Journal of Engineering Research and Education
Volume 12, 2020 [79-90]

High Gain UWB Antenna Array of Partial Conductor backed-coplanar waveguide (PCB-CPW) With Coaxial Fed for Microwave Imaging

M. A. Jamlos[1], M. F. Jamlos[1], A. H. Ismail[1] and Amirah Othman[1]

[1]*Advanced Communication Engineering Centre (ACE), School of Computer and Communication Engineering Universiti Malaysia Perlis (UniMAP), KampusPauh Putra. 02600, Arau, Perlis, Malaysia.*

ABSTRACT

In this paper, a partial conductor backed-coplanar waveguide (PCB-CPW) UWB antenna array is proposed, which consists of four identical circular patches appropriately connected using quarter wave transformer transmission line. Currently full CB-CPW technique is used in realizing UWB high gain antenna. However, the combination of partial conductor back and array technique with coaxial fed is yet to be explored for the same purpose. The novel proposed antenna is designed with PCB-CPW using circular array radiating element and coaxially fed in producing UWB antenna with higher and acceptable gain compared to full CB-CPW technique. This is proved by achieving excellent impedance matching (<-10 dB) across the band of 2.6 GHz up to 13.1 GHz. In addition, the gain obtained across the whole operated frequencies is ranging from 3.4 dB until 12.12 dB. Considering the compactness of 80 mm × 45 mm, the performance of proposed antenna with coaxially fed making it a suitable candidate for portable and efficient systems for microwave-based brain imaging as the scanning probe.

Keywords: UWB Antenna Array, PCB-CPW, Microwave-Based Brain Imaging.

1. INTRODUCTION

Currently microstrip UWB antennas have gaining great interested from researches due to their advantages such as simple structure, low profile, high data rate, easy integration with monolithic microwave integrated circuits (MMICs) and simple to fabricate. Thus, UWB antenna has turned to be the ideal candidate for future short-range (10 m) high-data wireless communication applications, peer-to-peer ultra-fast communications and a lot of other applications. This has inspired researchers to thoroughly investigate the design of UWB antennas [1]. Due to great advantages provided by UWB technology, various fields and domains with potential applications are deployed using this kind of technology such as in communications, imaging, radar, landmine detection, localization and biomedical systems [2, 3]. In microwave imaging system, UWB antenna utilized as the scanning probe for transmitting and receiving the microwave signals. The imaging system functioned to visualized internal human structure purposely for diagnostic. Wide ranges of operated frequency with constant high gain are required in successfully penetrating various structures with different permittivity and thickness in order to produce images with high details. Apart from that, high gain and good directional beam-width for wide frequency band antennas are required for target detection, localization systems and cancer screening applications in microwave imaging [3].

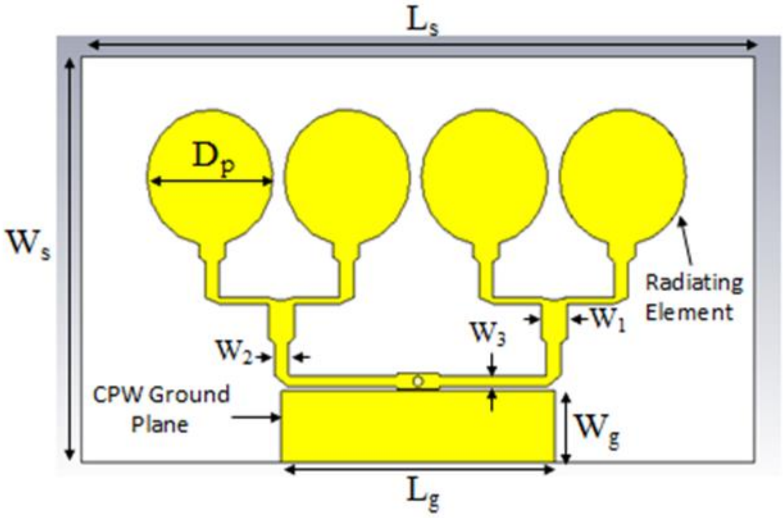
Most UWB antennas nowadays are big in size [3, 4, 5] and applied single patch element with side fed resulted in low gain performance. Realizing UWB antenna with high gain is a challenging task [3, 6]. Array structure and coaxial feed is proven able to increase the gain of an antenna [7] and these techniques are deployed towards UWB antenna in order to increase the antenna performance. Various techniques have been combined to obtain wide operated frequency such as probe compensation, coplanar parasitic patches, stacked parasitic patches, U-slot patch antenna, L-probe coupled patch, aperture coupled patches and ground plane medication [4]. Nowadays, CPW-fed printed antennas have demonstrated significant attractive characteristics such as ultra-wide frequency band, excellent radiation properties, good impedance matching, low radiation loss, less dispersion and easy integration with system circuits [8]. CPW arrangement is alike with the microstrip structure yet the ground plane is positioned in the front side which is close to the main feed line [13]. CPW consist of minimum one plane thin conductive strip substrate together with conductive ground plates printed on the same side of dielectric substrate made them as coplanar structure. The electromagnetic waves are separately by CPW into two different parts which is presented in the dielectric substrate and also in the air above the substrate. On the other hand, conductor-backed plane is another additional structure of ground plane covers the entire back side of the substrate which acts as another return conductor. Due to differences in dielectric constant value between the substrate and the air, the wave is travelling in an inhomogeneous medium [12].

However, most previously reported CPW-fed antenna designs are complex, with poor radiation patterns, unsuitable for practical applications [11], side-fed and consist of single radiating element only [9, 10] which lead to low gain [12, 18]. Apart from that, full CB-CPW method is commonly utilized in obtaining UWB high gain antenna [17, 19] where the combination of partial CB and array technique with coaxial fed is not thoroughly investigated for the similar purpose. The proposed antenna equipped with partial conductor backed-coplanar waveguide (PCB-CPW) with array radiating element and coaxially fed in providing a substantially wide impedance bandwidth to fulfil UWB requirement (3.1 GHz-10.6 GHz) with high gain performance which is easily integrated into the microwave imaging system as the scanning probe. The partial conductor-backed plane width as well as CPW ground length and width are significant parameters in optimizing the antenna impedance matching performance. This article covered the antenna design with parametric study as well as the overall simulated and fabricated antenna performance.

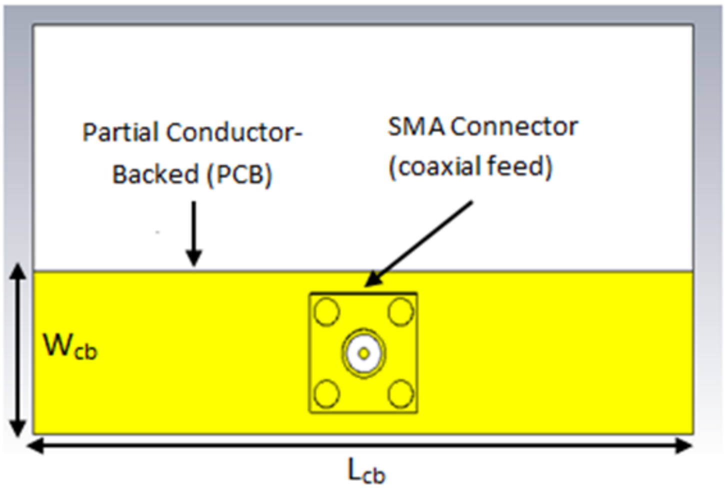
2. ANTENNA DESIGN AND FABRICATION

Figures 1 presents the simulated antenna structure. The presented UWB antenna is printed on both sides of the substrate as shown in figure 1 where the front side (a) shows copper radiating elements array associated with CPW ground plane and the back view (b) shows the partial copper conductor-backed plane with 50Ω SMA connector coaxially fed. Meanwhile figure 1(c) shows ground plane with partial copper conductor-backed plane (transparented), which is essential in providing a significant wideband impedance matching. The array consists of four small identical circular patches (diameter = 15 mm) that are connected to a quarter wave transformer transmission line. As shown in figure 1(a), each quarter wave transmission line has its own specific width represent by W1, W2 and W3 for 50 Ω, 70.71 Ω and 100 Ω respectively.

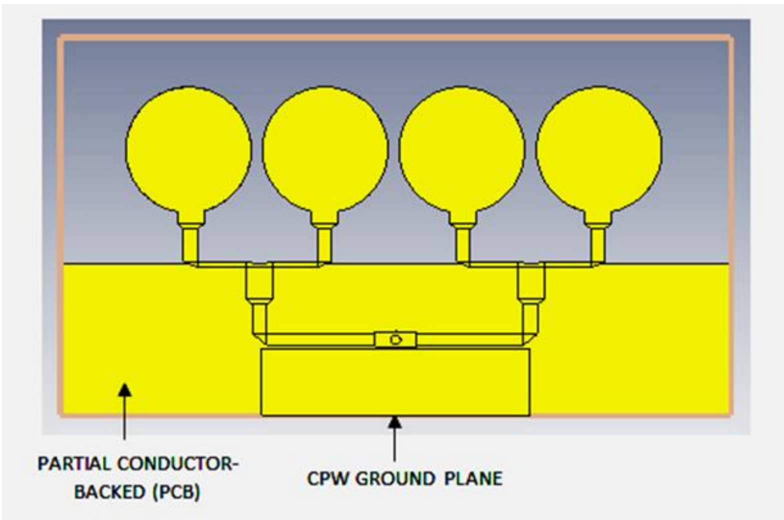
The conductor-backed plane measurement is highly significant in relation to the efficiency of the proposed UWB antenna. However, the antenna return loss performance did not achieve the expected matching across the whole intended UWB band using only the partial conductor-backed plane. Therefore, the unique ground of CPW structure is introduced located close to the main transmission line as shown in Figure 1(a). As a result, the proposed antenna design has successfully achieved a UWB operation bandwidth with excellent impedance matching. Hence, the determined dimension of the partial conductor-backed plane and CPW ground plane reflects the optimal antenna performance.



(a)



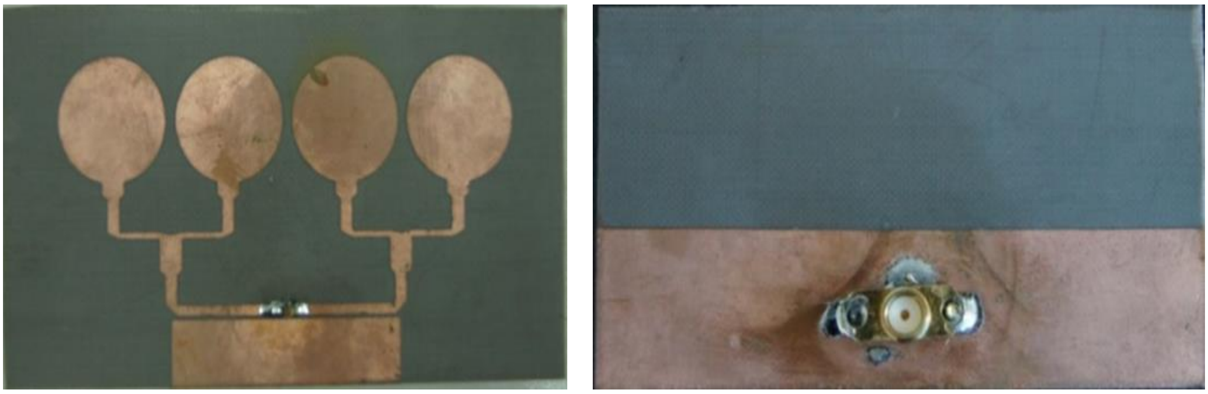
(b)



(c)

Figure 1. Geometry of the antenna, (a) Front view with L_s = 80 mm, W_s = 45 mm, D_p = 15 mm, W_1 = 2.9 mm, W_2 = 1.5 mm, W_3 = 0.65 mm, W_{pe} = 8 mm, L_{pe} = 32 mm, (b) Back view with W_g 18 mm, L_g = 80 mm (c) Structure of ground plane and partial conductor-backed plane (substrate transparented).

The proposed antenna is fabricated on a Taconic substrate (TLY-5) with a dielectric constant of εr = 2.2, a thickness of t = 1.5748+/−0.02 and tangent loss of tan δ = 0.0009, as shown in Figure 2. Table 1 presents the associated antenna array dimensions. The entire measurement process was carried out in the Advanced Communication Centre (ACE) of Universiti Malaysia Perlis (UniMAP) with the help of Agilent Technologies ENA 8051C Network Analyzer and an Anechoic Chamber.



(a) (b)

Figure 2. Fabricated UWB array antenna. a) Front view, b) Back view.

Table 1 Antenna Optimized Dimension

Parameter	Dimension
Substrate Length, L_s	80.0 mm
Substrate Width, W_s	45.0 mm
Patch Diameter, D_p	15.0 mm
CPW Ground Width, W_g	8.00 mm
CPW Ground Length, L_g	32.0 mm
Partial Conductor-Backed Width, W_{cb}	18.0 mm
Partial Conductor-Backed Length, L_{cb}	80.0 mm
50 Ω transmission line width, W_1	2.90 mm
70.71 Ω transmission line width, W_2	1.50 mm
100 Ω transmission line width, W_3	0.65 mm

3. EFFECT OF PARTIAL CONDUSTOR-BCKED (PCB) AND CPW GROUND ELEMENT

Parametric studies have been conducted to investigate the effects of varying certain antenna parameters which is CPW ground plane width and length as well as partial conductor-backed (PCB) width towards the proposed antenna performance in term of reflection coefficient. Figure 3 shows the comparison of the reflection coefficient over various W_{cb} values from 17 mm up to 22 mm. An optimum value of 18 mm is selected as the ideal partial conductor-backed plane width since its reflection coefficient value is the most constant (green line) with matching better than -10dB over the whole UWB spectrum.

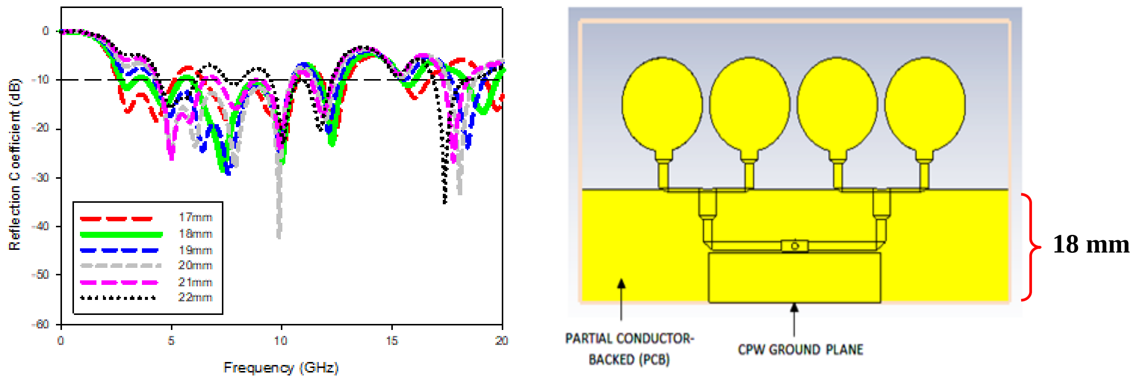


Figure 3. Reflection coefficient comparison over various partial conductor-backed width (W_{cb}).

Figure 4 illustrates the various reflection coefficient results obtained for different widths of the CPW ground plane (4 mm≤Wg≤ 8 mm). At the lower frequency band, the difference in the reflection coefficient values is not significant compared to the high frequency bands. A ground plane width of 8 mm (green line) is chosen as the optimum value.

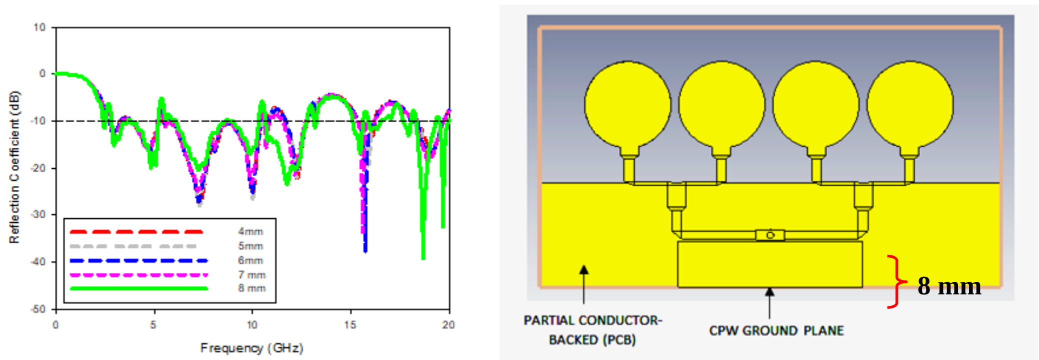


Figure 4. Reflection coefficient comparison over various CPW ground plane widths (Wg).

The parametric study is then extended to include the length of the CPW ground plane (Lg). The length parameter was varied from 30 mm to 34 mm. It is shown clearly in Figure 5 that changing the length parameter induces an incline and decline of the reflection coefficient respectively especially at the high frequency sections. The desired reflection coefficient performance is obtained for a length of 32mm (green line) as shown in Figure 5.

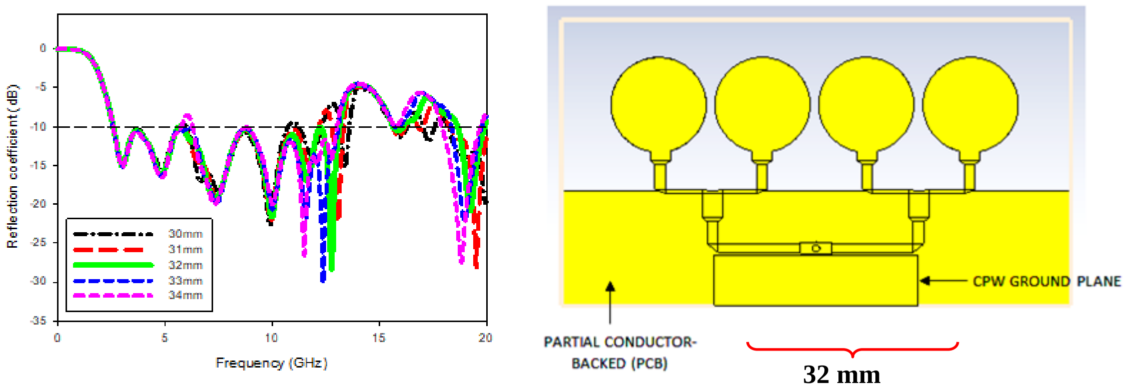


Figure 5. Reflection coefficient comparison over various CPW ground plane lengths (Lg).

For CPW structure, there is an optimum gap between the CPW ground and the main transmission line to obtain the whole reflection coefficient for UWB range requirement within the acceptable limit (< -10dB) as shown in Figure 6. Parametric study is done to observe the effect of varying the inter element spacing (D) and illustrates that the proposed UWB array reflection coefficient differs significantly among the various D values. Compared to all applied values from 0.1 to 0.5 mm, only D = 0.2 mm (green line) successfully achieves the reflection coefficient within the targeted operating frequencies of UWB band.

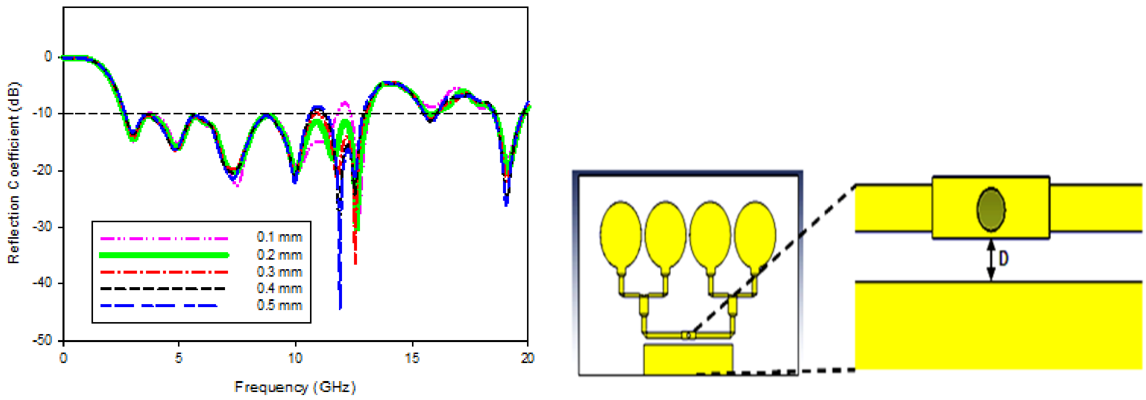


Figure 6. Reflection coefficient comparison over various CPW ground gap from transmission line.

As a result of the conducted parametric studies, the final optimum dimensions of the PCB and CPW ground plane are 40 mm × 18 mm and 32 mm × 8 mm, respectively, with a gap of 0.2 mm between the ground plane and main transmission line.

4. RESULTS AND DISCUSSION

Figure 7 demonstrates high agreement between measured and simulated reflection coefficient for the proposed antenna. It can be observed that both simulation and measurement have produced the resonance frequency regulated UWB's frequency under tolerable reflection coefficient of less than −10 dB. From the figure, it clearly shows the both simulated and measured proposed antenna recorded wide range bandwidth of operated frequency started from 2.6 GHz until 13.1 GHz. The simulated UWB antenna achieved 123.4% bandwidth while measured recorded bandwidth of 116.4% due to different value of impedance matching. Although there is a bit of a difference in terms of percentage of the bandwidth, the proposed antenna can still produce wideband and cover UWB applications. Reflection coefficient less than -10 dB is selected due to the condition where 90% of the signals are successfully transmitted while only the left 10% is reflected back [15].

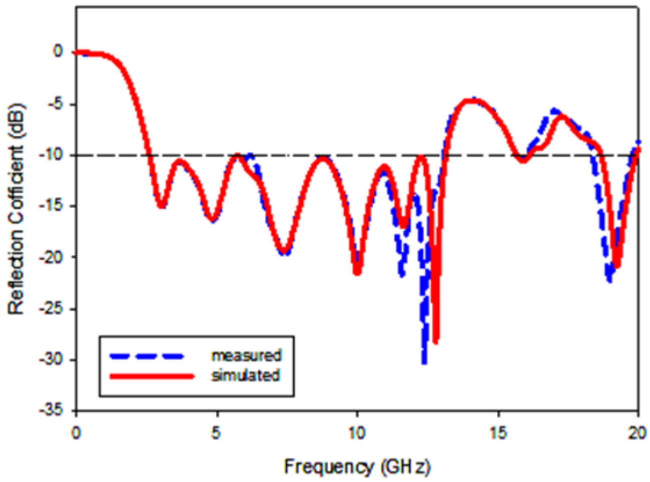


Figure 7. Measured and simulated reflection coefficient.

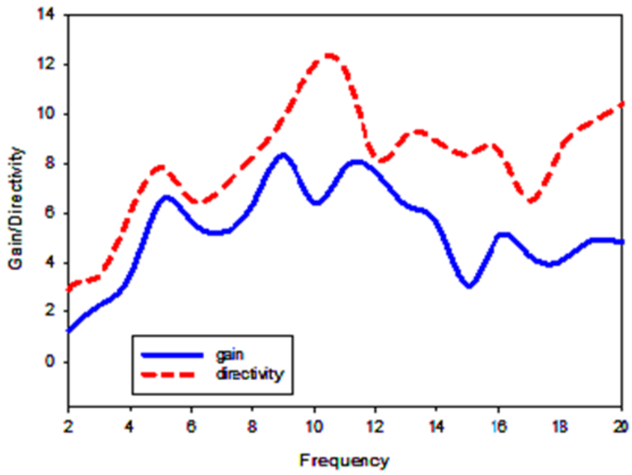


Figure 8. Graph of gain/directivity.

The proposed antenna exhibits high gain over the whole operated frequency start from 2.6 GHz until 13.1 GHz as depicted in figure 8. The lowest and the highest gain of the antenna are 3.4 dB and 12.12 dB respectively. Circular array structure, coaxial feed, optimized CPW ground and PCB collectively contribute in realizing high gain performance throughout the frequency ranges. The proposed antenna gain increased from 3.4 dB at 2.6 GHz to 7.9 dB at 5 GHz. The proposed antenna gain slightly decline between 5 GHz and 6.2 GHz before constantly incline from 6.2 dB until the maximum gain which is 12.12 dB. Started from 10.8 GHz, the UWB antenna experienced gain decline again until 12 GHz before recorded gain incline in the final phase. By preserving the antenna compactness, the proposed antenna peak gain of 12.12 dB is considered as high gain performance antenna. Theoretically, the gain and directivity are closely related with each other where gain is always smaller than the directivity due to the efficiency consideration of conductor and dielectric [7]. Hence, Figure 8 proves that gain element is constantly less than directivity for the entire UWB operated frequency. Apart from that, both figures indicate high and acceptable gain recorded throughout the whole operated frequency which is from 2.6 GHz until 13.1 GHz. The radiation efficiency plot of the proposed antenna is displayed in figure 9. The antenna recorded maximum radiation efficiency of 93% at the frequency of 12 GHz.

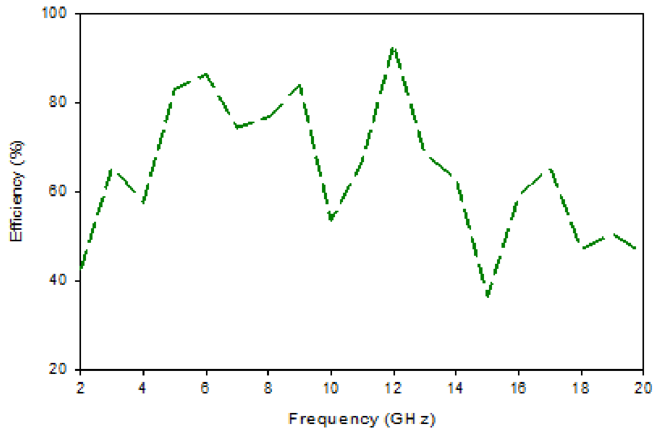
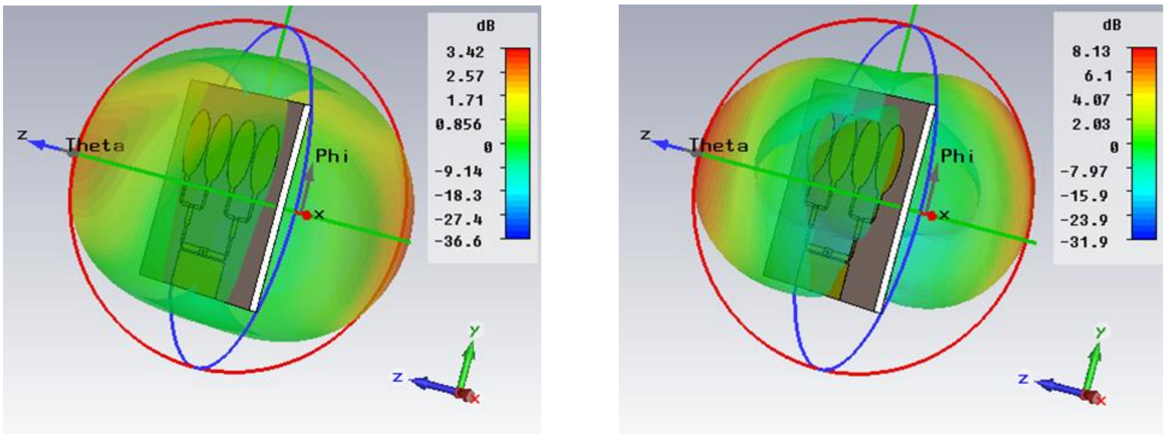
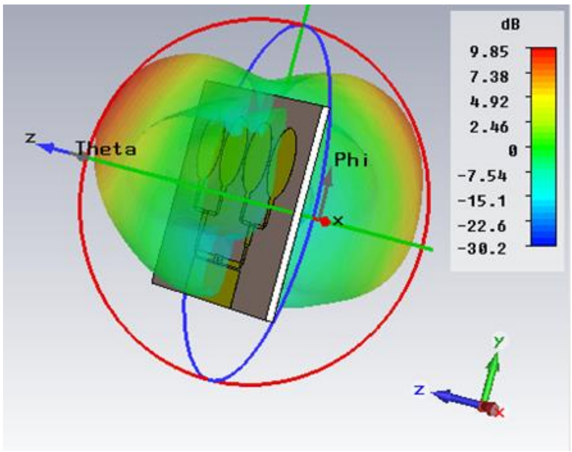


Figure 9. Radiation efficiency graph of proposed antenna.

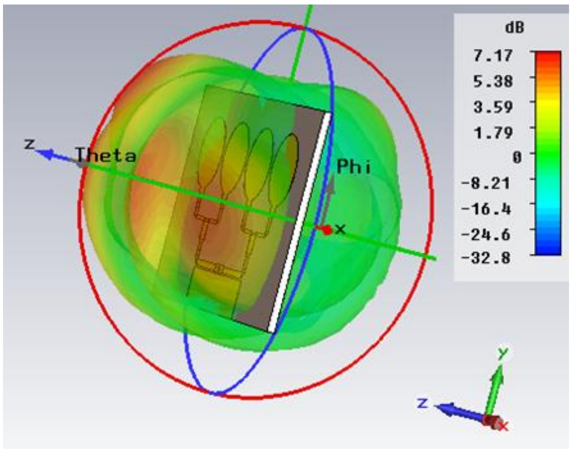
Instead of bandwidth, reflection coefficient and gain, radiation pattern is the other essential parameter to characterize the proposed antenna. The 3D plot radiation pattern of Azimuth-Plane is shown in figure 10 while the measurement and simulation results consist of Azimuth-Plane for polar plot is shown in figure 11. Both figures demonstrate radiation pattern for the proposed antenna at the frequency of 8 GHz, 9 GHz, 10 GHz and 11 GHz. These four particular frequencies recorded among the highest gain of the antenna. The radiation pattern indicates the antenna does radiate over a wide frequency band with good performance and high degree of consistency [14]. The results for measurement and simulation have differences because of minor fabrication tolerance. The ripples in the radiation patterns occurred probably due to the reflections into the field between the antenna under test and reference antenna. The power loss in the RF cable that is applied in the measurement also contributes to these small scale variations [15, 16]. The pattern, gain and frequency ranges of the antenna are the parameters as a good probe or sensor for human brain microwave imaging. Table 2 summarizes the overall performance of the antenna according to reflection coeeficient, gain, and directivity.



(a) (b)

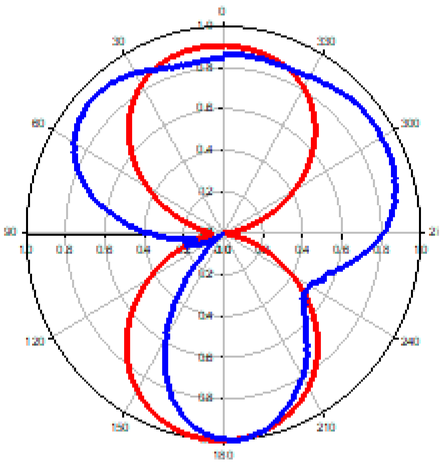


(c)

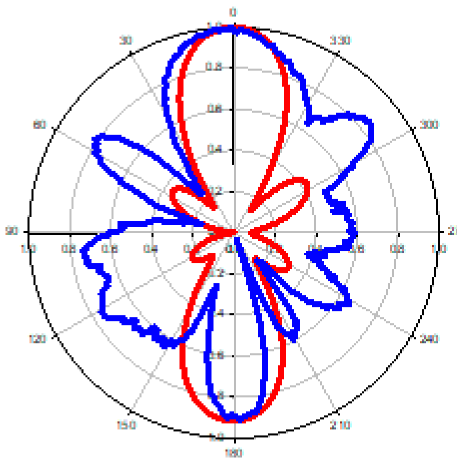


(d)

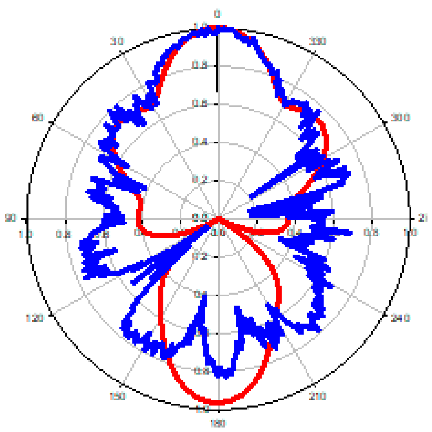
Figure 10. 3D Plot Radiation Pattern of Azimuth-Plane a) 8 GHz b) 9 GHz c) 10 GHz d) 11 GHz.



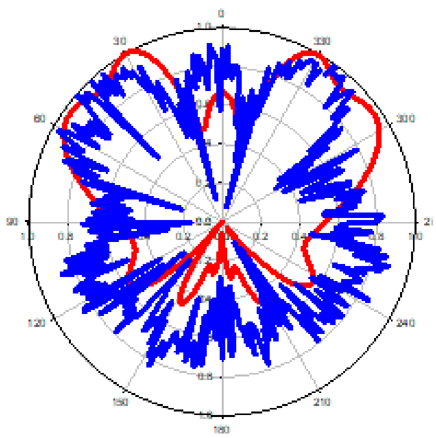
(a)



(b)



(c)



(d)

Figure 11. Measured (blue) and Simulated (red) of UWB Array Antenna's Polar Plot Radiation Pattern of Azimuth-Plane a) 8 GHz b) 9 GHz c) 10 GHz d) 11 GHz.

Table 2 Antenna Optimized Dimension

Frequency (GHz)	Reflection Coefficient (dB)	Gain (dB)	Directivity (dBi)
8	-14.5	8.135	8.248
9	-10.5	9.846	9.900
10	-20.5	11.83	11.94
11	-11.5	11.61	11.72

5. CONCLUSION

A compact and high gain UWB antenna array with coaxially fed elements is proposed. The incorporated structure between the partial conductor-backed and ground plane of CPW structure contributed the broad bandwidth and improved reflection coefficient performance. The antenna demonstrated reflection coefficient of less than -10dB in the band 2.6 GHz to 13.1 GHz with minimum and maximum gain of 3.4 dB and 12.12 dB, respectively. Moreover, measurements of bandwidth, reflection coefficient and patterns match very well with simulated performance. The above-mentioned features make the proposed antenna a very appropriate candidate to be implemented for human brain microwave imaging applications as the scanning probe in transmitting microwave signals to penetrate different structures of human being.

REFERENCES

[1] Anil Kr Gautam, Swati Yadav, & Binod Kr Kanaujia, "A CPW-Fed Compact UWB Microstrip Antenna", IEEE Antennas and Wireless Propagation Letters **12** (2013).

[2] Xue Ni Low, ZhiNing Chen, & Terence S. P. See, "A UWB Dipole Antenna with Enhanced Impedance and Gain Performance", IEEE Transactions on Antenna and Propagations **57**, 10 (2009).

[3] A. Eusuola, Y. Chen, & G. Y. Tian, "Novel Ultra-Wideband Directional Antenna for Microwave Breast Cancer Detection", AP-S/ URSI (2011).

[4] M. Rafiee Aghda, M. F. B. Ain, & A. B. Md. Shahar, "A New Ultra-Wideband Antenna with Unique Ground Plane Shape", Progress in Electromagnetics Research Letters **35** (2012) 165-179.

[5] X. Chen, J. Liang, S. Wang, Z. Wang, & C. Parini, "Small Ultra Wideband Antennas for Medical Imaging", Loughborough Antennas & Propagation Conference, (2008).

[6] Amin M. Abbosh, "Directive Antenna for Ultrawideband Medical Imaging Systems", International Journal of Antennas and Propagation, (2008).

[7] M. T. Islam, R. Azim, & A. T. Mobashsher, "Triple Band-Notched Planar UWB Antenna Using Parasitic Strips", Progress In Electromagnetics Research **129** (2012) 161-179.

[8] Mohammed Al-Husseini, Ali Ramadan, Youssef Tawk, Ali El-Hajj, Karim Y. Kabalan, "Design and Ground Plane Optimization of A CPW-fed Ultra-Wideband Antenna", Turk J Elec Eng & Comp Sci **19**, 2 (2011).

[9] M. Ojaroudi, Sh. Yazdanifard, N. Ojaroudi, & M. Naser-Moghaddasi, "Small Square Monopole Antenna with Enhanced Bandwidth by Using Inverted T-Shaped Slot and Conductor-Backed Plane", IEEE Transactions on Antennas and Propagation **59**, 2 (2011).

[10] Anil Kr Gautam, Swati Yadav, & Binod Kr Kanaujia, "A CPW-Fed Compact UWB Microstrip Antenna", IEEE Antennas and Wireless Propagation Letters **12** (2013).

[11] Shaowen Hu, Yiqiang Wu, Ye Zhang, Huilin Zhou, "Design of a CPW-Fed Ultra Wide Band Antenna", Open Journal of Antennas and Propagation **1** (2013) 18-22

[12] Sarawuth Chaimool & Prayoot Akkaraekthalin, CPW-Fed Antennas for WiFi and WiMAX, Advanced Transmission Techniques in WiMAX, Dr. Roberto Hincapie (Ed.), ISBN: 978-953-307-965-3, InTech, (2012).

[13] S. W. Lee, N. Kim, S. W. Park, S. K. Jeon, & S. Y. Rhee, "Design of Trapezoidal Ring Antenna Using Conductor-backed CPW Structure", Piers Online **5**, 3 (2009).

[14] N. Ojaroudi, M. Ojaroudi, F. Geran, & Sh. Amiri, "Omnidirectional Antenna with Multi-Resonance Performance for Microwave Imaging Systems", Telfor Journal **5**, 2 (2013).

[15] M. Jusoh, M. F. Jamlos, M. R. Kamarudin, F. Malek, M. H. Mat, & M. A. Jamlos, "A Novel Compact Tree-Design Antenna (Ncta) With High Gain Enhancement for UWB Application", J. of Electromagn. Waves and Appl. **25** (2011) 2474–2486.

[16] SatyabrataMaiti, Amrit Mukherjee, AmlanDutta, "Design of a Novel Shaped Ultra Wideband Co-axial Feed Microstrip PatchAntenna", Fourth International Conference on Advanced Computing & Communication Technologies, (2014).

[17] M. Nedil, M. A. Habib, T. A. Denidni, & H. Boutayeb, "Quasi-Metallic-Wall Technique for Increasing the Efficiency Of CB-CPW Antennas", Progress in Electromagnetics Research, PIER **78** (2008) 437–455,

[18] Fei Yu, Chunhua Wang, "A CPW-Fed Novel Planar Ultra-Wideband Antenna with a Band-Notch Characteristic", Radio engineering **18**, 4 (2009).

[19] Yow-Shyan Lin, Lieh-Chuan Lin, Toshihide Kitazawa, & Yu-De Lin, "Circularly Polarized Slotted Conductor-backed Coplanar Waveguide (CBCPW) Antenna Array with Sequentially Rotated Feeding Structure", PIERS Proceedings, Moscow, Russia, August 18-21 (2009).