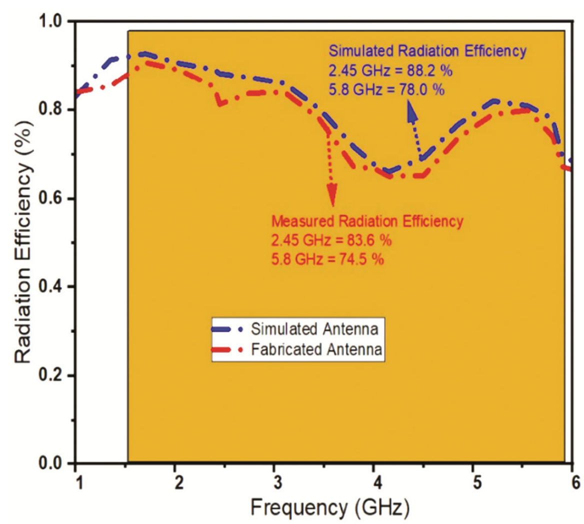

Fig. 24 — Simulated and experimentally measured radiation efficiency of designed antenna

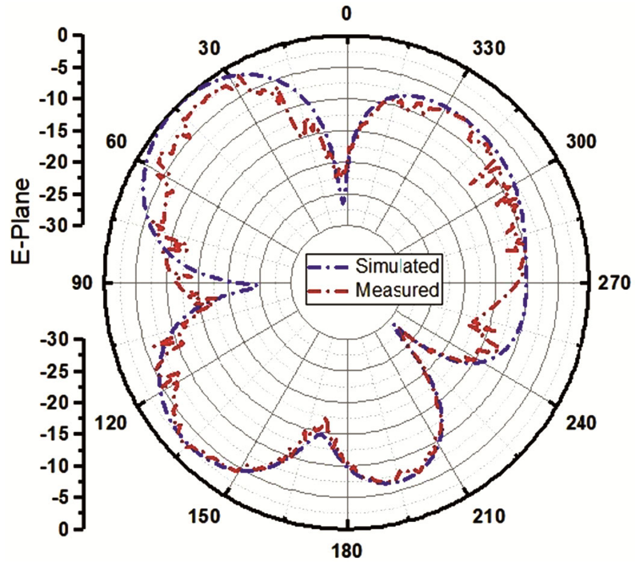

Fig. 25 — Simulated and experimentally measured E-plane curve at 5.8 GHz with of designed antenna

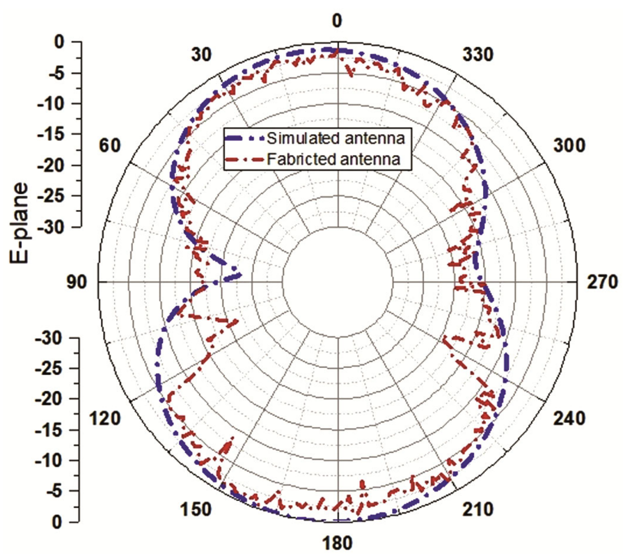

Fig. 26 — Simulated and experimentally measured E-plane curve at 2.45 GHz with of designed antenna

5 Conclusion

The paper introduces an UWB planar antenna based on the CB-CPW technique designed for biomedical applications. The antenna support both MBAN (2.45 GHz) and WBAN (5.8 GHz) applications as well as wide range of other applications.The SAR value for the designed antenna is 0.728W/Kg and it adheres to IEEE guidelines, confirming that the proposed antenna is suitable biomedical applications.Comprehensive simulations of all antenna parameters have been carried out under two conditions: in free space and with the body phantom. The results revealed a consistent impedance bandwidth covering the ISM band relevant to biomedical applications in both scenarios. The intended antenna is simulated with CB-CPW technique using CST MWS. The main advantage of this technique is broader bandwidth (1.6-6 GHz). The simulations and fabricated antenna have shown stable performance in terms of impedance bandwidth and gain. The proposed antenna exhibits a simulated radiation efficiency of 88.2 % at 2.45 GHz and 78 % at 5.8 GHz. The fabricated antenna shows a radiation efficiency of 83.6 % at 2.45 GHz and 74.5% at 5.8 GHz. The antenna maintains robust performance even under deformation conditions, such as bending. This design demonstrates promising performance, particularly in mitigating SAR concerns, making it well-suited for BAN (MBAN and WBAN) applications.

References

1 Hall P S & Hao Y, Antenna and Propagation for Body-Centric Wireless Communications, (Artech House, Norwood, MA, USA), 2012.
2 Roblin C, *et al*., *Annal Telecommun*, 66 (2011) 139.
3 Federal Communications Commission Office of Engineering, and Technology, Washington, DC, USA, Evaluating compliance with FCC guidelines for human exposure to radiofrequency electromagnetic fields, Supplement C, 2001.
4 Karimyian-Mohammadabadi M, Dorostkar M A, Shokuohi F, Shanbeh M & Torkan A, *J Electromagn Waves Appl*, 29 (2015) 1728.
5 Hajj W El, Person C & Wiart J, *IEEE Trans Antennas Propag*, 62 (2014) 3843.
6 Jiang Z H, Brocker D E, Sieber P E & Werner D H, *IEEE Trans Antennas Propag*, 62 (2014) 4021.
7 Kim S, Ren Y J, Lee H, Rida A, Nikolaou S & Tentzeris M M, *IEEE Antennas Wireless Propag Lett*, 11 (2012) 663.
8 Poffelie L A Y, Soh P J, Yan S & Vandenbosch G A E, *IEEE Trans Antennas Propag*, 64 (2016) 757.
9 Yan S, Soh P J & Vandenbosch G A E, *IEEE Trans Antennas Propag*, 63 (2015) 4165.
10 Agneessens S & Rogier H, *IEEE Trans Antennas Propag*, 62 (2014) 2374.
11 Yun S, Kim D Y & Nam S, in *IEEE Antennas Wireless Propag Lett*, 14 (2015) 36.
12 Sheikh S I M, Abu-Al-Saud W & Numan A B, *Int J Antennas Propag,* 389571 (2013) 6.
13 Samal P B, Soh P J & Vandenbosch G A E, *IEEE Trans Antennas Propag*, 62 (2014) 102.
14 Khan M, Kumari L, Sani M M, Zahreeuddin & Salhan A, *2023 Int Conf Power, Instr, Energy Control (PIECON)*, Aligarh, India, (2023) 1.
15 *International Symposium on Antennas and Propagation and USNC-URSI Radio Science Meeting*, APS/URSI, (2021) 51.
16 Gao G, Hu N, Wang S & Yang C, *Microwave Opt Technol Lett,* 60 (2018) 876.
17 Kumari L, Khan M, Sani M M, Zahreeuddin Z & Khan M A, *Int Conf Recent Adv Electrical, Electronics Digital*

Healthcare Technol (REEDCON), New Delhi, India, (2023) 236.

18 Sreelakshmy R & Srinivasan A K & Shanmuganantham T S, et al*., Microwave Opt Technol Lett*, 59 (2017) 2159.

19 Gao G, Hu N, Wang S & Yang C, *Microwave Opt Technol Lett,* 60 (2018) 876.

20 Zhou S-W, Li P-H, Wang Y, Feng W-H & Liu Z-Q, *IEEE Antennas Wireless Propag Lett*, 10 (2011) 1182.

21 Saini R K, Dwari S & Mandal M K, *IEEE Antennas Wireless Propag Lett*, 16 (2017) 2497.

22 Xue H-G, Yang X-X & Ma Z, *IEEE Antennas Wireless Propag Lett*, 14 (2015) 1392.

23 Cos M E de, Álvarez Y, Hadarig R C & Las-Heras F, *IEEE Antennas Wireless Propag Lett*, 9 (2010) 44.

24 Zhou S W, Li P H, Wang Y, Feng W H & Liu Z-Q, IEEE *Antenna Wireless Propag Lett*, 10 (2011) 1182.

25 Ding Z, Zhang D & Ma C, IEEE Access, 8 (2020) 42877.

26 Benkhadda O, Saih M, Chaji K, *et al*. *Arab J Sci Eng,* 48 (2023) 6089.

27 Arulmurugan S, Kumar T R S & Alex Z C, *Int J Commun Syst*, (2024) 5716.

28 Sharma N, Kumar A, De A & Jain R K, *Frequenz*, 76 (2022) 229.

29 Thomas A K, Pandey T K, Dubey M, Shashidhar T M, Roy V & Kankalla N, *CRC Press* (2024) 1.

30 Kumar S G, Yadav D & Kumar A, *Int J Electron Telecommun*, (2024) 525.