A Novel Approach of Brain Tumor Detection using Miniaturized High-Fidelity UWB Slot Antenna Array

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Mohammad Ojaroudi[1], Stephane Bila[1], and Mehdi Salimi[2]
[1] XLIM, UMR no7252, University of Limoges, 123 Av. Albert Thomas, 87060 Limoges, France
[2] Department of Biomedical Engineering, Gazi University, Ankara, Turkey
* *Mohammad.ojaroudi@xlim.fr*

***Abstract*—In this paper a novel high resolution of the array based ultra-wideband (UWB) microwave imaging system is employed to improve the accuracy of tumor detection inside human brain phantom for 2D reconstructed image results. In order to create a circular array based microwave imaging system 18 elements of the proposed UWB slot antennas are simulated in CST medium around the phantom inside a designed matching medium. The proposed slot antenna consists of a square radiating patch with a microstrip feed-line on one side, a rectangular slot and a defected ground plane by a pair of C-shaped slots on the other side which provides a wide usable fractional bandwidth of more than 100% (3.19-10.73 GHz). Two C-shaped slots are inserted on the ground plane's corners, hence additional resonance is excited and much wider impedance bandwidth is produced. In order to demonstrate the usefulness of the proposed antenna for microwave imaging system, the fidelity analysis for angles up to 90 away from bore-sight radiated pulses is presented (fidelity factor > 80%). In addition, a novel hierarchical calibration method is employed to improve the accuracy reconstructed image results. This calibration includes all delays of multi-static antenna array to put more energy at coherence reflected signal integration. Hence, stronger signals are available to achieve higher accuracy for precise spatial localization. In the proposed image reconstruction method a confocal image reconstructing algorithm based on back-projection method has been employed. Simulated results are presented to validate the effectiveness of the proposed method for precisely calculating the time-dependent location of targets.**

***Index Terms*—Microwave Near-Field Imaging System, UWB Microstrip Slot Antenna, Defected Ground Structre (DGS), Confocal Image Reconctruction Algorithm, Tumor Detection, Focal Points.**

I. Introduction

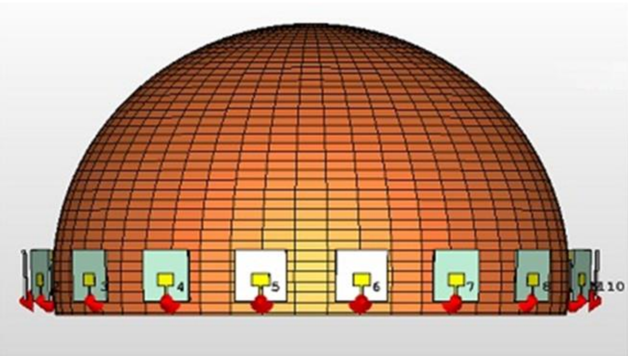
Over the last two decades, non-ionizing and non-invasive electromagnetic (EM) waves at microwave frequencies has been investigated as a novel sensing, imaging for medical diagnostics and treating technique [1-2]. A number of early small-scale clinical experiments have clearly illustrated the potential of the technology, while also revealing some significant remaining challenges. These technical challenges must be addressed before microwave system is accepted as a viable alternative (or complement) to other medical techniques such as X-ray, ultra-sound, and magnetic resonance imaging. Current techniques for medical imaging include x-rays, computed tomography (CT), ultrasound (US), and magnetic resonance imaging (MRI). Conventional X-rays and CT scanners emit ionizing radiation, and exposure to them should therefore be minimized [3-4]. Ultrasound requires direct skin contact, and is suited only for short term monitoring. Due to their mechanical complexity and size, magnetic resonance imaging is not practical for long term continuous monitoring. In addition, metallic objects are prohibited, thereby excluding patients with a surgical prosthesis or pace maker [5]. Since microwave-based diagnostic systems could easily be implemented as compact and portable systems, this appears to be one of the most attractive areas of application of the new technology.

The objective of human head microwave imaging is the detection of cancerous tumors and damaged brain tissue due to ischemic or hemorrhagic stroke [6]. One of the key factors in the imaging performance is the antenna dimension and its impedance and radiation characteristics. Several compact size and low distortion UWB antennas have been designed to utilize in the medical imaging systems. Each of the antennas have its own compatibility and weak points. Because of space limitation in human head imaging, reducing antennas physical dimension is a considerable challenge because, maintaining of the high-gain, distortion-less and its broadband features must be considered in a compact microwave imaging detection. It is an undoubted fact that printed slot antennas present quite appealing physical features, such as simple structure, small size, and low cost. Due to all these interesting characteristics, printed slots are extremely attractive to be used in emerging UWB applications, and growing research activity is being focused on them [7].

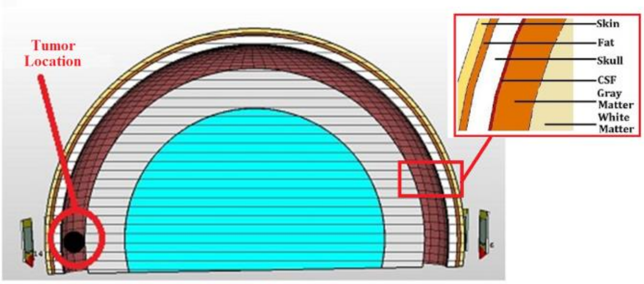
In this paper, we explore the advantages of using new UWB slot antenna to detect a tumor from a multi-layer head phantom. In this context, a novel design of compact slot antenna with a pair of C-shaped slots in the ground plane is presented. By using these modified structures, the usable upper frequency of the proposed monopole is progressed from 3.19 GHz to 10.73 GHz. The size of the proposed antenna is smaller than the UWB antennas that were reported recently [8-10]. In order to demonstrate the usefulness of the proposed antenna for microwave imaging system, the fidelity analysis for angles up to 90 away from bore-sight radiated pulses is presented (fidelity factor > 80%). In addition, the designed antenna has a small size of $20\times20\times0.8$ mm^3. By using a hierarchical calibration method and confocal image reconstruction algorithm a brain tumor has been detected and localized inside a full head phantom. The 2 D image results of this study show that the proposed antenna has excellent performance for microwave imaging system applications.

II. Antenna Design for the proposed Microwave Imaging Setup

The proposed scenario under test setup of the microwave imaging system with 18 UWB slot antennas is shown in Fig. 1. The simple head model is constructed in CST microwave studio [6] as presented in Fig. 1. It is a hemisphere with a radius of 120 mm containing head layers, from skin layer to white matter of the brain for ease of modeling and imaging. As shown in Fig. 1 (a), eighteen of the proposed antennas encircling the head at equal distances 10 mm from skin layer, and a tumor are located at (15, 80, 0) shown in Fig.1 (b). The background material should be set as a coupling medium with $\varepsilon_r = 9$ and $\sigma = 0.22\ S/m$ to ensure electrical matching between antenna and internal breast.



(a)



(b)

Fig. 1. Multi-static UWB microwave imaging system schematic for tumor detection. (a) Simulated head model with a tumor in CST medium, (b) Multi layer structure of the simulated head phantom.

TABLE I. Electrical characteritics of the multi-layer brain phantom

Tissue	*Thickness (mm)*	*Relative Permittivity*	*Conductivity (S/m)*
Skin (dry)	2	40.93	0.89
Fat	1.4	5.44	0.05
Skull (bone cortical)	4.1	12.36	0.15
Cerebrospinal fluid (CSF)	0.5	68.43	2.45
Gray Matter (GM)	7	52.28	0.98
White Matter (WM)	Inner Part	38.57	0.62

It is a well-known fact that printed slot antennas present really appealing physical features, such as simple structure, small size and high gain. In this study, UWB slot antenna is designed to cover the entire 3.2-10.70 GHz frequency range [8]. A FR-4 substrate was used, with a relative permittivity of 4.3 and a thickness of 0.8 mm. The basic antenna structure consists of a square patch, a feed line, and a ground plane. All dimensions of the antenna are given in Table 1. The proposed slot antenna schematic and its return loss of the proposed antenna in various situations are shown in Figure 2. The incident signal from antennas to biological brain phantom is a modulated Gaussian Pulse (MGP). Fig. 3 shows the generated incident signal in time domain. It is shown that the transmitted pulse-width is pico-second range.

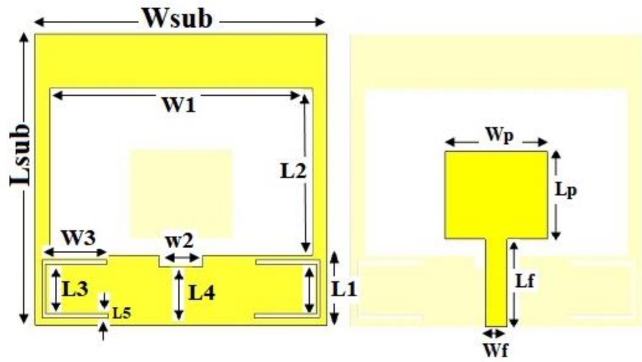


Fig. 2. (a) The proposed UWB slot antenna schematic.

TABLE II. The proposed slot antenna dimensions

Param.	*Value (mm)*	*Param.*	*Value (mm)*	*Param.*	*Value (mm)*
W_{sub}	20	L_{sub}	20	L_P	6
W_P	7	L_F	6	W_f	1.5
L_1	4.8	W_1	18	L_2	11.45
W_2	3	L_3	4.4	W_3	4
L_4	4	L_5	0.3	h	0.8

The first step befrore starting simulation of the microwave imaging setup is designing a matching medium. By shielding antennas in the matching medium it is possible to decrease the mismatch effectes between antenna and head phantom. Figure 3 shows the comparison of simulated return loss characteristics for antennas with various scenarios. It can be seen from Figure 3 that by determining a good choise for permitivity and conductivity of the matching medium the antenna will be radiated from 1.2 to 9 GHz.

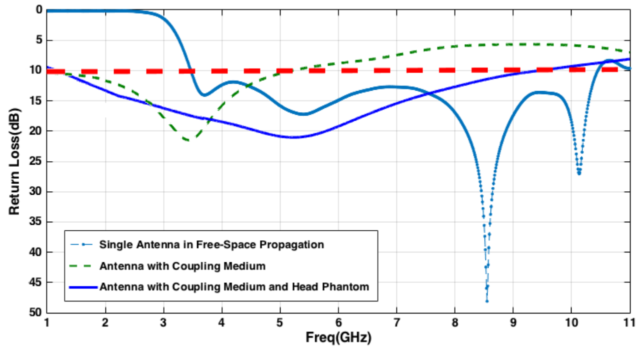


Fig. 3. Comparison of simulated return loss characteristics for antennas with various scenarios.

In telecommunication systems, the correlation between the transmitted (T_X) and received (R_X) signals is evaluated using the fidelity factor [11]. For impulse radar in UWB microwave imaging system, it is indispensable to have a high degree of correlation between the T_X and R_X signals to avoid losing the modulated information. However, for most other telecommunication systems, the fidelity parameter is not that relevant. Fig. 4 shows normalized input and received signals that are obtained by using CST with virtual probes for varying angles in the E-plane. As shown in Fig. 4, three results (top, right and bottom row) are evaluated to the best and reference ones (top left) in terms. Values of the fidelity factor show that the antenna imposes negligible effects on the transmitted pulses and the fidelity factor is more than 84%.

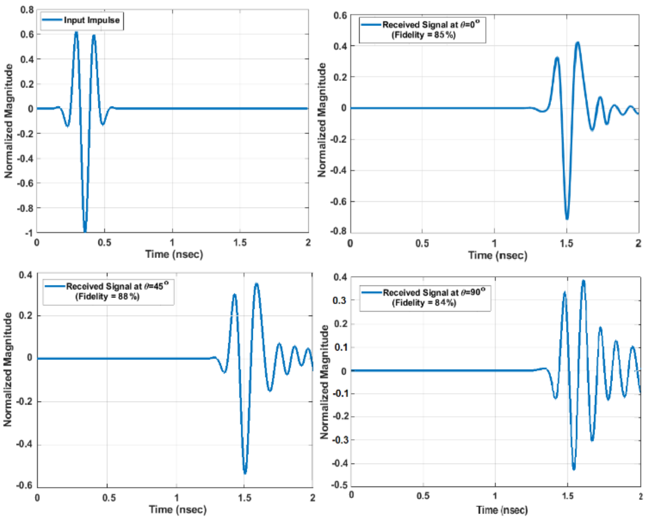


Fig. 4. Normalized input and received signals by virtual probes for varying angles in the E-plane.

III. Image Reconstruction Method

In this section, in order to evaluate the performance of the proposed microwave imaging system, the confocal imaging algorithm is performed and the results are analyzed and discussed. It is obvious detecting a tumor from a biological tissue is a near-filed imaging. First, we do the **c**alibration of the received time domain signals in order to remove the skin effect and coupling between antennas in the early time. In first step of the proposed calibration, it should be estimated the delay time result in by antennas themselves. The second step in the calibration method is the finding delays between antennas. For this case, we need to find the phase shifting between each antenna with others. This delay time which is called T_{da} is equal to direct distance between transmitter and receiver divided by light velocity in the coupling medium. The next step is extracting tumor location from the reflected signals. In order to reach this goal, we need to calibrate the previous steps to judge about the starting point and the incident pulse duty time in the reflected signals. The tumor location will be the time position in the reflected signals after adding starting point plus pulse width in the reflected signals.

$$T_{tumor}=T_{start}+T_{delay}+T_{pulse} \qquad (1)$$

After determining these time delays, the second step of calibration has been applied to the fixed starting point signals. In the following as a final step in calibration method, in order to extract the tumor response after finding T_{toumr} we make zero all of the values before $T_{toumr.}$ Figure 6 shows all the determined calibration parameters [9]. After applying these parameters to reflected signals, Figure 6 shows the extracted tumor responses for six cases in the case of antenna number one is transmitter and others are receivers.

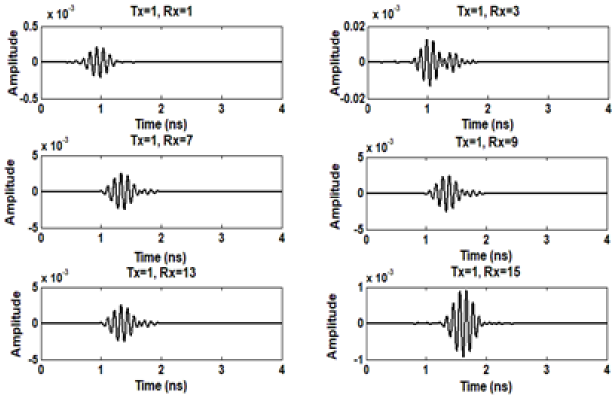


Fig. 5. Variety of different delays in received signal related to different antenna's position around breast.

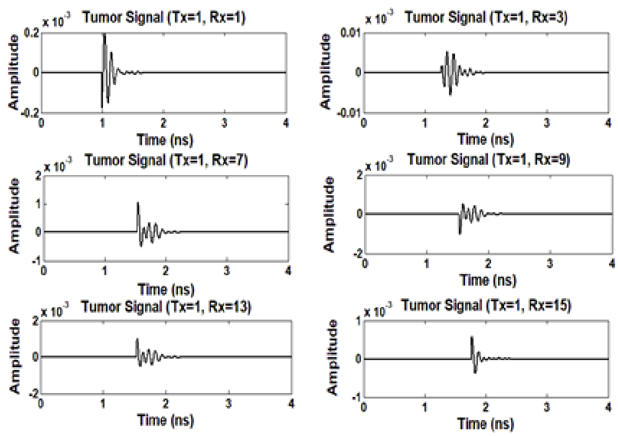


Fig. 6. Extracting of tumor response from reflected signals

In near filed imaging in order to reconstruct an image we need to apply a focused algorithm such as confocal algorithm. For this, the first step is identifying focal points to calculate energy pattern of the reflected signal, which for multi-static scenario under test it will be done by coherence signal integration. Figure 7 shows the focal point identification inside the region of interest.

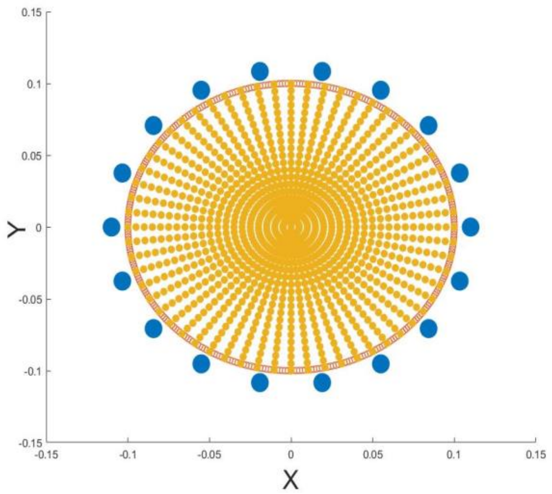


Fig. 7. Focal point identification inside the region of interest.

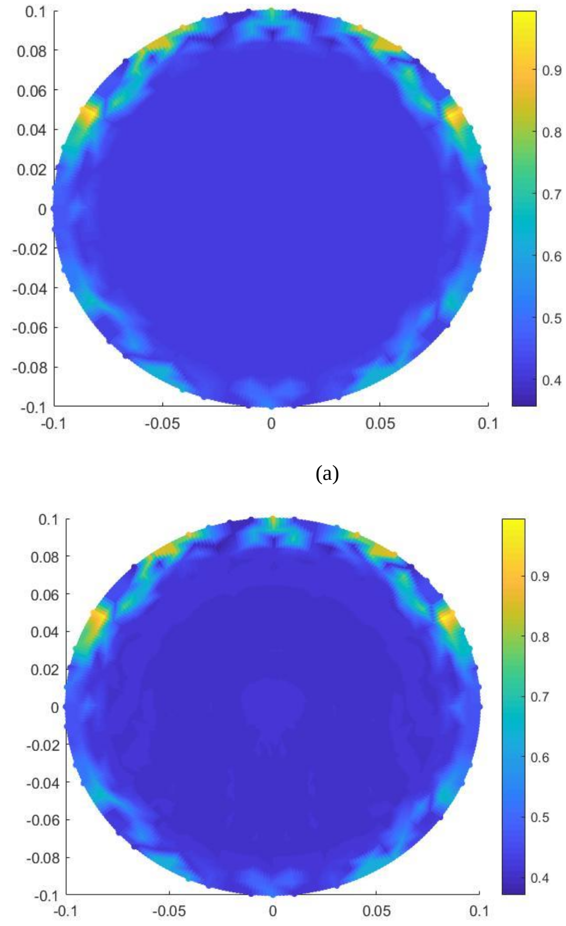
Before applying confocal algorithm, it is necessary to identify the best choice for effective permittivity of the scattering point. In order to get a realistic effective permittivity map of the human head interior, a simulation model is created in CST Microwave studio. The radiating antenna is placed in front of the point of entry of the human head, which is theoretically at the transition of air and skin layer. Electromagnetic field probes are inserted in different distances into the head model and the antenna is excited with the frequency band of interest and run in time-domain solver. The best choice for effective permittivity from the point of entry is calculated 38.9 in the proposed study case.

The Confocal Microwave Imaging Algorithm (CMIA) for brain tumor detection is an easy and robust technique for tumor detection, which is used to approximate the precise location of the tumor [4]. By assuming that the wave inside the biological tissue phantom has a spherical wave front and $X_i(n)$ be the complex received signal from antenna, the output $F_i(n)$ represents the intensity (brightness) of the picture pixel at the n^{th} range cell and direction θ and is given by the following relation

$$F_i(n) = \sum_{n=1}^{N} f_i . X_i(n) . e^{j\varphi_i} \quad (2)$$

Where N is the total number of receiving antennas, f_i is the correction for phantom medium attenuations and propagation loss and was assumed constant because of the same signal incidence angle. The phase component φ_i is applied to compensate for the phase difference due to distinct traveling paths [14].

Through processing raw data, simulated result by using confocal image reconstruction method, the back-projection reconstructed images from two scenarios are achieved and show in Figure 10. It can be observed that in the reconstructed image, the reflected signal is noisy, containing, in addition, clutters. In addition, poor reflections are seen at deeper section of the brain. From this viewpoint, the target may be illuminated over the complete half space. However, due to the large attenuation, the antenna at the left side of the head hardly see the antennas on the right side.

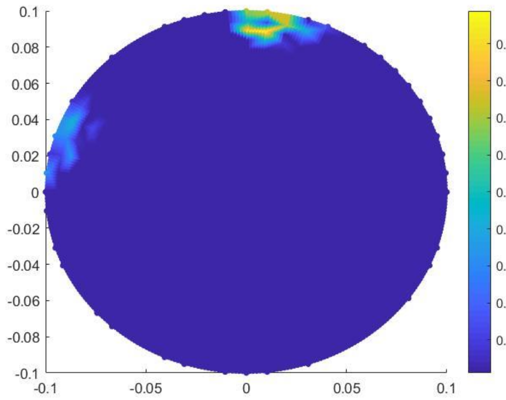


(a)

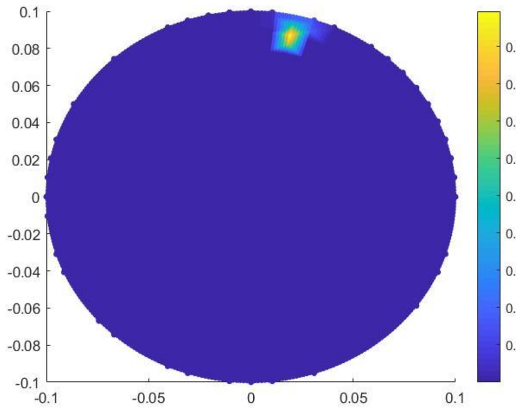
(b)

Fig. 8. Reconstructed image from confocal image reconstruction method in different steps of the proposed method, (a) Tomur and Background, (b) Background.

Figure 8 (a) shows 2D results of reconstructed differential image from subtracting a background that is the scenario without tumor. As illustrated in Figure 8, the reconstructed result has a good resolution and contrast to determine the exact location of the tumors. Also in in order to increase the performance of the system we apply multiplying calibration technique in confocal algorithm as shown in Figure 8 (b).



(a)



(b)

Fig. 9. Reconstructed image from confocal image reconstruction method, (a) 2D results, and 3D results.

IV. Conclusion

This paper has presented an UWB hemi-spherical microwave imaging system to detect and locate small tumor in a human head phantom setup using the time domain data. Additionally a novel approach for high resolution MIS system using a hierarchically calibration method to improve the reflected signal of localizing target is presented. The validity of the presented system and its target detection algorithm has been verified via simulation in examples. Results obtained by our MIS system prove that our system has a good ability to finding small tumors. The proposed modified MIS is very practical as it is based on more realistic reflected signals from various angles rather than assuming single reflected signal. The results show that the developed UWB-MIS system has a good ability in detecting tumors in biological medium, even small targets of several centimeters.

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