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Brain Cancer Detection Using U-Shaped Slot VIVALDI Antenna and Confocal Radar Based Microwave Imaging Algorithm

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Abstract

VIVALDI antenna has been designed to work at frequency band [2.33-7.09] GHz with a maximum gain of 6.62dB. The antenna performance has been improved by creating a U-shaped slot on the upper layer of the antenna. etching U shape slot provides an improvement of 35.28% in return loss, 2.7% in bandwidth and 10% in gain. Spherical head phantom which consists of four layers whose dielectric properties have been compatible with their natural values has been designed by CST package to test the efficiency of antenna in the microwave imaging systems**.** 1g average specific absorption rate (SAR) values has been measured in case the human brain without tumor and achieved international healthy standards. After that, it has been measured the value of SAR in case the human brain with tumor and observed that SAR value increased. Finally, monostatic radar-based confocal microwave imaging algorithm has been used to reconstruct image which appeared tumor location inside the head phantom. MATLAB software has been used to process data that obtained by CST package and generate the tumor image.

Keywords: VIVALDI antenna; U-shaped slot; head phantom; specific absorption rate (SAR); confocal microwave imaging algorithm.

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1. Introduction

Brain is the most important organ because it is responsible of all functions of human body. So that any brain disease affects other body 's organs such as cancer. Early detection can reduce the risk of cancer by using medical imaging. However, conventional imaging methods use x-rays which can damage human body and take a big place such as magnetic resonance imaging (MRI) and computed tomography (CT). Microwave imaging provides safe, rapid, low-cost and noninvasive medical diagnosis technique without creating health risks [1]. This technique is based on the fact that microwaves are reflected in different human tissues due to differences in their dielectric properties or difference in properties of the same tissue in different conditions (healthy tissue and malignant tissue). There are two types of this technique. one is called microwave tomography imaging which aims to reconstructing the electrical distribution in the body by solving inverse nonlinear function problem. Although this technique is more complicated and requires large mathematical operations, it can provide a complete map of the permittivity or conductivity distribution of brain tissue [2]. Another type is called Radar-based microwave imaging.in this method, only tumor location which has higher dielectric properties appears in the reconstruction image [3]. short pulse is radiated into a body phantom and back-scattered signals are received by one or more antennas.

1.1 structure

Microwave imaging system consists of three main components. They are antennas, microwave transceiver and signal storing and processing unit as shown in figure 1. Antenna is considered as the most important element of any microwave imaging system for image quality assurance. Recent studies have tended to use directional wideband antennas to design microwave imaging system because they achieve a balance between image resolution which increases with increasing frequency and penetration depth which decreases with increasing frequency. The bandwidth [1-10] GHz is suitable for microwave imaging because high frequencies may cause skin damage [4].

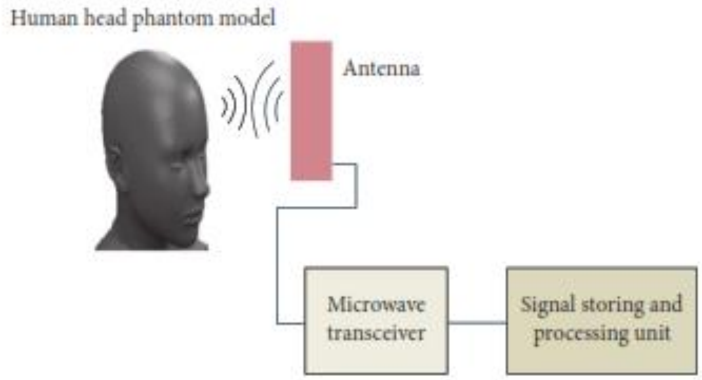


Figure 1: structure of microwave imaging system [4].

Many kinds of antenna have been proposed for microwave imaging. For example, in [5], it has designed a reflector array antenna for brain cancer detection using specific absorption rate (SAR) technique. Some researches use microstrip patch antenna to minimize antenna's size but its bandwidth is narrow and its gain is not stable over its bandwidth. So that many techniques have been used to improve its performance to detect brain tumor by confocal microwave imaging such as EBG technique in [4]. Also, dipole antenna has been used for microwave imaging in [6] but it has non directional radiation and have to improve its directivity. Bow tie antenna has been used to detect brain tumor. However, it needs to reduce the losses because of mismatch between the antenna output and the human head [7]. Also, many researches have used many kinds of VIVALDI antenna for microwave imaging such as [8] it has made ultra-wideband antipodal VIVALDI antenna with triangular-shaped slits. Another kind of VIVALDI is microstrip fed tapered slot VIVALDI antenna which is utilized because of its features that made it attractive for using in microwave imaging systems. Beside of its efficiency and light weight, it could work on wide bandwidth and provide directional radiation with good gain [4-8] dBi and low side lobe levels [9]. To improve the efficiency of the antenna, it has suggested to add slots on the upper layer of the antenna such as [10] which used triangle slots. In this research, it has designed microstrip fed VIVALDI antenna. To enhance its performance, it has created two U shaped slots on the upper layer of the antenna. The proposed antenna was designed using the CST studio software. A four layers spherical head phantom contained of skin, fat, skull, and brain, is designed to test antenna efficiency to use it in the microwave head imaging. specific absorption rate SAR is measured to ensure the safety of antenna on the patient healthy. Monostatic radar based confocal microwave imaging algorithm has been used to process the acquired data from CST simulation.

2. Proposed antenna design

VIVALDI antenna is a kind of tapered antenna (TSA) which has an exponentially tapered slot profile. It consists of upper layer, substrate layer and microstrip feed line as shown in figure (1). Upper layer comprises of three different type of slot lines. Circular slot is used to achieve impedance matching of the microstrip line. Rectangular slot is used to couple the electromagnetic wave from transmission line. The exponential tapered slot is used to guide the electromagnetic wave to radiate. The exponential tapered slot equation can be calculated by following [11]:

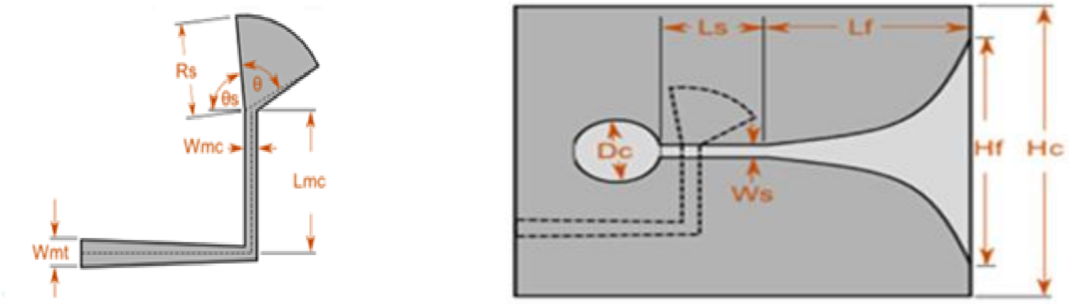
$$\mathbf{Y = \pm C_1 . e^{RX} \mp C_2} \qquad (1)$$

Where:

$$\mathbf{C_1 = \frac{Y_2 - Y_1}{e^{RX_2} - e^{RX_1}}} \qquad (2)$$

$$\mathbf{C_2 = \frac{Y_1 e^{RX_2} - Y_2 e^{RX_1}}{e^{RX_2} - e^{RX_1}}} \qquad (3)$$

Length of tapered slot is $\mathbf{L_f = X_2 - X_1}$,and width of tapered slot is $\mathbf{W_f = Y_2 - Y_1}$.



(b) (a)

Figure 1: a) upper layer of antenna b) microstrip feed line of antenna.

Table 1: Dimensions of VIVALDI antenna.

Dimension	Description	value
f_L	Lower frequency	2GHz
f_H	High frequency	7GHz
f_0	Center frequency	4.5GHz
H_f	Flare height	32mm
L_f	Flare length	40mm
H_C	Substrate width	65mm
D_c	Cavity diameter	7mm
S_{mc}	Distance from cavity to the center of microstrip coupler	2mm
L_{mc}	Microstrip coupler length	16mm
W_{mc}	Microstrip coupler width	0.79 mm
L_{mt}	Microstrip taper length	18mm
W_{mt}	Microstrip taper width	3.04 mm
L_s	Rectangular slot length	9mm
W_s	Rectangular slot width	0.98mm
R_s	Stub radius	9mm
θ_s	Start stub angle	90
θ	Stub angle	80

FR4 substrate with relative permittivity of 4.4 and with the thickness and dimension of 1.6 mm and 55mmx65mm was selected to design the antenna. U-shaped slot was created on the upper layer of the VIVALDI antenna to improve its performance. The dimension of U-shaped slot was shown in figure (2).

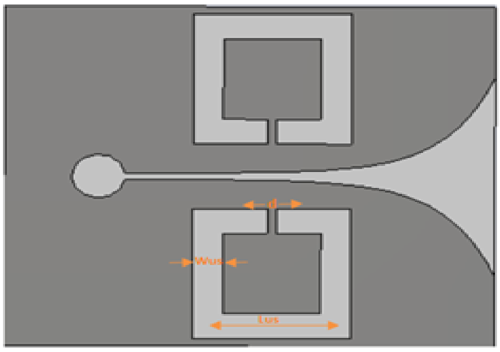


Figure 2: U-shaped slot VIVALDI antenna.

Where d=1mm,W_{us} = 4mm, L_{us} = 17mm.

3. Modeling of human head phantom

Dielectric properties of human head tissue, i.e. permittivity and conductivity, are dependent on frequency. So that, to analyze the interaction between microwaves and tissue, dielectric properties of head phantom must be close to that of real one. This phantom consists of four layers which are skin, fat, skull and brain as shown in figure (3). Table 2 provides values of dielectric properties for four layers spherical head phantom and tumor [12].

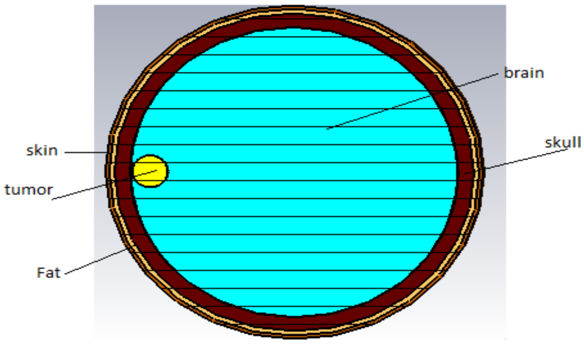


Figure 3: Four layers spherical head phantom.

Table 2: Dielectric properties and radius for four layers spherical head phantom and tumor [12].

Layer	Radius (mm)	Permittivity ($\boldsymbol{\varepsilon_r}$)	Conductivity(S/m)
skin	50	38.18	1.4
fat	49	5.3	0.1
skull	48	15.1	0.56
brain	43	42.75	1.42
tumor	5	55	7

4. specific Absorption Rate (SAR)

Specific Absorption Rate (SAR) is a measure of the deposition of electromagnetic energy over time into human body tissue and its values depends on the geometry of the body, operation frequency, type of antenna and the distance between antenna and human body. The units are generally watts per kilogram of body mass. In mathematical form, it is defined as [4]:

$$\mathrm{SAR} = \frac{\sigma}{\rho}|\mathrm{E}|^2 = \frac{\mathrm{J}^2}{\rho\sigma} \tag{4}$$

Where, E is the rms value of the electric field strength in the tissue [V/m], J is the current density [A/m], σ is the conductivity of the head tissue [S/m], and ρ is the density of head tissues [kg/m^3]. The internationally healthy standard SAR limits are 1.6 W/kg for each 1g of tissue which set by United States or 2 W/kg for each 10g of tissue which set by the European Union [4]. If there is a tumor in the brain, value SAR increases to be higher than these standards.

5. Confocal radar-based microwave imaging algorithm

Confocal or delay and sum algorithm is mostly applied as a part of UWB systems in recent years. The confocal microwave imaging (CMI) technique is used in monostatic microwave imaging system which means that one antenna rotates mechanically around the human head phantom to radiate microwave imaging and receive backscattered signals from the head phantom and an UWB pulse is used as an excitation signal at the antenna [4]. For a confocal algorithm to be applied on received signal, first the area of the head region under consideration is divided in a grid like structure known as focal points (x_i, y_i). The distance from the antenna to the focal point is calculated by [13]:

$$d = \sqrt{(X - x_i)^2 + (Y - y_i)^2} \tag{5}$$

Where (X, Y) is a position of antenna, and then these distances are used to find out the time delays. time delay is defined by following equation [13]:

$$t_{XY}(x_i, y_i) = \frac{2 * d}{c/\varepsilon_r} \tag{6}$$

Where $c = 3 * 10^8 m/s$ is the speed of light, ε_r is average relative permittivity of propagation medium.

These time delays are used to get the signal values from the received signal to generate the intensity values which calculated by [13]:

$$I_{(x,y)} = \left[\sum_{X=1}^{m} \sum_{Y=1}^{n} X[n].\, t_{XY}(x_i, y_i)\right]^4 \tag{7}$$

Where X[n] is tumor response. m, n are numbers of antenna’s positions. Since there are five propagation medium which are air, skin, fat, bone and brain. So that time delay can be calculated by:

$$t_{XY}(x,y) = t_{air} + t_{skin} + t_{fat} + t_{bone} + t_{brain} \tag{8}$$

These intensities are then mapped and an image is generated to identify the tumor location [13]. However, in CST simulation environment, mechanical rotation is accomplished by moving the antenna to all the possible locations around and simulating the system for each antenna location. The confocal microwave imaging algorithm is written into a MATLAB program and process scatter parameters S1P which are collected for all antenna's location by CST program.

6. Results And Discussions

6.1 Performance Analysis of the Designed Antennas

the reflection loss of the antenna should be minimized to ensure that the sufficient amount of power can be radiated to the target for improvement the quality of microwave head images which depend on magnitude of scattered signal from the target. Another important parameter for quality of microwave head image is gain of antenna. reflection loss S11 of conventional and U-shaped slot VIVALDI antenna is shown in figure (4). Where values of S11 must be -10dB at least.

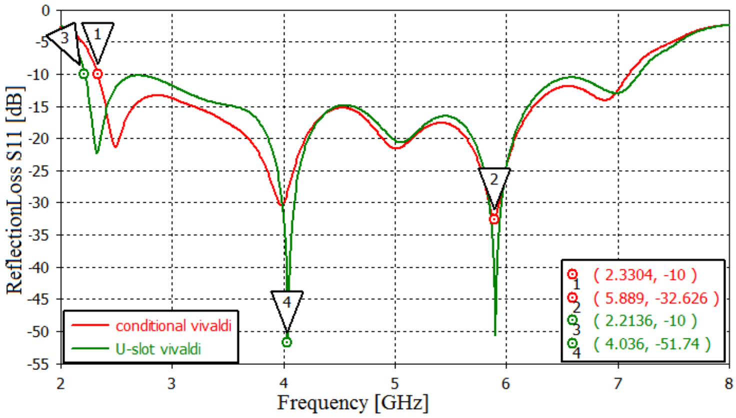


Figure 4: compared of reflection loss S11 between conventional and U-shaped slot VIVALDI antenna.

Where Fig.5 describe values of gain for conventional and U-shaped slot VIVALDI antenna over bandwidth. And the comparison of two antennas are illuminated in table 3.

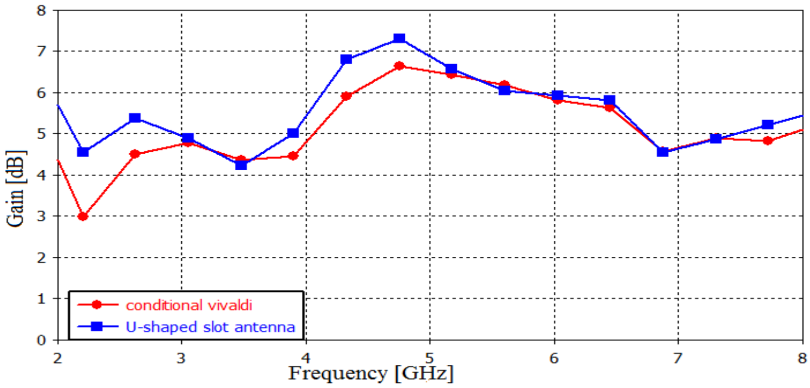


Figure 5: values of Gain for conventional and U-shaped slot VIVALDI antenna.

Table 3: comparison of conventional and U-shaped slot VIVALDI antenna.

Antenna	Low Frequency [GHz] $\mathbf{f_{min}}$	High Frequency [GHz] $\mathbf{f_{max}}$	Bandwidth FBW%	Max Gain [dB] $\mathbf{G_{max}}$	Reflection Loss [dB] $\mathbf{S11}$
Conventional VIVALDI Antenna	2.33	7.09	80	6.62	-32.62
U-Shaped Slot VIVALDI Antenna	2.213	7.187	82.7	7.36	-51.73

It can be observed from table 3 that U-shaped slot VIVALDI antenna decreases low frequency and increases high frequency so that bandwidth increases about 2.7% in addition to increase maximum gain in the front direction and decrease reflection loss S11 about 35.28% which means reducing losses resulting from mismatching and focuses radiation in the front direction which improves the quality of the microwave image.

As it is shown in Fig.5, values of Gain of conventional VIVALDI antenna are between [2.97-6.62] dB while values of Gain of U-shaped slot VIVALDI antenna are between [4.22-7.36] dB so that U-shaped slot VIVALDI antenna increases values of gain through frequency band and it is more stable than conventional antenna over the bandpass. Table 4 shows a comparison between antenna optimized using a U-shaped slot and an antenna optimized using a triangle slot in [10]. It is clear from table 4 that the U-shaped slot increases the gain and reduces the reflection loss clearly more than the triangle slot [10].

Table 4: comparison between U-shaped slot VIVALDI antenna and triangle slot VIVALDI antenna

Antenna	Max gain without slot $\mathbf{G}_{\mathbf{max}}$ [dB]	Max gain with slot $\mathbf{G}_{\mathbf{max}}$ [dB]	Reflection loss without slot S11[dB]	Reflection loss with slot S11[dB]
U shaped slot VIVALDI antenna	6.62	7.36	-32.62	-51.73
Triangle slot VIVALDI antenna [10]	5.477	6.041	-17.818	-18.495

6.2 Evaluation of Specific Absorption Rate (SAR)

The effect of the distance Hd between the antenna and the head phantom on the SAR value for each 1g of tissue has been studied at resonance frequency for a power of 0.5 Watt as shown in figure 6.

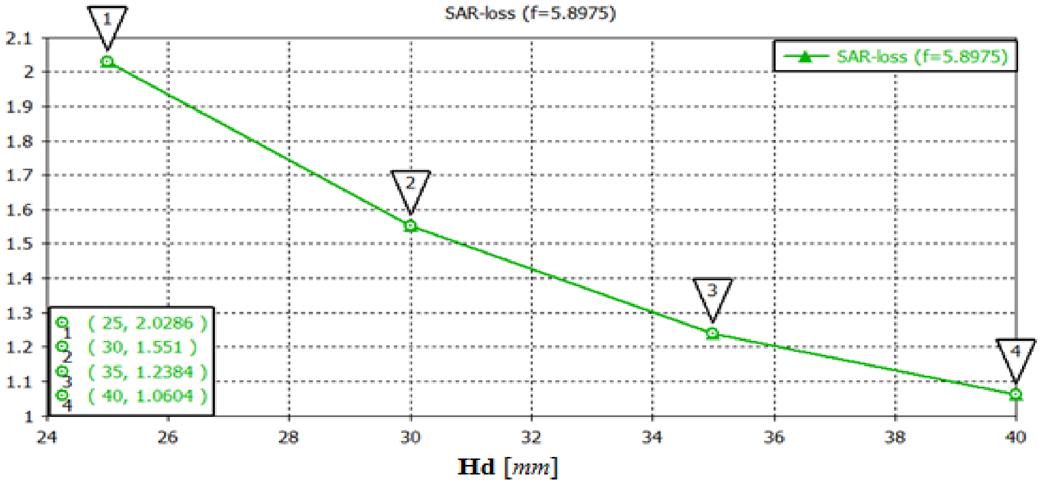
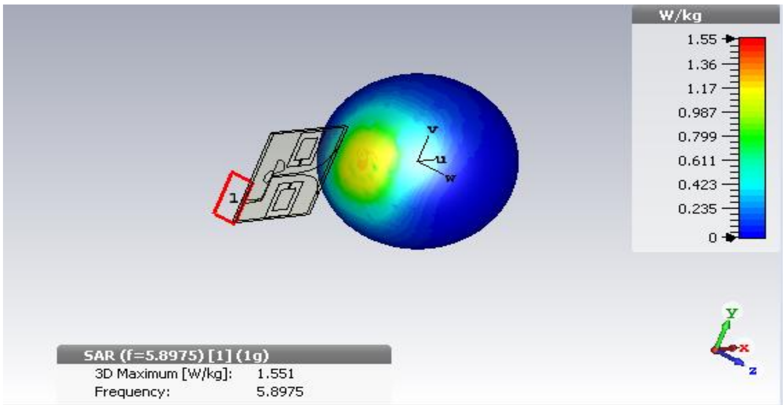


Figure 6: relationship between antenna distance Hd and value of SAR for each 1g of tissue.

It's clear from figure 6 that the shorter distance Hd where the antenna realizes the international healthy standards for each 1g of tissue is 30mm. figure 7 shows that the value of SAR for each 1g of tissue which equals to 1.551 W/kg which is lower than 1.6w/kg for each 1g of tissue at frequency *f* =5.8975GHz when power is 0.5Watt.

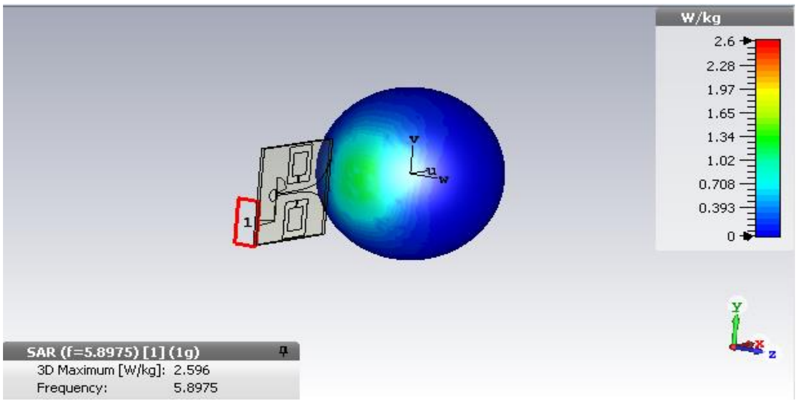


SAR (f=5.8975) [1] (1g)
3D Maximum [W/kg]: 1.551
Frequency: 5.8975

Figure 7: the value of SAR for each 1g of tissue at frequency *f* =5.8975GHz.

6.3 brain tumor detection by specific absorption rate technique

In the case of tumor presence as a spherical with radius 5mm and its dielectric properties was described in table 2, the value of SAR increases to be 2.596W/kg which is bigger than the international healthy standards for each 1g of tissue as shown in figure 8. That means the antenna can detect tumor presence by a specific absorption rate technique.



SAR (f=5.8975) [1] (1g)
3D Maximum [W/kg]: 2.596
Frequency: 5.8975

Figure 8: the value of SAR for each 1g of tissue with tumor at frequency *f* =5.8975GHz

1g averaging maximum SAR cube which surround the maximum point of SAR is visualized to determine the position of tumor inside the head as shown in figure 9.

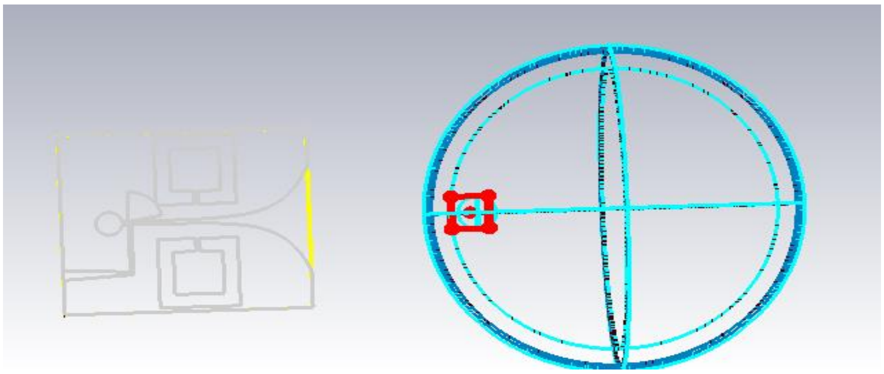


Figure 9: 1g averaging volume for maximum SAR value

It can be observed from figure 9 that the tumor is located inside the cube. The center of cube is located at the coordinates (38.725,0.14875, -1.8) while the center of the tumor is located at the coordinates (36,0, -1.606). it means that antenna can determine the location of tumor with a displacement (1.875,0.14875, -0.194).

6.4 brain tumor detection by confocal microwave imaging

Figure 10 describes the distance the microwave imaging system which consists of the antenna and head phantom.

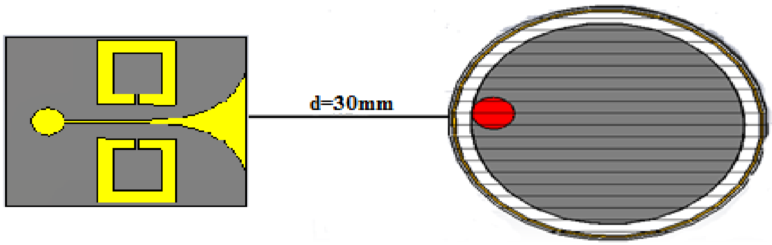


Figure10: structure of the microwave imaging system.

The head phantom has been scanned by rotating antenna around it each 10 degree in X-Y plane. Then confocal microwave imaging algorithm has been used to process the acquired data from CST simulation to reconstruct the image of tumor as shown in figure 11.

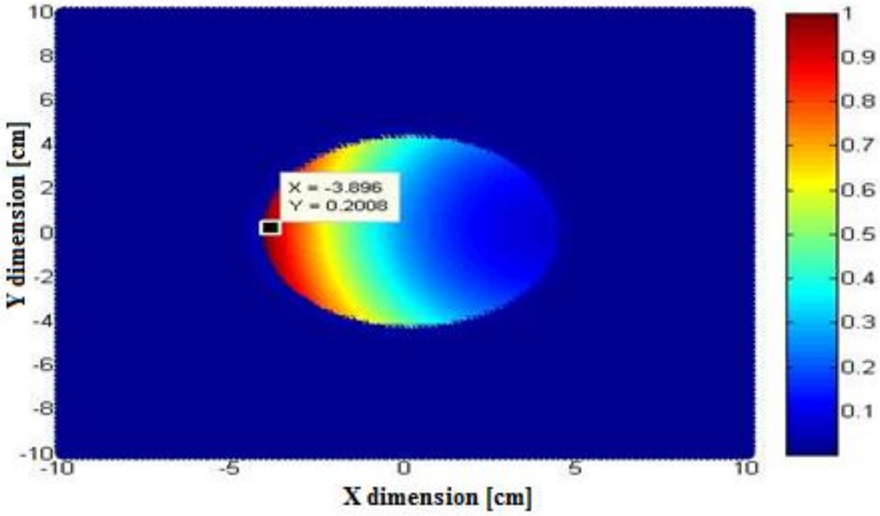


Figure 11: Reconstructed microwave image of tumor by scanning head phantom in X-Y plane.

Where red color refers to the highest intensity value which represents the location of tumor inside the head. It can be noticed that the tumor is located at the coordinates (38.96,2) mm which is close to the actual location (36,0)mm which means that antenna can detect tumor presence and its location with a displacement (0.96,2)mm by using confocal microwave imaging which depends on delay and sum algorithm.

7. Conclusion

A brain imaging system working in microwave frequency range for human brain tumor detection is envisaged. An efficiency VIVALDI antenna is devised whose performance is improved by creating U-shaped slot on the upper layer. The U-shaped slot improved bandwidth and gain of Conventional antenna . the proposed antenna is applied in the medical imaging application. The antenna is used to scan a spherical four-layer human head phantom model. The specific absorption rate (SAR) technique is used to prove the efficacy of antenna to detect the tumor and determine its location. The S parameter data obtained from a scanning mode performed in x-y plane is utilized in a confocal microwave imaging algorithm to reconstruct the image of tumor inside the human brain. The overall results obtained confirm that the studied brain imaging system can successfully diagnose brain tumor at an early stage while maintaining safety regulation of the patient under test.

Reference

[1] F.S.G.B. Barnes ,Handbook of Biological Effects of Electromagnetic Fields, CRC/Taylor & Francis, Boca Raton, Fl, USA, 2007.

[2] D. A. Shtoda, E. A. Antonenko and N. P. Mustetsov, "Possibilities of microwave imaging in medicine,"2016 8th International Conference on Ultrawideband and Ultrashort Impulse Signals (UWBUSIS), Odessa, 2016, pp. 175-178.

[3] H. Zhang, B. Flynn, A. T. Erdogan and T. Arslan, "Microwave imaging for brain tumour detection using an UWB Vivaldi Antenna array," 2012 Loughborough Antennas & Propagation Conference (LAPC), Loughborough, 2012, pp. 1-4.

[4] R. Inum, M. M. Rana, K. N. Shushama, M. A. Quader, "EBG based microstrip patch antenna for brain tumor detection via scattering parameters in microwave imaging system", Int. J. Biomed. Imag., vol. 2018, 2018, [online] Available: https://www.hindawi.com/journals/ijbi/2018/8241438/.

[5] M. A. jamlos, W.A. Mustafa, W. Khairunizam, I. Zunaidi, Z. M. Razlan, and A. B. Shahriman," Tumor Detection via Specific Absorption Rate Technique Using Ultra-Wideband Antenna," IOP Conference Series: Materials Science and Engineering, Vol.557, ,2019,[online] Available: https://iopscience.iop.org/article/10.1088/1757-899X/557/1/012024.

[6] Mobashsher A. T., "Wideband microwave imaging system for brain injury diagnosis", 2016.

[7] Abtahi Sh., Development of UWB antenna for stroke diagnosis, Master's Thesis, department of signal and system Chalmers University of Technology 2011

[8] M. Moosazadeh and S. Kharkovsky, "Design of Ultra-Wideband Antipodal Vivaldi Antenna for Microwave Imaging Applications," 2015 IEEE International Conference on Ubiquitous Wireless Broadband (ICUWB), Montreal, QC, 2015, pp. 1-4.

[9] M. Y. Perdana, T. Hariyadi, Y. Wahyu, *Design of Vivaldi Microstrip Antenna for Ultra-Wideband Radar Applications*, pp. 012058, 2017.

[10] W. N. A. W. A. Khairuddin, M. A. Othman, M. S. N. Azizi, M. Yaakob, M. H. Ramli, "Bandwidth enhancement of Vivaldi antenna using triangular shaped slots", Jurnal Teknologi, vol. 78, no. 6-3, pp. 121-125, 2016.

[11] N. Vignesh, G.A. Sathish, Kumar. R. Brindha, "Design and Development of a Tapered Slot Vivaldi Antenna for Ultra-Wide Band Application", *International Journal of Advanced Research in Computer Science and Software Engineering*, vol. 4, no. 5, May 2014.

[12] L. Belrhiti, F. Riouch, A. Tribak, J. Terhzaz, Angel Mediavilla Sanchez, "Investigation of dosimetry in four human head models for planar monopole antenna with a coupling feed for LTE/WWAN/WLAN internal mobile phone", Journal of Microwaves Optoelectronics and Electromagnetic Applications, vol. 16, 2017.

[13] Z. ABDUL-SATTAR, "Experimental Analysis on Effectiveness of Confocal Algorithm for Radar Based Breast Cancer Detection " Durham University, 2012.