Tumor Detection via Specific Absorption Rate Technique Using Ultra-Wideband Antenna

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Abstract. This paper proposes high gain ultra-wide band (UWB) reflector array antenna for human brain tumor detection using specific absorption rate (SAR) technique in microwave detection system. Introduction of copper reflector with ideal distance contribute in increasing the proposed antenna gain. High gain antenna is essential in human microwave detection system for penetrating the multilayer structures by enhancing the focus of the electromagnetic energy into the desired structure. The antenna with reflector recorded wider bandwidth; 1.6 GHz-10.8 GHz associated with higher gain ranged from 3.2 dB until 14.1 dB compared with antenna without reflector operated from 2.2 GHz to 10.8 GHz with lower gain ranges of 2.1 dB to 10.2 dB. The antenna is successfully detecting human brain tumor based on SAR technique. Amount of energy or gain produced by the antenna which being absorbed by the human brain indicated the present of tumor inside. Human brain with tumor absorbed more energy and recorded higher SAR value compared to human brain without tumor. In this paper, human head phantom associated with tumor recorded SAR value of 2.53 W/kg and 2.51 W/kg for simulated and measured respectively meanwhile head phantom without tumor stated SAR value of 1.06 W/kg for simulated and 1.05 W/kg for measured. The biggest different in SAR value according to area precisely determine the location of the tumor in the brain which in this case position 5 (tumor location) resulted biggest SAR different value of 1.47 W/kg for simulated and 1.46 W/kg for measured.

1. Introduction

Brain tumor is defined as a mass of tissue formed by an accumulation of abnormal cells within the brain. Primary brain tumor is the condition where the tumor originated from the brain itself while secondary brain tumor occurs when the tumor originated from other parts of the body [1]. It could be the most dramatic form of human illness, and among the most rapidly fatal of all cancers. In 2030, around 13.2 million people worldwide will suffer and die cause of cancer since cancer is one of the most complex disease exist in the world [2]. Early cancer detection which allows early cancer treatment could increase the cure rates as the treatment is more efficient and effective compared with treatment done at the late stage of cancer. Application of microwave energy in the imaging and treatment for brain tumor is currently gaining interest by the research community. Microwave detection systems have the high potential of being simple, safe, portable and cost-effective [3]. In addition, almost all of current microwave imaging are concentrating on breast cancer only and have limited effort in building complete microwave brain imaging [4].

In this paper, specific absorption rate (SAR) technique to detect brain tumor for human being was proposed. Principally, the technique based on different ability of the healthy tissue and tumor tissue in absorbing energy. Tumor tissue will absorbed more energy and resulted in higher SAR value compared with healthy tissues due to present of self-blood vessel of the tumor itself. Antenna that produces energy radiated towards the human head phantom with tumor and without tumor. The result SAR values was compared between brain with tumor and without tumor in order to validate the SAR technique in detecting brain tumor. The rest of this paper is organized as follows: Section 2 describes the antenna design and performances. Methodology for the proposed technique, experimental results of comparison between SAR values of human...
Conventional X-ray, magnetic resonance imaging (MRI), computed tomography (CT Scan) and ultrasound technique are the common imaging modalities utilized to detect cancer [5]. However, all those modalities come with major drawbacks such as involving ionizing radiation, too expensive, invasive, personnel dependent and long scanning time [6]. Lately, microwave frequency based device has been utilized in tumor detection for one of its medical application. Microwave cancer detection offers several significant advantages compared to others imaging technique including low costs, noninvasive, involves nonionizing radiation and have high accuracy in detecting tumor existence [7]. In Specific Absorption Rate (SAR), microwave cancer detection is realized by the interesting characteristic of the normal tissue and malignant tissue which demonstrated huge difference in term of dielectric property at the microwave frequency. Malignant tissues will record higher dielectric property due to more absorption of electric field compared to normal tissues which help the researcher to identify the tumor presence [8]. Hence, microwave based technique, SAR technique is selected as the alternative method for detection since such technique could accurately detect the presence of the tumor in the brain. SAR is used to measure the energy rate absorbed by the human body when exposed to electromagnetic field [2]. The rate could be calculated from following scientific formula (1):

\[
\text{SAR} = \frac{\sigma |E|^2}{\rho}
\]  

where \(\sigma\) is the tissue conductivity (S/m), \(E\) is the internal electric field (V/m) and \(\rho\) is tissue mass density (Kg/m³). The values of SAR can be categorized as 1g or 10g mass of tissue which equivalence to 1g or 10g spatial average SAR. According to IEEE C95.1:1999, 1.6W/kg is the limit value for 1g spatial average SAR while it has been updated as 2W/kg for 10g spatial average SAR based on IEEE C95.1:2005.

Currently, utilization of UWB antennas promising significant function in cancer detection due to UWB antennas are well suited for medical applications since it offer high gain good return loss compared with most of the conventional compact UWB antennas which have low gain and poor return loss [5]. High gain and wide bandwidth antenna is essential in human microwave imaging for interacting and penetrating the multilayer structures with different characteristics by enhancing the focus of the electromagnetic energy into the desired structure [9]. Partial ground technique and present of parasitic element applied in the design lead to realization of UWB characteristic [14]. Apart from array structure [10] and coaxially fed [11], introduction of additional copper reflector contribute 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. Due to excellent electrical characteristics including high gain, low side lobe level and low cross polarization reflector antennas have been widely used in radio astronomy, microwave communication, tracking and telemetry nowadays [12].

Basically, the proposed technique used improved gain and better return loss of UWB reflector array antenna in order to detect the brain tumor using SAR technique. A human head phantom with tumor inside is realized and placed close to proposed antenna to measure the desired SAR value. It has been discovered that the SAR rate for the healthy brain model is lower compared to the model with tumor inside where the respective SAR values for both condition are tabulated to see the significant differences.

2. Antenna Design, Fabrication and Performances

Figure 1 demonstrated the simulated design of UWB reflector array antenna using taconic (TLY-5) with a dielectric constant of \(\varepsilon_r = 2.2\), a thickness of \(t = 1.5748 +/- 0.02\) 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. 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 50Ω, 70.71Ω and 100Ω 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 50Ω 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 uni-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 UWB antenna. There is a hole through the reflector specially made for connector connection
as shown in Figure 1(d). Small dimensions of the antenna made it suitable enough to be integrated as the signal radiator in microwave detection 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
Some 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 tabulated 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, whereas antenna under test (AUT), UWB reflector array as the receiver. Both antennas are placed at DAUT about 0.84 m apart.

Table 1. Optimized Antenna Parameter

| Parameter | Quantity |
|-----------|----------|
| Ls        | 90.0 mm  |
| Ws        | 45.0 mm  |
| Dp        | 7.50 mm  |
| Wpe       | 8.00 mm  |
| Lpe       | 32.0 mm  |
| Rd        | 20.0 mm  |
| Wd        | 18.0 mm  |
| Ld        | 90.0 mm  |
| Wr        | 90.0 mm  |
| Lr        | 45.0 mm  |
| Lw        | 90.0 mm  |
| Wr        | 45.0 mm  |

Figure 2 shows Quarter-wave transmission line impedance matching for the corporate feed network. 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 70.71 Ω are utilized for perfect matching between the 100 Ω lines and the 50 Ω lines [13]. The dimensions of the feedline are shown in Table 2.

![Figure 2. Quarter-wave transmission line impedance matching](image_url)

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

\[ Z_1 = \sqrt{Z_0 R_{in}} \]

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 \( Z_0 = 50 \) Ω and \( R_{in} = 100 \) Ω, 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]:

\[
\frac{W}{h} < 2 \quad \Rightarrow \quad W = 8e^A/(e^{2A} - 2)
\]

\[
\frac{W}{h} > 2 \quad \Rightarrow \quad \frac{W}{h} = \frac{2}{\pi} \left( B - 1 - \ln(2B - 1) + \frac{\varepsilon_r - 1}{2\varepsilon_r} \left( \ln(B - 1) + 0.39 - \frac{0.61}{\varepsilon_r} \right) \right)
\]

Where \( h \) = substrate height and

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

\[
B = \frac{377\pi}{(2Z_0 \sqrt{\varepsilon_r})}
\]

**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.
Simulation and measurement results for both antenna, with reflector and without reflector in term of reflection coefficient are shown in Figure 4. Both simulation and measurement results for the antennas formed a good agreement fulfilling the requirement for UWB characteristic (3.1 GHz to 10.6 GHz). The UWB reflector array antenna performances are better than UWB array antenna performances. From the figure, it clearly 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 1.6 GHz until 11.4 GHz while antenna without reflector started from 2.1 GHz until 11.4 GHz. On the other hand, antenna with reflector and without reflector recorded 1.6 GHz until 10.8 GHz and 2.2 GHz until 10.8 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 [14]. Partial ground technique and additional of parasitic element assure lower reflection coefficient achieved.

The antenna with reflector exhibits higher gain than antenna without reflector over the whole operated frequency as depicted in Figure 5. The measured gain for antenna with reflector and without reflector ranged from 3.2 dB until 14.1 dB and 2.1 dB until 10.2 dB respectively. Reflector element contributes in increasing the antenna gain by reflecting the backwards radiation towards frontwards radiation and hence increases the gain by summing up the original frontwards radiation with reflected one. Once the reflector integrated into an antenna structure, the reflector functions to modify the radiation pattern of the antenna resulted in increasing gain due to reflecting the incoming signal back to the original direction from where it came which is from front direction [12].
Instead of bandwidth and gain, radiation pattern is the other essential parameter in evaluating the proposed antenna performance. The measurement radiation pattern results of Azimuth-Plane for both antennas are shown in Figure 6. The figure demonstrates the polar radiation pattern for the proposed antenna at the frequency of 4 GHz and 5 GHz. These two particular frequencies are vital for brain microwave imaging application. The radiation pattern indicates both antenna with reflector and without reflector does radiate over a wide frequency band [15] where reflector antenna recorded better radiation pattern indicated by wider area covered especially the main lobe. Antenna with reflector categorized under uni-directional antenna since the radiated wave radiates more on main lobe compared to the side and back lobe while antenna without reflector considered as bi-directional antenna due to mostly equal in radiated wave for front lobe and back lobe [16]. In addition, simulation and measurement results indicate high agreement between them. The antenna exhibits the averaged total radiation efficiency of 92% and 90% for antenna with reflector and without reflector respectively. The total radiation efficiency of the antenna promising the good signal radiator for human brain tumor detection. The pattern, gain and frequency ranges are the parameters indicating the antenna as an excellent microwave signal radiator for human brain tumor detection using SAR technique.

![Figure 6. Measured and simulated polar radiation pattern in Azimuth plane for antenna with reflector and without reflector; (a) 2 GHz and (b) 3 GHz](image)

3. SAR Measurement Results and Discussion

Figure 7 illustrated the measurement setup for brain tumor detection system using SAR technique. The system consist of UWB array antenna as the microwave signal radiator, Vector Network Analyzer as the power source of the antenna, multilayer human head phantom with liquid tissues that have similar dielectric property of real human head tissue structures and SAR probe to absorb energy produced by the antenna.

![Figure 7. SAR measurement setup](image)
On the other hand, Figure 8 shows the whole SAR probe (Probe Amplifier IXA – 020) used in the system which is consist of tip, processors and cable meanwhile IndexSAR software applied to generate the processed SAR values. The UWB reflector array antenna is placed 10 mm away from the multilayer human head phantom as the ideal distance to have maximum energy absorption by the probe as shown in Figure 9. Other distances would lead to less energy absorption due to air interference and high reflection of the phantom as the antenna position is too far and too close from the phantom respectively. The self-made multilayer phantom consist of 4 different layers; skin, fat, skull and brain in resembling the actual structure of human head [18]. With the brain region as the center and first surrounded by the skull layer followed by fat layer and skin layer as the outer most layers completely construct the human head phantom. The phantom is made of Plexiglas with permittivity of 2.3 (εr).

![SAR probe (Probe Amplifier IXA – 020)](image)

**Figure 8.** SAR probe (Probe Amplifier IXA – 020)

The whole probe tip must be immersed within the liquid tissue in order to absorb the total microwave signal/energy radiated towards the tissue by the UWB reflector antenna. The self-made phantom also provide specific compartment for tumor to be filled by liquid tumor tissue which has the similar dielectric property of actual tumor; permittivity of 63.2 at 3 GHz [17]. The major constituents of the liquids are water and Tween 20 which are mixed in different ratios to achieve the dielectric properties of the brain tumor in the frequency range of 1-5GHz. The same goes for human head structures of skin, fat, skull and brain. Ideal mixture composition of Tween 20 and water are required in order to obtain similar permittivity value for actual human head structure with human head phantom structure. The liquids are nonreactive, harmless, and safe for handling. The antenna radiated the energy towards human head phantoms within two different conditions; one with tumor present meanwhile another one is without the tumor present to obtain the different SAR value. On the other hand, in order to precisely detecting the tumor, the sensor radiated the energy towards nine different areas to cover the whole one sided area of the phantom as shown in Figure 10.

![Antenna placement in SAR measurement](image)

**Figure 9.** Antenna placement in SAR measurement
As the result, the highest different in SAR value among the nine scanned areas between phantom with tumor and without tumor among indicate the tumor present at that particular position or area. The antenna precisely positioned for each area with specific coordinate values of X, Y and Z axis. The values obtained are tabulated in Table 3 for simulated and measured SAR. The results for SAR different values proposed the tumor position at area 5 that recorded the highest SAR difference values of 1.47 W/Kg and 1.46 W/Kg for simulated and measured respectively as indicated in Table 3. This is due to tumor structures consist of their own blood vessels will record higher dielectric property due to more absorption of electric field compared to normal surrounded tissues which help the researcher to identify the tumor presence.

Table 3. SAR difference values for simulated and measured

| Area/Coordinate (x,y,z) | With Tumor | Without Tumor | SAR Difference |
|------------------------|------------|---------------|----------------|
|                        | simulated  | measured      | simulated      | measured      |
| 1 (50,150,-10)         | 2.07       | 1.98          | 1.04           | 1.00          | 1.03 | 0.98 |
| 2 (125,150,-10)        | 2.33       | 2.27          | 1.04           | 1.01          | 1.29 | 1.26 |
| 3 (175,150,-10)        | 2.00       | 2.01          | 1.05           | 1.04          | 0.95 | 0.97 |
| 4 (50,90,-10)          | 2.31       | 2.34          | 1.05           | 1.02          | 1.26 | 1.32 |
| 5 (125,90,-10)         | 2.53       | 2.51          | 1.06           | 1.05          | 1.47 | 1.46 |
| 6 (175,90,-10)         | 2.33       | 2.29          | 1.05           | 1.02          | 1.28 | 1.27 |
| 7 (50,30,-10)          | 2.02       | 1.99          | 1.04           | 1.01          | 0.98 | 0.98 |
| 8 (125,30,-10)         | 2.29       | 2.26          | 1.03           | 1.01          | 1.26 | 1.25 |
| 9 (175,30,-10)         | 2.04       | 2.00          | 1.02           | 1.00          | 1.02 | 1.00 |

Figure 10. Scanning area for head phantom

Figure 11. SAR difference at area 5 (tumor location); blue line & dot (with tumor), red line & dot (without tumor)
On the other hand, Figure 11 shows the graph of simulated and measured SAR values different at area 5 (tumor location) within head phantom, for with tumor and without tumor condition with variable antenna distances from the phantom; 10 mm, 20 mm and 30 mm. According to the graph, there is significant different between SAR values for with tumor and without tumor obviously at distance of 10 mm compared with two others distances indicating the 10 mm is the ideal distance between the antenna and the phantom for SAR measurement. In addition, as the distance increase, the SAR difference value become less significant due to less concentrated signal/energy manage to reach the phantom because of air resistance. Apart from that, measured values exhibit slightly less compared with simulated values due to environment effect that interfere the radiated energy such as air and humidity. However, the differences are ignorable since most of the values are less than 0.1 W/kg.

4. Conclusion
A high gain ultra-wide band (UWB) reflector array antenna for human brain tumor detection using specific absorption rate (SAR) technique in microwave detection system is proposed. Reflector element contributes in improving the overall sensor performance especially the gain, operated bandwidth and radiation pattern leads to an excellent microwave signal radiator in SAR measurement. The UWB antenna with reflector demonstrated wider reflection coefficient of less than -10dB started from 1.6 GHz until 10.8 GHz with the ranges of gain between 3.2 dB to 14.1 dB as compared with UWB antenna without reflector that recorded 2.2 GHz to 10.8 GHz and 2.1 dB to 10.2 dB for the reflection coefficient and gain respectively. Moreover, measurements of bandwidth and reflection coefficient have identical behavior compared to simulations. The antenna is successfully detecting human brain tumor based on SAR technique. Amount of energy or gain produced by the antenna which being absorbed by the human brain indicated the present of tumor inside. Human brain with tumor absorbed more energy and recorded higher SAR value compared to human brain without tumor. In this paper, human head phantom associated with tumor recorded SAR value of 2.53 W/kg and 2.51 W/kg for simulated and measured respectively meanwhile head phantom without tumor stated SAR value of 1.06 W/kg for simulated and 1.05 W/kg for measured. The biggest different in SAR value according to area precisely determine the location of the tumor in the brain which in this case position 5 (tumor location) resulted biggest SAR different value of 1.47 W/kg for simulated and 1.46 W/kg for measured.

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