BREAST TUMOUR DETECTION USING A FLAT 16 ELEMENT ARRAY

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***Abstract* — A new experimental prototype of a breast cancer detection technique using real aperture multi-static radar is presented. The system comprises a fully-populated 16 element flat array and an associated system to switch between different transmit and receive elements. 3D images are produced using backscatter signals from a synthetic breast phantom. After suppression of skin reflections, initial images demonstrate the successful detection of 4-mm-diameter tumours.**

I. INTRODUCTION

Breast cancer is the most common cancer in woman, and early detection increases the likelihood of successful treatment and long-term survival. Screen film mammography is currently the most effective method for detecting breast tumours [1], however this technique suffers from relatively high false negative and positive detection rates, and it involves uncomfortable compression of the breast - frequent ionising X-ray screenings are also a matter of concern. Ultrasound, whilst non-ionising, is not sensitive enough for some tumours, whilst MRI based systems are too expensive and time consuming for routine screening.

Microwave detection of breast tumours is a promising and potentially low-cost alternative. It, too, involves only non-ionising radiation, and it benefits from the significant dielectric contrast between normal tissue and malignant tumours. A number of groups [2][3] have proposed microwave-based systems in which, in an analogous fashion to Ground Penetrating Radars (GPRs), microwaves are transmitted from an antenna or antenna array, and the received signals, which contain reflections from tumours, are recorded and analysed.

The work presented herein originated as a theoretical study employing FDTD models, which produced very promising results [4],[5]. Subsequently these theoretical results were confirmed by means of a mechanically-scanned 2 element antenna array [6] and a breast phantom consisting of synthetic biological materials [7].

The mechanically-scanned array was however limited in accuracy and scan-time and, with confidence in the experimental technique established, it was decided to replace it with a fully-populated 16 element stacked-patch antenna array and a 16-way RF switching matrix.

This new experimental system is described for the first time by this contribution. Results are presented using the 16 element array, scanning a flat skin and breast phantom including a synthetic tumour.

These initial practical investigations further demonstrate the promise of microwave screening, and are intended to assist the development of a next generation curved-array prototype, for clinical trials, such as that shown schematically in Fig. 1.

II. REAL APERTURE DETECTION SYSTEM

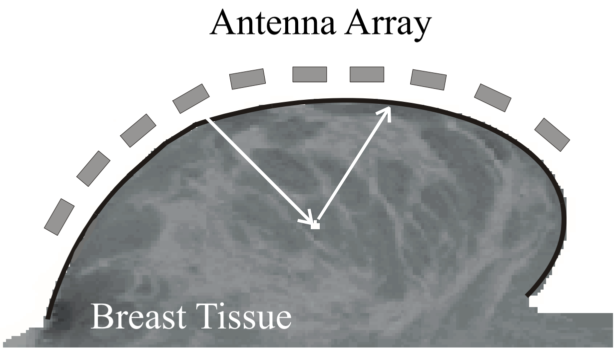

Fig. 1. Real Aperture Synthetic focusing system

The work presented here is based on a real aperture post-reception synthetically focussed detection system developed for land mine detection [8],[9]. In the proposed system all elements of a flat or conformal array transmit a broadband pulse (1.5 cycles of a 7GHz carrier in our experimental implementation) in turn. All elements sharing any operationally relevant 3D field of view with the current transmit element then record the received signal. By predicting the path delay from each transmit antenna via any desired resolution cell to each receiving antenna, it is then possible to retrospectively extract and time-align all the signals from that resolution cell, thus forming a basis for imaging the breast in 3D. The high dielectric contrast between malignant and normal breast tissues, at these microwave frequencies, will help to detect the tumour cells. The focusing mechanism can be mathematically described as in equation 1,

$$V = \int_0^{\tau} \left(\sum_{i=1}^{N(N-1)/2} w_i y_i (t - T_i) \right)^2 dt \qquad (1)$$

y_i = signal recorded from path i

w_i = weighting factors, applied to compensate for the predicted attenuation in round-trip path i.

N = number of antenna elements

τ = integration window length corresponding to the pulse width.

III. Experimental Setup

Given the increased losses in the medium above 10 GHz, a centre-frequency of 7 GHz was selected. The antenna was designed to be wide-band (7±3 GHz), inexpensive to manufacture, easy to integrate into an array, and optimised to radiate directly into a medium with a specific permittivity of approximately 9.5.

Fig. 2 shows the FDTD model used to design the antenna elements and array, which consists of 16 microstrip-fed wideband stacked patch antenna elements.

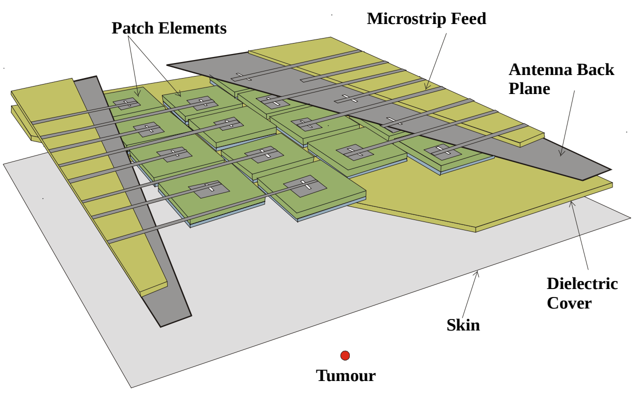

Fig. 2. FDTD Antenna Array Model

Following this design exercise, the patch antennas were printed on a ε_r = 2.2 dielectric substrate which was separated from the antenna ground plane with a ε_r = 10.2 substrate. The stacked patch was fed from a microstrip line printed on the reverse side via a slot in the ground plane. The constructed array is shown – now facing "upwards" - in Fig. 3.

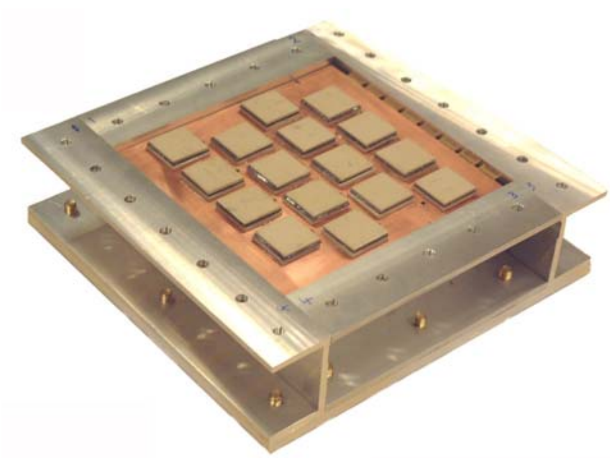

Fig. 3. Constructed Array

The complete experimental setup, shown in Fig. 4, incorporates the antenna array at the bottom centre of a Perspex tank which is filled with a breast phantom.

An Agilent 8722ES network analyzer is connected via a custom-built switching system to each of the 120 possible combinations of transmit and receive antennas in turn. The analyser collects frequency-domain S_{21} data from 4 – 10 GHz for each of these combinations. The complete measurement process takes approximately 2.5 minutes.

The Perspex tank contains breast-, skin- and tumour-phantoms. The flat skin phantom employed in these experiments was 1 – 2mm thick and had similar dielectric properties to published values for normal skin. Different tumour sizes of 15mm to 4mm diameter with ε_r = 40 - 50 were employed for these initial experiments.

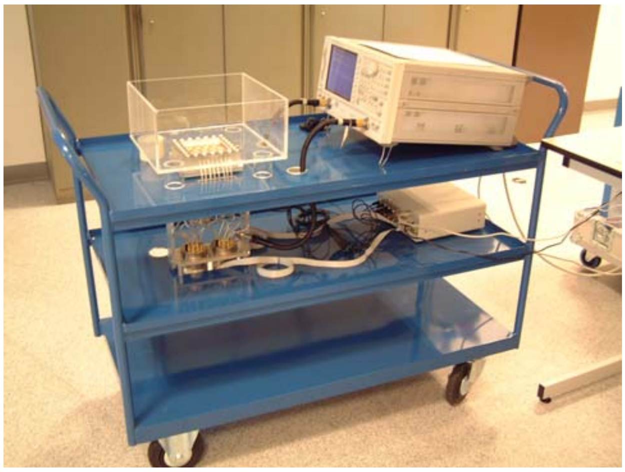

Fig. 4. Experimental Setup

The frequency-domain data collected using the network analyzer were employed in the focussing algorithm of section II. This involved weighting the spectrum measured data to synthesize a modulated Gaussian pulse [10], and transforming the signals to time-domain, using an Inverse Fast Fourier Transform (IFFT) algorithm.

IV. Experimental Results

The received signals include direct coupling between the antennas, reflections from the skin, and the tumour echo. The direct coupling will not significantly interfere with the tumour echo, as it is time separated and it also can be easily subtracted. But the skin clutter poses a significant challenge, as it tends to mask the reflections from tumours close to skin. It is then difficult to separate the strong skin reflections from the weak tumour echo. Although the synthetic focusing mechanism will coherently add the wanted echo at the tumour location, small tumour sizes need further consideration.

A reduction in the strong skin reflections may be obtained by recording the reflections at a slightly offset array location [5]. Data collected with the array position slightly offset will contain approximately the same skin clutter, but signals from the tumour will undergo phase and amplitude changes. Subtraction of these two sets of data and subsequent focussing will indicate a positive sum of signals at the tumour location and a negative sum at the offset location. Perfect skin cancellation is not possible, due to skin imperfections and the non-flat nature of breast, but a significant reduction is possible with this simple technique.

Fig. 5 shows a three dimensional image of a 15mm tumour at x =0, y =0, z = 45mm. The skin is shown at z = 18mm and the antenna array at z =0mm. This image was obtained with the skin clutter present and the direct antenna couplings eliminated by subtraction. Fig. 6 shows the horizontal slice at the tumour location for this 15mm tumour.

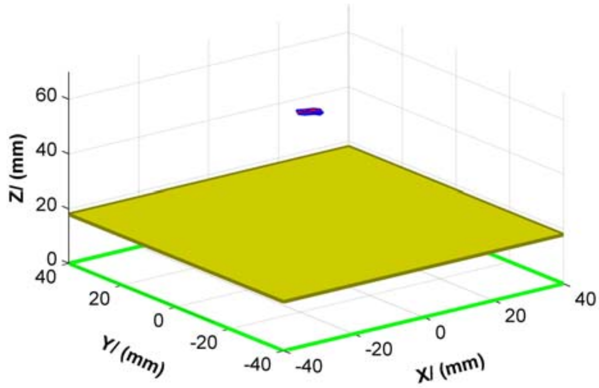

Fig. 5. Three dimensional Imaging of 15mm tumour: Skin clutter present in the focusing data

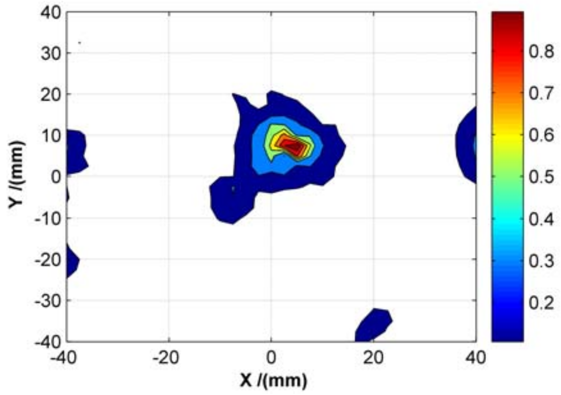

Fig. 6. Horizontal Slice at tumour location for 15mm tumour: Skin clutter present in the focusing data

Fig. 7 and Fig. 8 show the three dimensional image and the horizontal slice of a 4mm tumour at x= 20mm, y=-15mm, z = 45mm. For this small 4mm tumour, the skin reflections were eliminated by background subtraction. The background data was obtained without the tumour present.

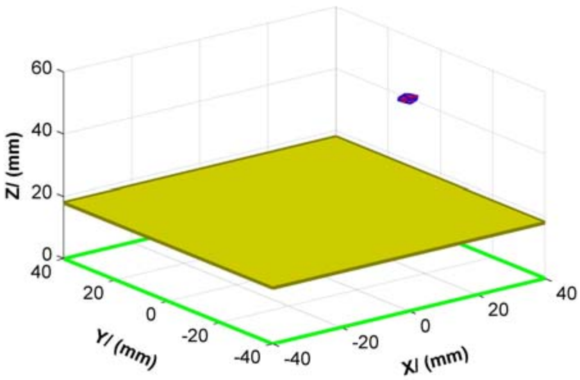

Fig. 7. Three dimensional Imaging of 4mm tumour: Skin clutter eliminated using background subtraction

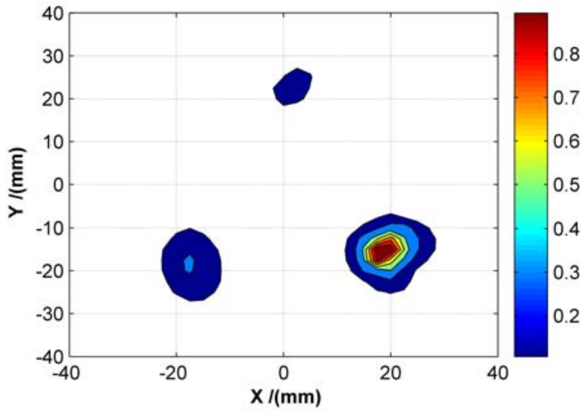

Fig. 8. Horizontal Slice at tumour location for 4mm tumour: Skin clutter eliminated using background subtraction

These results clearly show the synthetic tumours are detected at their correct locations. However the small size tumour would have been masked by skin reflections in the absence of background subtraction. Theoretical and numerical analyses of further techniques to reduce skin reflections has produced promising results and it is expected that the authors will be able to present further new practical results shortly.

V. Conclusions and Future Work

A microwave radar approach to the detection of breast tumours has been presented. This system exploits the significant dielectric contrast between a tumour and normal tissue.

For the first time, a newly-constructed experimental system has been described, and the initial results obtained from this implementation have been presented.

Imaging results for 15mm and 4mm diameter tumours placed in a breast phantom have been presented. Although the 15mm tumour is detected in the presence of the skin clutter, the 4mm tumour needed a full background subtraction.

These results further confirm the promise of microwave screening for breast cancer, and will assist in the development of a curved-array clinical prototype. As was expected, the skin-reflection is a significant obstacle to detecting smaller tumours and further techniques to reduce or eliminate skin reflections are currently being evaluated.

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