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An Ultra Wideband Microwave Imaging System for Breast Cancer Detection

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Abstract

An experimental study concerning Ultra Wideband (UWB) Microwave Radar for breast cancer detection is described. A simple phantom, consisting of a cylindrical plastic container with low dielectric constant material imitating fatty tissues and a high dielectric constant object emulating tumour, is scanned with a tapered slot UWB probe antenna between 3.1 to 10.6 GHz. Different calibration schemes are considered for the successful detection of the target.

1. INTRODUCTION

Recently, microwave imaging has found a considerable interest with respect to a new application, which is detection and location of malignant tissue in woman's breast [1-9]. In this application, a microwave imaging system is considered as a viable alternative to X-ray mammography. It involves the propagation of very low levels (1000 times less than a mobile phone) of microwave energy through the breast tissue. The basis for tumour detection and location is the difference in the electrical properties of normal and malignant breast tissue. Normal breast tissue is largely transparent to microwave radiation while the malignant one containing more water and blood, causes microwave signal back scattering. This scattered signal can be picked by a microwave antenna and analysed using a computer [5], [6].

Several research groups, including Dartmouth College and the University of Wisconsin-Madison in the USA, University of Calgary in Canada and Technical University Denmark are currently working in this area.

In general, two approaches are used with respect to detecting cancerous tissue, Microwave Tomography and Radar Technique. For microwave tomography, a forward and reverse electromagnetic field problem is solved to detect and locate cancerous tissues in woman's breast. Each of the inverse problems is solved at a single frequency [1-4].

The radar approach to microwave imaging employs generating and receiving short pulses for various locations of probe antenna or alternatively by an array antenna [5-9]. Such short pulses can be generated in practice by applying a step-frequency pulse synthesis technique [10], [11]. The space or time-domain representation is then achieved using an Inverse Fast Fourier Transform. The processed signals for various locations of a probe antenna or from array elements are combined to form a two or three-dimensional image showing the location of highly reflecting objects representing a cancerous tissue [11].

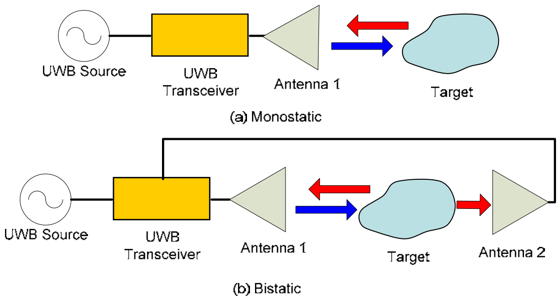

Fig. 1. General configurations of a microwave imaging system of (a) monostatic, and (b) bistatic type radar.

The first configuration, shown in Fig. 1(a), is based on the principle of monostatic radar [12]. In this configuration, the same antenna is used for both transmitting and receiving of a microwave signal. As a result, the transceiver performs the function of a reflectometer [13], [14].

The configuration shown in Fig. 1(b) uses two antennas, which are displaced by some distance. In this case, the microwave imaging system is based on the principle of bistatic radar [12].

Based on the monostatic radar configuration, a first generation linear/circular scanning system prototype was built at the University of Queensland [11]. The system has a limited frequency band of 8.2 to 12.4 GHz and has been tested for targets with high conductivity (copper). This paper reports on a significant extension of this initial work. The system is modified to be an UWB system covering the frequency range of 3.1 to 10.6 GHz. This operation is possible with the use of an UWB tapered slot antenna.

The paper is organised as follows. Section 2 describes the configuration of the UWB radar system. Section 3 describes the design of the Tapered Slot UWB antenna. Section 4 describes the results of experimental imaging of a circular container filled with vegetable oil which emulates the skin and healthy breast tissue respectively. A high dielectric constant object (a small plastic container filled with distilled water) is used to emulate the target tumour. Finally, Section V concludes the paper.

2. EXPERIMENTAL SETUP

The configuration of the prototype UWB radar system is shown in the Fig.2. The system consists of a Φ-Y circular cylindrical scanning platform which includes a turntable with a resolution of 22.5° to support a breast phantom, and a mechanical scanning platform with resolution of 0.1mm in the Y axis.

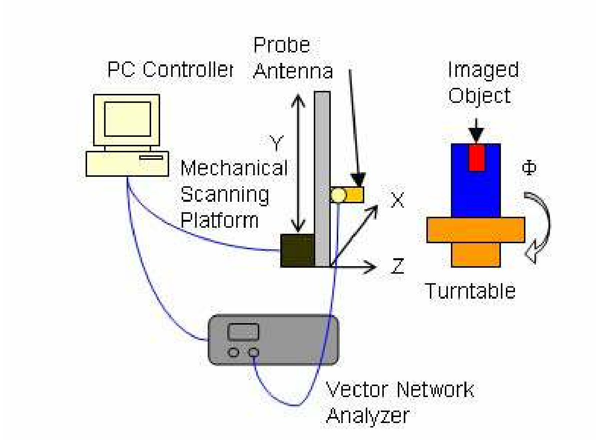

Fig. 2: Configuration of the UWB radar system.

The scanning platform supports a probe antenna which is in the form of an UWB tapered slot antenna. This antenna operates in the frequency range from 3.1GHz to 10.6GHz and is described in more detail in Section 3 [15]. A coaxial cable is used to connect the probe antenna to a microwave Vector Network Analyser (VNA), which is capable of measuring the full set of S-parameters of a 2 port network.

A short duration pulse is synthesised by transmitting Continuous Wave signals at equidistant frequencies from 3.1GHz to 10.6GHz [10]. The time/space domain equivalent is obtained by performing an Inverse Fast Fourier Transform on transmitted and received signals. The synthesised pulse, which is launched towards the target, is shown in Fig.3 [14].

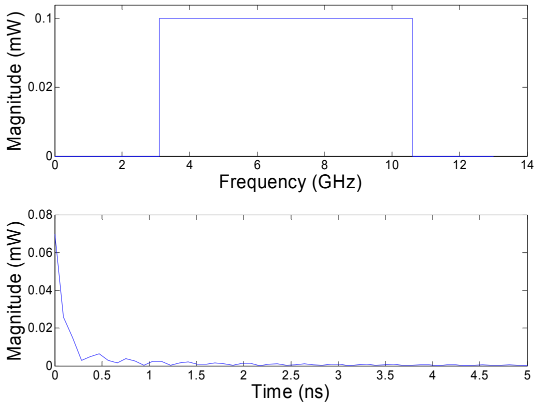

Fig. 3: Synthesized pulse (Frequency and Time Domain Representation)

Prior to measurements, the system is calibrated over the frequency band from 3.1GHz to 10.6GHz using a *modified* one port calibration procedure. The coaxial short and shielded open circuit are used as in the standard calibration procedure. However the coaxial match termination is replaced by a load realized by the probe antenna radiating a microwave signal in free space [11]. We call this modified calibration procedure as Method A. By using Method A, undesired signals including internal reflections inside the probe antenna and at the antenna-air interface are either reduced or removed completely [11].

The measurement procedure is as follows. Specify the area to be scanned. These include the step size and number of steps in the Φ-Y scanning platforms. At each Φ-Y probe location, the PC controller triggers the source in the Vector Network Analyser and 50 to 800 (depending on specifications) measurement points for reflection coefficient over the frequency band of interest are performed. After the frequency domain measurements of reflection coefficients are completed, they are converted to the time domain using IFFT. Having obtained the frequency and time domain data for a given location, the results are stored in the PC and the probe is moved to a new position and the measurement procedure is repeated. The obtained data is then processed by the PC to create an image. Using false colours, the location of a target can be shown in a colour distinctive from the colours representing other parts of the breast phantom.

3. ANTENNA DESIGN

The design of the Tapered slot UWB antenna is accomplished using simple design formulas [15]. This is an advantage over previously reported UWB antenna designs which rely on the trial and error method and simulation tools. Following its design, the antenna is fabricated on a Rogers RT6010LM substrate featuring a dielectric constant of 10.2 and a loss tangent of 0.0023, 0.64mm thickness plus 17µm thick conductive coating. This radiating element features a compact size of 50mm × 50mm. The configuration and photograph of the antenna is shown in Fig.4 and Fig.5 [15].

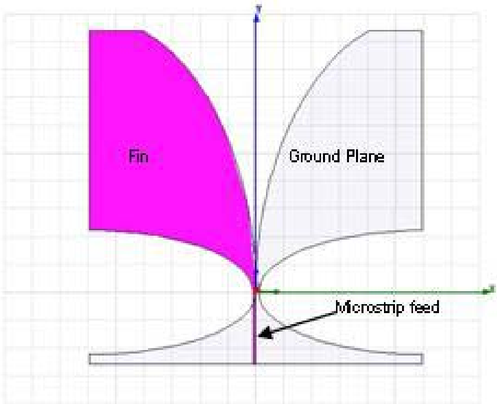

Fig. 4: Configurations of the Tapered Slot UWB antennas.

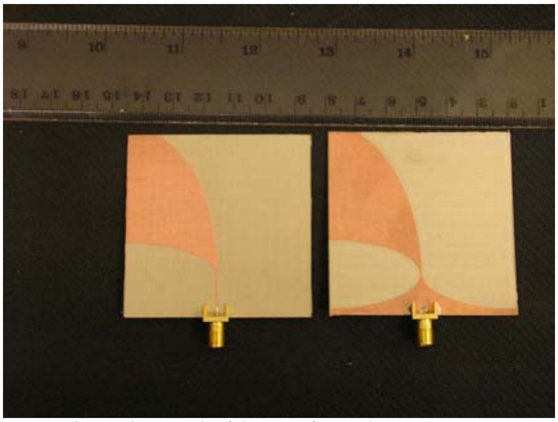

Fig. 5: Photograph of the manufactured UWB antenna.
Left: Upper Layer (Radiating Structure). Right: Lower Layer (Ground Plane).

The return loss performance of the designed antenna is first verified using a Finite Element Method design and analysis package, Ansoft HFSSv9.2. A personal computer with dual Xeon 2.8GHz processors and 3.5GB of RAM is used as a simulation platform. The developed antenna's return losses are tested in an anechoic chamber using an HP8530/HP8510 microwave receiver/network analyser.
Fig.6 shows the simulated and measured return loss of the planar tapered slot antenna. As can be seen from the figure, the antenna operates from 2.75 GHz to over 11 GHz for the 10dB return loss reference. The measured return loss graph closely resembles the simulated one. This antenna is definitely capable to operate in the desired frequency range from 3.1GHz to 10.6GHz [15].

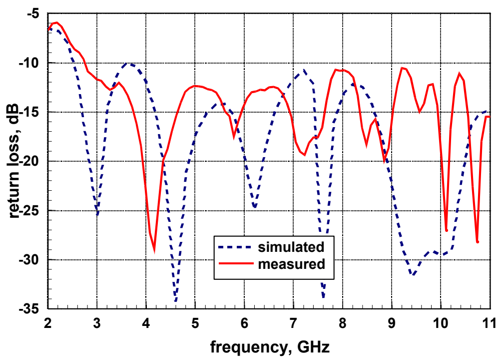

Fig. 6: Measured and Simulated return loss performance of the Tapered Slot UWB antennas.

4. RESULT

The imaging capabilities of the above-described UWB radar system are carried out for the monostatic case with respect to the experimental setup shown in Fig.7, which includes a simple breast phantom. This phantom consists of a circular cylindrical plastic container with a diameter of 12.5cm with thickness of 1mm. The container is filled with vegetable oil which has a dielectric constant of 4. The container and oil are used to represent the skin layer and breast tissue. A second small plastic container filled with water (dielectric constant of 80) representing the tumour is located close to the centre of the first plastic container. This provides an experimental model which is quite close to the actual healthy breast tissues and cancerous tumours which have typical relative dielectric constants of 9 and 50 respectively [7].
For the 1st generation Microwave imaging system (reported in [11]), the experimental setup is even simpler. It consists of a circular cylindrical plastic container filled with air representing the skin layer and breast tissue and a copper pipe (1.2cm in diameter) representing the tumour located close to the centre of the plastic container.

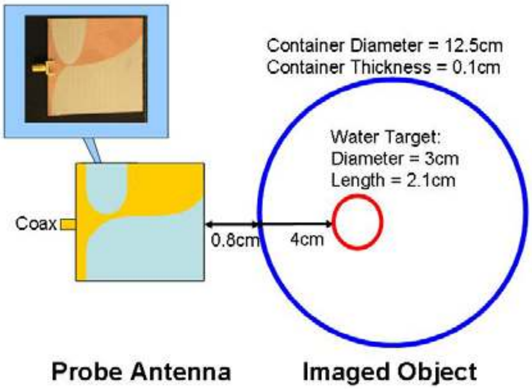

Fig. 7: Experimental Setup

For the initial testing of UWB radar system, the probe antenna is stationary and the image object is rotated in increments of 22.5°. Reflection coefficient measurements are performed at each angular position and the result is recorded. Fig.8 shows the imaging result when the system is calibrated using Method A. We can clearly see the boundaries of the plastic container and the location, size and shape of the water target. The measured diameter of the water target is approximately 3.3cm which is quite close to the actual size of 3cm.

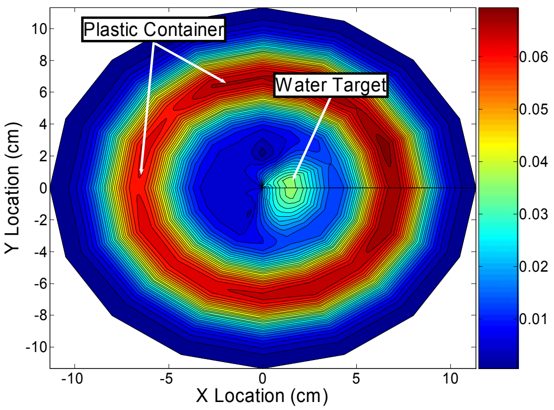

Fig. 8: Imaging Result of UWB Radar System with Calibration method A.

By comparing the results from the UWB radar system in Fig.8 and the image captured with the 1st generation prototype results shown in Fig.9, one can see that the UWB radar system features a better resolution, and less smearing/blurring of the target. Note that the image of the target obtained with the 1st generation system is about 7 times of the actual size of the target.

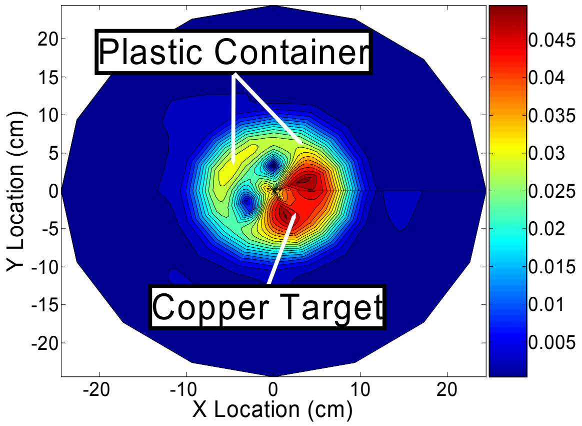

Fig. 9: Imaging Result of the 1st generation Microwave Imaging System with Calibration method A

To remove or reduce the smearing/blurring problem in the 1st generation of the system, we extend the modified calibration procedure (Method A) by realizing the match load calibration standard by positioning the probe antenna right in front of the air filled container without the target (as before, being a section of copper pipe), and beaming a microwave signal into it (Method B) [11]. Fig.10 shows the imaging results produced with the 1st generation system that employs this new calibration procedure. When compared to Fig.9, the modified calibration procedure is able to remove the reflection due to the container interface and reduce the smearing/blurring of the target. This enables us to pinpoint the actual location of the *tumour* target. From the result we can estimate the diameter of the copper target to be approximately 2.5cm, which is almost twice its actual diameter of 1.1cm.

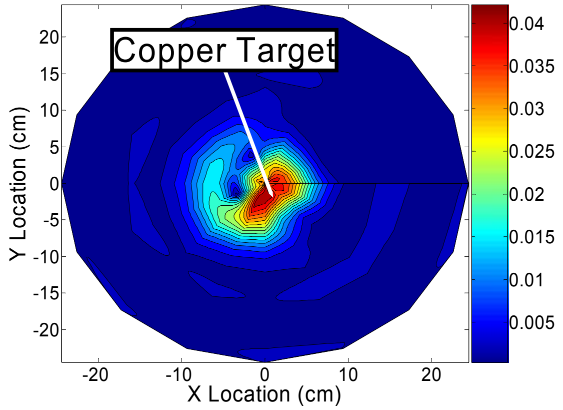

Fig. 10: Imaging Result of the 1st generation Microwave Imaging System with Calibration method B

Encouraged by this result, we decide to implement the modified calibration method B for the UWB system. The results are shown in Fig.11. As observed in Fig. 11, the improvement is minimal in comparison with the result observed in Fig.8. The modified calibration applied to the UWB system just removes the container but does not enhance the resolution of the target. This shows that the new UWB radar system is capable of locating and estimating the actual size of the actual target which is approximately 3cm in diameter without the use of the modified calibration method B.

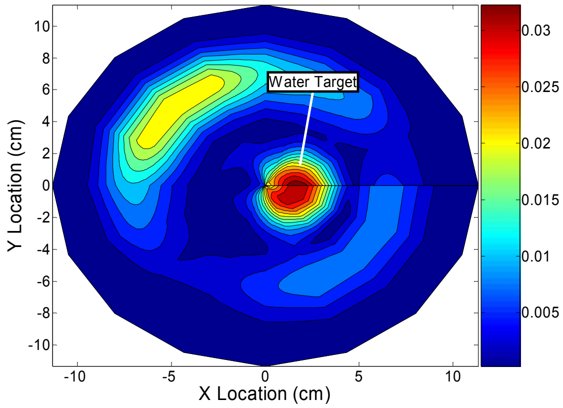

Fig. 11: Imaging Result of UWB Radar System with Calibration method B.

However, further investigation into the modified calibration method B will be conducted in the next stage of the UWB radar system development.

5. Conclusion

A UWB microwave imaging system based on a step frequency synthesised pulse technique for possible use in breast cancer detection has been presented. The system has been tested when an imaged object is a cylindrical plastic container filled with a low dielectric constant material and includes a small high dielectric constant target. It has been found that the use of UWB signal enables better resolution images than its 1st generation counter part operating only over the 8-12GHz band. This better resolution offers an enhanced capability for identifying the shape and location of a target. It has been demonstrated that by applying suitable calibration procedures that the undesired effects of internal probe antenna reflections and interface of imaged objects can be removed or minimized, thus doing away with the need of using time-gating technique or sophisticated signal processing. One of these special calibration methods (Method B) to remove the unwanted reflection component caused by air-image body surface interface has been found to work well for a circular system. The introduced calibration technique can be further modified to enhance the ability of a UWB microwave radar system to detect small targets, as required in the breast tumour diagnostic.

Acknowledgement

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