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High Gain of Directional Ultra-Wideband Array Antenna Using Flat Reflector Structure for Microwave Imaging

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Abstract. UWB array antenna with high gain is proposed. The 4×1 array antenna consists of four identical copper circular patches are appropriately connected using quarter-wavelength transformer transmission line. The array elements and its feed network are properly optimized to have a high gain performance over wide range bandwidth frequencies. New additional flat reflector with distance of 20 mm enhances the proposed antenna gain. UWB antenna performance with reflector is better than UWB antenna without reflector structure. Antenna with reflector recorded wider operated bandwidth; 1.9GHz-10.6GHz with higher gain ranged from 3.5dB until 14.2dB compared with without reflector antenna operated from 2.2GHz to 10.6GHz with lower gain ranges of 1.9dB to 9.8dB. The reflector structure enhanced the antenna gain by 50% where the average gain throughout operated frequency for antenna with reflector and antenna without reflector is 10.2dB and 6.8dB respectively. Dimensions of 80 mm × 45 mm is considered as small UWB array antenna. The high gain and wide operator bandwidth of proposed antenna finds it very suitable to be integrated in human brain microwave imaging system due to ability of the wide signal with high energy penetrating human head structure.

1. Introduction

Microwave imaging could be defined as seeing the internal structure of an object by exposing electromagnetic fields at microwave frequencies of 300MHz- 30GHz [1]. It is done by producing images consist of distributed electrical property in human body called human microwave imaging. Techniques for microwave imaging generally divided by three major parts involving active, passive and hybrid techniques. As for active microwave imaging, several antennas transmit microwave signals into tissues and reflected signals known as backscattered signals are used to generate microwave images. Active microwave imaging can be further separated into ultra-wideband (UWB) radar imaging and tomography imaging. At first, UWB radar imaging technique is introduced purposely only for breast tumor detection [2] and then followed by emerging modification technique used comparable principles technique for stroke and tumor detection in the brain later [3]. Radar based techniques is preferable since it only need to identify strong scattering point caused by inclusions with high frequent occasion [4]. This kind of technique is less complicated which involve less sophisticated algorithm of delay and sum confocal microwave imaging algorithm. This algorithm is the most commonly algorithm used in ultra-wideband radar based microwave imaging technique.

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 [5]. Due to great benefits 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 [6, 7]. Application of microwave energy in the medical field is currently gaining interest by the research community where microwave based systems have the high potential of being simple, safe, portable and cost-effective.

Due to high gain and better return loss offered by UWB antenna that well suitable for medical applications, the utilization of UWB antenna promising significant function for detection purpose compared with most of the conventional compact antennas which have low gain and poor return loss. In microwave imaging, high gain and good directional beam-width for wide frequency band antennas are really necessary for target detection, localization systems and cancer screening applications [8]. High gain and wide operated bandwidth antenna that boost the focus of the electromagnetic energy is crucial in microwave imaging for interacting and penetrating the multilayer structures with different characteristics [9] contributes in providing images with high details. Clear and sharp images lead to accurate diagnostic and avoid false treatment given to the patient.

Currently, most of the UWB antenna structures explained in literature are consist of single patch element exhibited nearly omnidirectional radiation patterns and considerably low gain. [10]. Furthermore, single UWB antenna has been explored comprehensively before and already established worldwide. According to [11, 12], most of the compact UWB antennas demonstrated omnidirectional radiation patterns with moderately low gain and noticeable distortion within the impulse response. UWB arrays antenna can be considered to be applied once directional radiation pattern and higher value of antenna gain is required [10]. Apart from directional and high gain antenna, UWB array antenna also required to overcome the disadvantages of microstrip single antenna which is narrow bandwidth with low efficiency [13]. Partial ground technique and present of parasitic element applied in the design lead to realization of UWB array characteristic. The arrays structures are very effective in capture the scattered signal that can be analyzed to solve the inverse problem and obtain the constructed images of the preferred tissues [14].

Apart from array structure and coaxially fed, introduction of additional copper reflector contribute significantly in increasing the proposed antenna gain in order to penetrate multi-structure human head so that the signal could reach the tumor inside brain. It is done by reflecting the backwards radiation towards frontwards radiation and hence increases the gain by summing up the original frontwards radiation with reflected one. Reflector in antenna is a structure that reflects electromagnetic waves towards desired direction. Reflectors also work to stop undesirable signals from interfering either the side or back of the antenna [15]. Reflector is extremely necessary for single direction transmission and reception or maximum gain possible required. Reflectors could be either standalone device or being integrated with the antenna as a whole structure. Standalone reflector function is to redirect electro-magnetic (EM) energy where corner reflector is one of the most common standalone reflector types. This kind of reflector generally used for radar application as a passive repeater.

On the other hand, integrated reflector function to modify the radiation pattern of the antenna and increasing gain in a wanted direction. It consists of passive element located behind a radiating dipole element in order to absorb and radiates back the signal in a directional way. Among the common integrated reflector types are parabolic reflector, flat reflector, corner reflector and cylindrical reflector [16]. In this paper, flat reflector has been integrated with UWB array antenna in improving the gain and return loss.

2. Antenna Design and Fabrication

A 4x1 UWB array antenna has been designed in this paper. This proposed antenna consists of partial ground plane, single layer of taconic as the substrate and circular patches with parasitic element as shown in Figure 1. Parasitic element is placed on the same layer of radiating patch and very close to feeding line with the gap only 0.2 mm. The antenna has small dimensions of 80 mm x 45 mm in size. As shown in Figure 1 (b), the proposed antenna is coaxially feed using 50 Ohm SMA connector located in the middle of the lower part of the antenna back. The proposed antenna implemented the coaxial probe feed where the signal is fed directly to the radiating patch. Here, inner conductor of the coax is connected to the patch with soldering of the dielectric substrate and also its outer conductor which is directly connected to the ground plane [14]. Figure 1 demonstrated the simulated design of UWB array antenna using taconic (TLY-5) with a dielectric constant of $\epsilon_r = 2.2$, a thickness of $t = 1.5748 \pm 0.02$ and tangent loss of $\tan \delta = 0.0009$ as the substrate. The antenna is printed with 4x1 copper radiating patch array properly connected with quarter wave transformer transmission line associated with copper parasitic element for the front side as shown in Figure 1(a). The patches comprise of four identical circular with diameter of 15 mm. The parasitic element is placed on very close to feeding line with the gap only 0.2 mm. As shown in Figure 1 (a), each quarter wave transmission line has its own specific wide dimension for 50 Ω , 70.71 Ω and 100 Ω to ensure equal current distribution towards all four patches could be realized. Quarter-wave transformers of 70.71 Ω are used to have ideal match between the 100 Ω lines and the 50 Ω lines [13].

On the other hand, Figure 1(b) shows copper partial ground plane is printed at the back side with 50 Ω SMA connector coaxially fed in the middle of the lower part of the antenna back where the signal is fed directly to the radiating patch. Meanwhile Figure 1 (c) and (d) show the copper reflector with 20 mm gap

functioned to reduce the side lobe and realized the directional antenna which has higher gain property by reflecting the backwards radiation towards frontwards radiation. The size of the reflector is similar with the size of the sensor. There is a hole through the reflector specially made for connector connection as shown in Figure 1(d). Small dimensions of the sensor made it suitable enough to be integrated as the sensor in microwave imaging system.

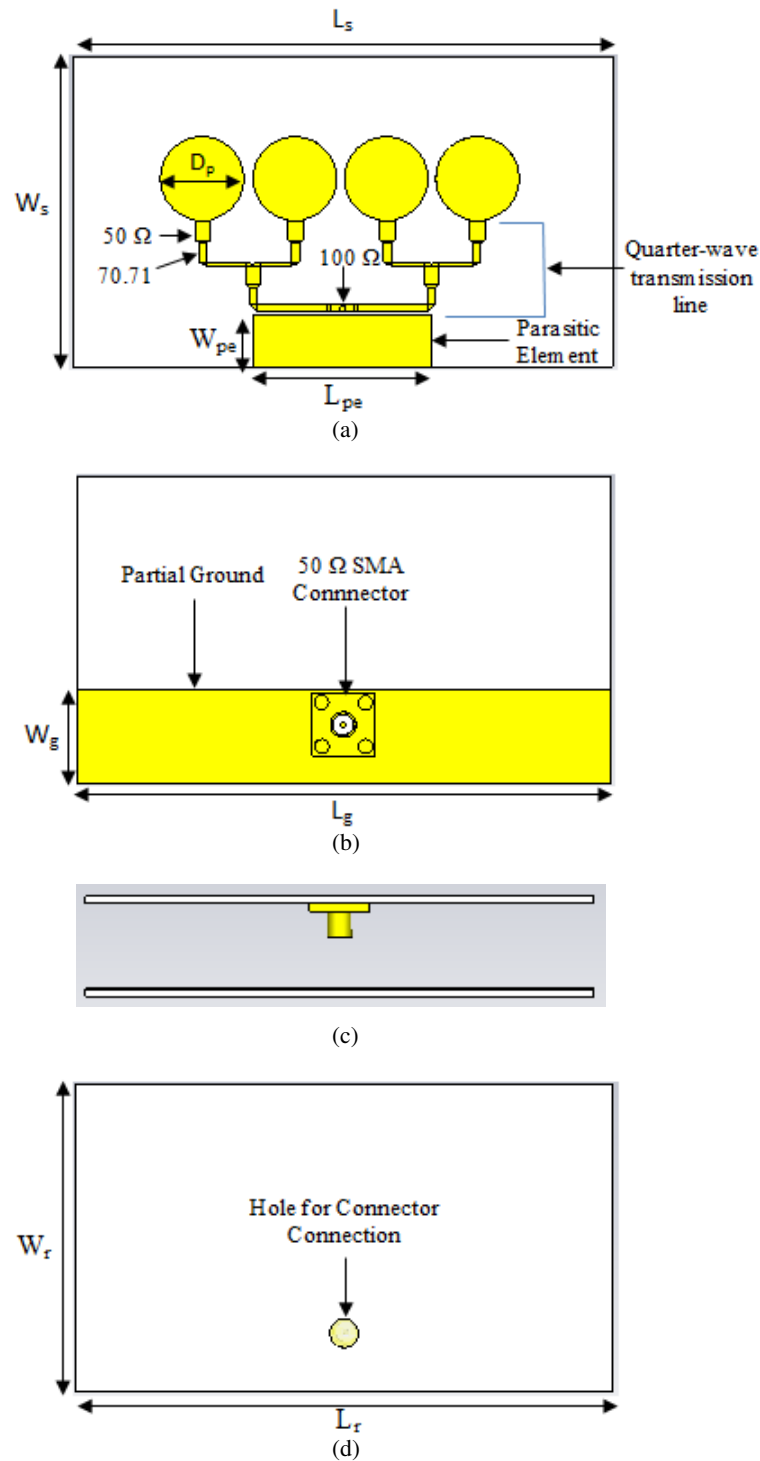


Figure 1. The simulated geometry of the proposed UWB array antenna, a) front view, b) transparent back view (without reflector) c) top view e) back view

All important parameters of the designed antenna are optimized to obtain the best result in term of compact size, high gain and wide bandwidth. The optimized dimensions for the antenna are listed in Table 1. Measurements of gain, patterns and s-parameter have been performed using the setup consisting of Agilent ENA 8051C and anechoic chamber. The horn antenna is used as the transmitting antenna while antenna under test (AUT), UWB array as the receiver with a distance of 0.84 m between them.

Table 1. Optimized Antenna Parameter

Parameter	Quantity
L_s	90.0 mm
W_s	45.0 mm
D_p	7.50 mm
W_{pe}	8.00 mm
L_{pe}	32.0 mm
R_d	20.0 mm
W_g	18.0 mm
L_g	90.0mm
W_r	90.0 mm
L_r	45.0 mm
L_s	90.0 mm
W_s	45.0 mm

Corporate feed network is utilized in realizing four elements array structure where each patch is fed parallelly using transmission lines. The transmission lines are separated into four divisions based on the number of the radiating patch. The quarter-wave transformer impedance matching technique is applied to distribute the power correspondingly toward entire patches where the feed lines of 70.71Ω are utilized for perfect matching between the 100Ω lines and the 50Ω lines as shown in Figure 1 (a). Figure 2 shows Quarter-wave transmission line impedance matching for the corporate feed network.

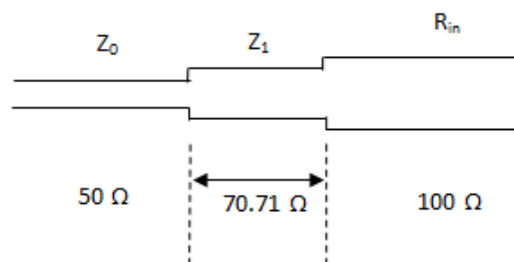


Figure 2. Quarter-wave transmission line impedance matching

The formula for the quarter-wave transformer is shown in following equation [13]:

$$Z_1 = \sqrt{Z_0 R_{in}} \quad (1)$$

where:

Z_1 = transformer characteristic impedance

Z_0 = input transmission line characteristic impedance

R_{in} = edge resistance at resonance.

Impedance calculation for array antenna is alike for single patch calculation. The formula to perfectly match 100 Ω and 50 Ω transmission lines is shown as followed. Via equation above where $Z_0 = 50 \Omega$ and $R_{in} = 100 \Omega$, the transformer impedance value is:

$$Z_1 = \sqrt{50(100)}$$

$$= 70.71 \Omega$$

The sizes for 50 Ω feedline, 70.71 Ω quarterwave transformer and 100 Ω impedance line are acquired by applying following equations [13]:

$$\text{for } \frac{W}{h} < 2$$

$$\frac{W}{h} = 8e^A / (e^{2A} - 2)$$

$$\text{for } W/h > 2 \quad (2)$$

$$\frac{W}{h} = \frac{2}{\pi} \left[B - 1 - \ln(2B - 1) + \frac{\epsilon_r - 1}{2\epsilon_r} \left\{ \ln(B - 1) + 0.39 - \left(\frac{0.61}{\epsilon_r} \right) \right\} \right] \quad (3)$$

Where h = substrate height and

$$A = \frac{Z_0}{60} \left[\frac{\epsilon_r + 1}{2} \right]^{\frac{1}{2}} + \left[\frac{\epsilon_r - 1}{(\epsilon_r + 1)(0.23 + \left(\frac{0.11}{\epsilon_r} \right))} \right]$$

$$B = 377\pi / (2Z_0 \sqrt{\epsilon_r}) \quad (4)$$

Table 2. Optimized Antenna Parameter

Impedance (Ω)	Length (mm)	Width (mm)
50	8.00	2.90
70.71	8.19	1.50
100	8.40	0.65

Figure 3 shows the comparison image between the fabricated UWB antenna with reflector and UWB antenna without reflector as shown in Figure 3(a) and (b) respectively.

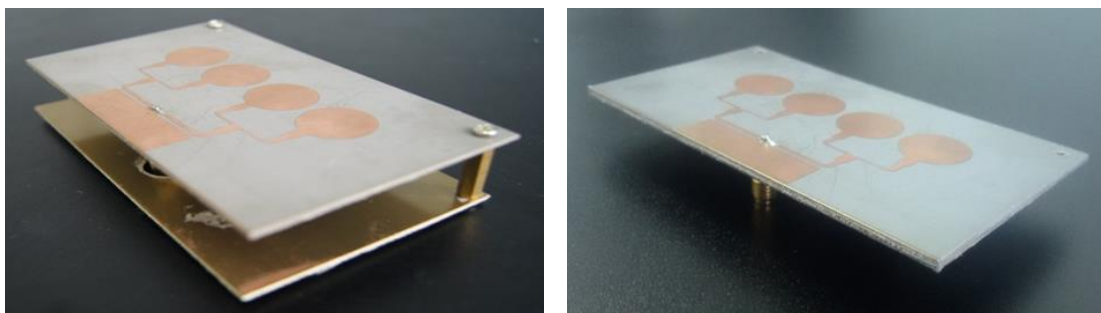


Figure 3. Fabricated UWB-Array antenna, a) with reflector, b) without reflector

On the other hand, Figure 4 demonstrated the geometry of the fabricated UWB array antenna with reflector in detail.

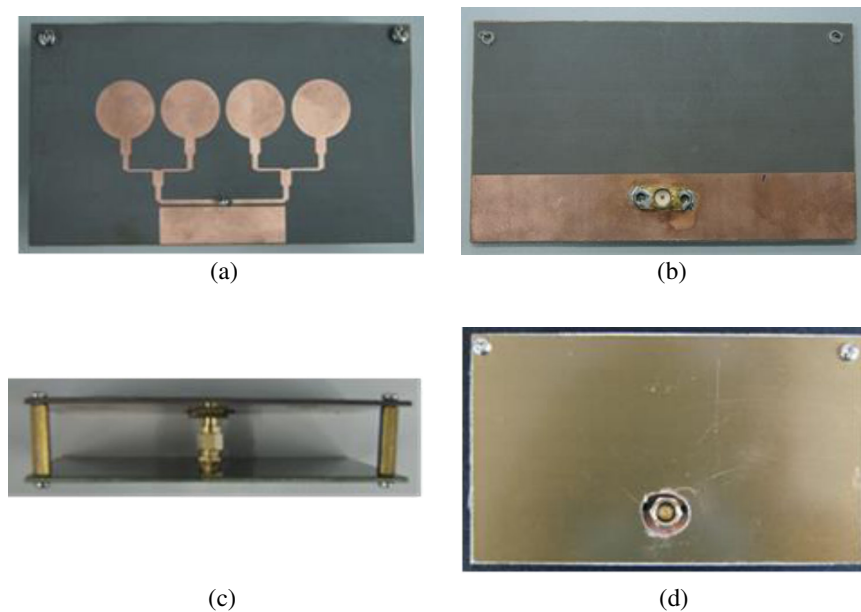


Figure 4. The fabricated UWB array antenna with reflector. a) front view, b) transparent back view (without reflector), c) top view, d) back view

3. Results and Discussion

Simulation and measurement results for both antennas with reflector and without reflector in term of reflection coefficient are shown in Figure 5. Both simulation and measurement results for each antenna fulfilling the requirement for UWB characteristic; 3.1 GHz until 10.6 GHz. The antenna with reflector performance is better than antenna without reflector performance. From the figure, it shows the antenna with reflector recorded wider range bandwidth of operated frequency compared with antenna without reflector for both simulated and measured results. For simulated, antenna with reflector recorded UWB operated frequency started from 1.8 GHz until 10.8 GHz while antenna without reflector started from 2.0 GHz until 10.8 GHz. On the other hand, antenna with reflector and without reflector recorded 1.9 GHz until 10.6 GHz and 2.2 GHz until 10.6 GHz respectively for measured results. 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 [17]. Partial ground technique and additional of parasitic element assure lower reflection coefficient achieved.

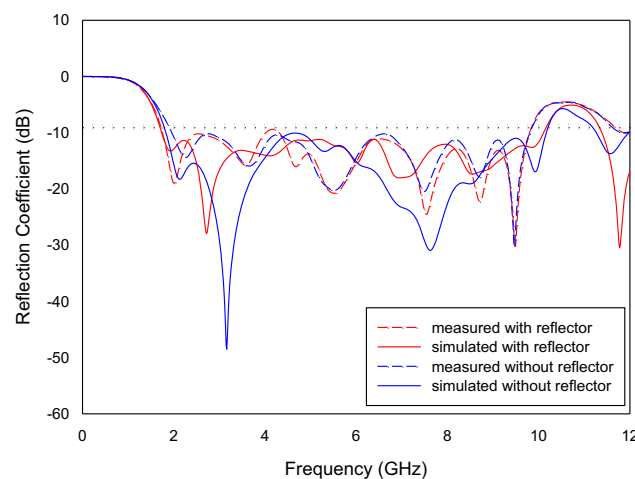


Figure 5. Simulated and measured reflection coefficient for UWB array antenna with reflector and without reflector

The antenna with reflector exhibits higher gain than antenna without reflector over the whole operated frequency both for simulated and measured as depicted in Figure 6. Simulated and measured results recorded almost similar readings and considered as adequate agreement between them. The measured gain for antenna with reflector and without reflector ranged from 3.5 dB until 14.2 dB and 1.9 dB until 9.8 dB respectively. The reflector structure enhanced the antenna gain by 50% where the average gain throughout operated frequency for antenna with reflector and antenna without reflector is 10.2 dB and 6.8 dB respectively. The significant gain enhancement is done with the function of reflector in reflecting the backwards radiation towards frontwards radiation and executed as a unidirectional beam associated with high gain.

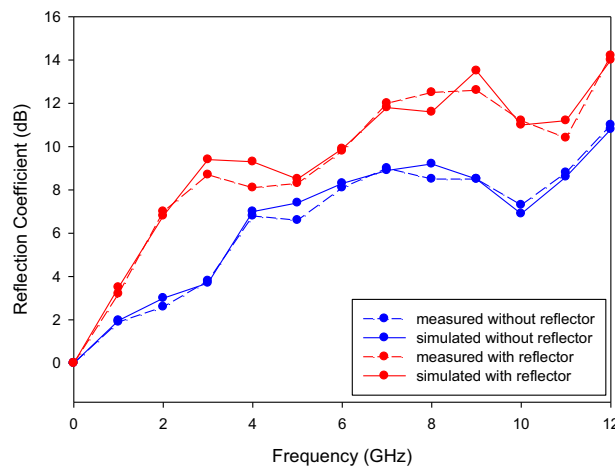


Figure 6. Simulated and measured gain for UWB array antenna with reflector and without reflector

In this design, one of the efficient method to obtain directional sensor and optimize the gain while maintaining the UWB frequency is by adjusting the reflector distance (R_d) as shown in Figure 7. Meanwhile, Figure 8 illustrates that the proposed UWB array's reflection coefficient differ significantly among the various R_d . Compared to other R_d , which is 5 mm, 10 mm, 15 mm, 25 mm and 30 mm, only $R_d = 20$ mm successfully achieves the reflection coefficient within the targeted operating frequencies. Hence, the reflector with specific distance of $R_d = 20$ mm has been chosen in the UWB sensor design with a dimension of 90 mm $\times$ 45 mm.

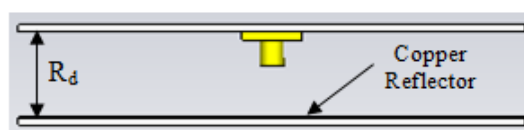


Figure 7. Reflector distance for UWB array antenna (top view)

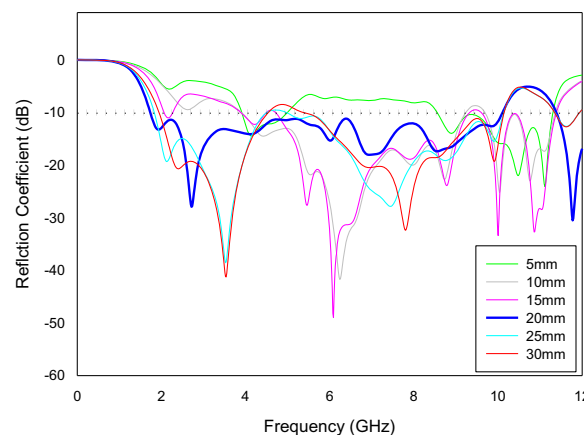


Figure 8. Reflection coefficient of various R_d for UWB array antenna

Instead of bandwidth and gain, radiation pattern is the other essential parameter to evaluate the proposed antenna. The measurement and simulated radiation pattern results of Azimuth-Plane for both antennas are shown in Figure 9. The figure demonstrates the polar radiation pattern for the proposed antenna at the frequency of 2 GHz and 3 GHz that are essential frequencies for brain microwave imaging application [1]. The radiation pattern indicates both antenna with reflector and without reflector does radiate over a wide frequency band [12] where antenna with reflector recorded better radiation pattern indicated by wider area covered especially the main lobe. Antenna with reflector also could be categorized under unidirectional antenna since the radiated wave radiates more on main lobe compared to the side and back lobe. In addition, simulation and measurement results indicate acceptable agreement between them. The sensor exhibits the averaged total radiation efficiency of 95% and 87% for antenna with reflector and antenna without reflector respectively. The total radiation efficiency of the antenna promising the good probe or sensor for human brain microwave imaging. The pattern, gain and frequency ranges of the antenna are the parameters as a good probe or sensor for human brain microwave imaging.

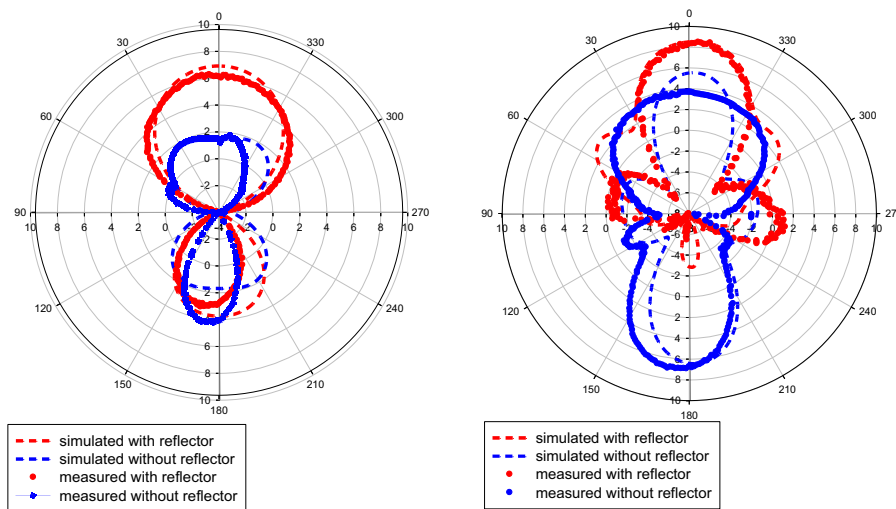


Figure 9. Measured and simulated polar radiation pattern in Azimuth plane for antenna with reflector and without reflector; (a) 2 GHz and (b) 3 GHz

4. Conclusion

A UWB array antenna with high enhancement of gain for brain microwave imaging is proposed. Additional flat reflector structure contributes significantly in improving the overall antenna performance especially the gain and radiation pattern. The antenna with reflector demonstrated wider reflection coefficient of less than -10dB started from 1.8 GHz until 10.6 GHz with the ranges of gain between 3.5 dB to 14.2 dB as compared with antenna without reflector that recorded 2.2 GHz to 10.6 GHz and 1.9 dB to 9.8 dB for the reflection coefficient and gain respectively. Moreover, measurement results have identical behavior compared to simulations. Thus, in a nutshell, the proposed antenna is very suitable to be implemented in brain microwave imaging applications due to high gain and wide bandwidth.

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