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DEVELOPMENT AND APPLICATION OF A UWB RADAR SYSTEM FOR BREAST IMAGING

I. J. Craddock, M. Klemm, J. Leendertz, A. W. Preece and R. Benjamin

University of Bristol, Merchant Venturers Building, Woodland Road, Bristol UK.

Email ian.craddock@bristol.ac.uk

Abstract

This contribution describes recent progress towards a functioning UWB radar system for imaging the human breast. The antenna and array design are described and a typical phantom result is presented herein. The project is currently conducting clinical trials and images from these trials will be presented at the conference, along with many more phantom images.

1 Introduction

Breast cancer is the most common cancer in women. X-ray mammography is currently the most effective detection technique, however it suffers from relatively high missed- and false-detection rates, involves uncomfortable compression of the breast and also entails exposure to ionizing radiation.

Microwave detection of breast tumours is a potential non-ionising alternative being investigated by a number of groups [1, 2, 3]. In the radar-based approaches, in a similar fashion to Ground Penetrating Radars, microwaves are transmitted from an antenna or antenna array, and the received signals, which contain reflections from tumours, are recorded and analysed.

Initial work at Bristol concentrated on developing a simple but low-profile and wide-band antenna that would cover the 4-10GHz frequency range. Through extensive FDTD simulation a stacked patch element was designed that broadly met the design criteria [4]. This antenna was initially employed in a mechanically-scanned system that used stepper motors to move a pair of antennas over a 4 x 4 grid of element locations. This arrangement was then replaced by a planar array and, most recently, by a curved array.

The intention from the outset was to design not only an array for laboratory use on a realistic, curved phantom, but also one that would serve as an initial clinical prototype. The fit between the breasts of a number of female volunteers and various plastic spherical sections was assessed with them lying in a prone position – this position allowing the breast to form a uniformly-curved shape.

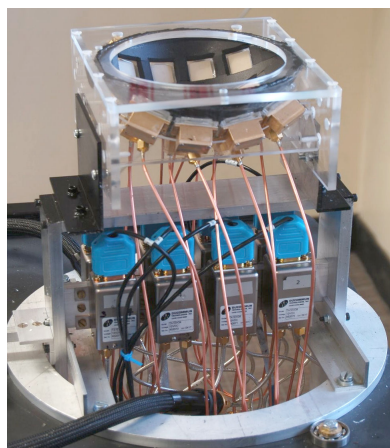


Figure 1: Conformal imaging array

A view of the array is shown in Figure 1, the array being formed around approximately the lower third of a 78mm-radius sphere. Visible in the image are the semi-rigid coaxial feeds to the stacked patches, each of which is cavity-backed to avoid undesirable influences from outside the array. As can be seen,

the feeds connect to Ducommun electromechanical switches, which interface, in turn, all possible pairs of antennas in the array to the transmit and receive ports of an Agilent VNA. The VNA performs a frequency sweep from 4 to 10GHz and the resulting bistatic radar measurement is transferred by GPIB to a PC. The PC takes an inverse FFT to give time-domain radar signals, which are equalised, processed and combined by a variety of multistatic signal processing techniques, many designed at Bristol specifically for this scenario.

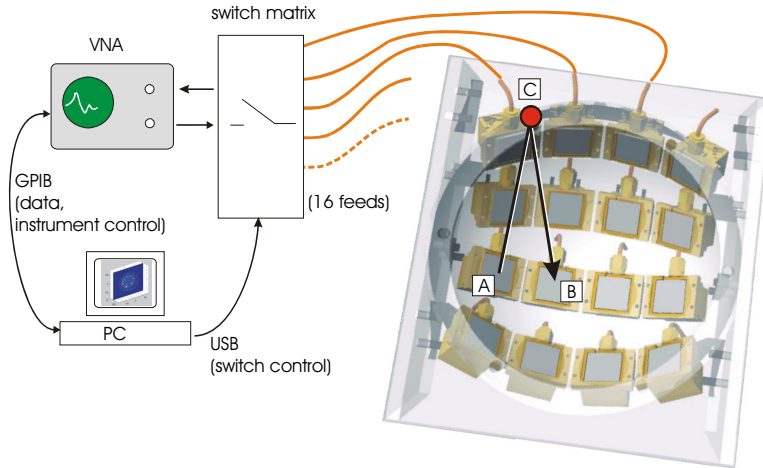


Figure 2: System Schematic

The most basic approach is a simple Delay-And-Sum where the recorded data is synthetically focused at any point of interest in the volume by time-aligning the received signals $y_i(t)$, using the estimated propagation time T_i from the transmit antenna A to the receive antenna B via the point of interest C . The return from C is then computed by integrating the data over a window corresponding to the transmit pulse width τ :

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

- where w_i are weighting factors that are applied to compensate for differences in the predicted attenuation between the round-trip paths (depending on the depth of point C and the spacing from antenna A to antenna B). With 16 antennas, there are 120 unique bistatic signals which gives considerable immunity to clutter, certainly far more than a monostatic approach.

2 Antenna Design

While stacked-patch antennas are well-known to have good operating bandwidths, the bandwidths achieved are usually only of the order of 20%, and in particular are limited by the usual probe-fed arrangement. The stacked-patch antenna, visible in Figure 1 and 2, incorporates a microstrip feed, coupled electromagnetically into the lower patch via a slot, in order to avoid the bandwidth limitation of a probe feed (although some greater back-radiation is then expected).

The full list of antenna dimensions can be found in [1] but for this paper it is sufficient to note that the total substrate thickness of the antenna is approximately 4mm, with the microstrip feed on the reverse being an additional thickness of 0.64mm. The two patches have $x_2=6.0\text{mm}$, $x_3=9.0\text{mm}$, $z_1=6.5\text{mm}$ and $z_2=6.0\text{mm}$.

With a good (10dB) input match and good radiation characteristics from 4.5 to 9 GHz, combined with a small physical size, this antenna clearly represents a very attractive solution for this application.

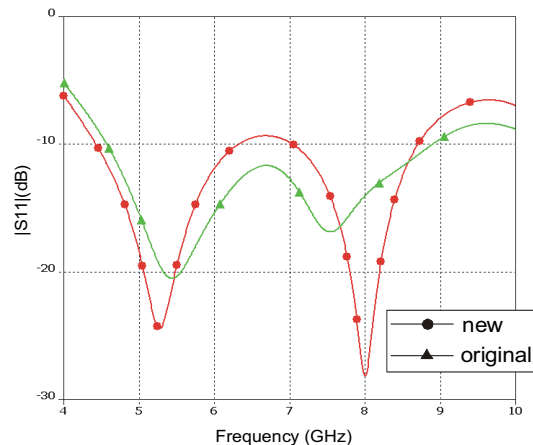


Figure 4: Original and New antennas compared

In the array application (Figure 1) the microstrip feed needs to be terminated in an SMA connector and the antenna's rear face enclosed inside a cavity to prevent back-radiation from the slot/microstrip. The substrate must therefore be finite in size. Careful optimisation has reduced the size of the required substrate from 17 x 17 mm to 12mm x 12mm, a reduction in area of 50% and hence better array-ability. The substrate therefore now only extends 1.5mm on either side of the largest patch, and the microstrip to SMA transition occurs only 2mm from the patch edge.

Figure 4 shows the results of a CST simulation of the original (17mm) and the new (12mm) design, in terms of input match. A -10dB input match is maintained from 4.5GHz to 8.6GHz for the new design, with the very minor exception of the band from 6.2GHz to 7GHz. Above 8.6GHz the smaller antenna performs slightly less well than the original design but at 9 GHz it is still matched to -8dB, which is quite acceptable. Further details of the antenna's performance can be found in [5]

3 Array Design

With confidence established in the revised, smaller, stacked patch antenna, the array design was created, as shown in Figure 1.

4 Phantom Images

During laboratory experiments, the array is first filled with the matching medium, a (hemi-)spherical skin phantom is placed in the correct position, and then a tank is attached to the top of the antenna array and filled with a breast-fat-equivalent liquid (the same as the matching medium). This setup represents truly three-dimensional (3D) breast phantom. The chest wall is not considered in the experiments however this is in other respects an accurate electrical representation of a post-menopausal woman.

Figure 5 shows the generated image for every point of the volume of the phantom breast, displayed in 3D by Matlab on a linear density and colour scales. The obtained image is clear with little clutter and this is typical of the phantom images. More experimental results using the developed system can be found in [6] and more will be presented at the conference.

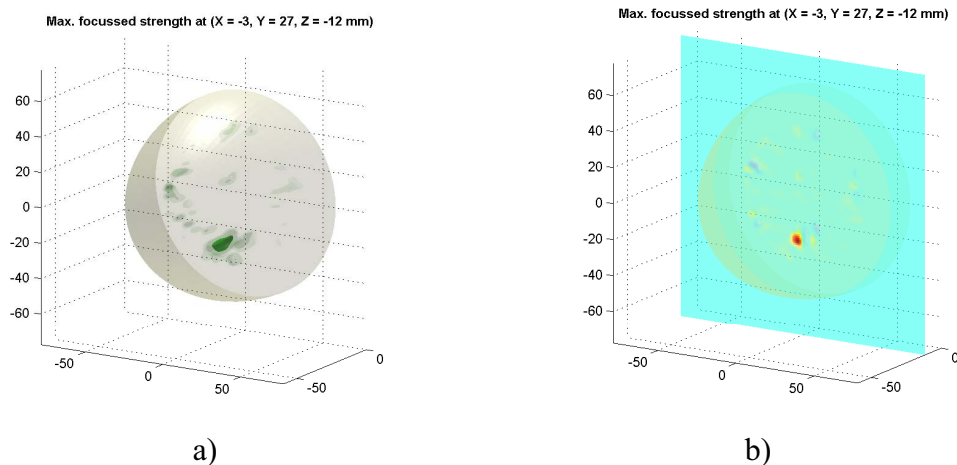


Figure 5. Experimental imaging results for 8mm diameter spherical phantom-tumor located at position $x=0, y=30, z=-20$ mm: a) 3D focused image, b) 2D image through the horizontal plane $z=-15$ mm. Figures are best viewed in colour.

5 Conclusions

This paper has presented recent progress in developing a practical imaging array for the human breast. Phantom results are very encouraging and the system is undergoing clinical trials, with the aim of further optimising the hardware and software configuration in the light of real clinical experience. It is hoped to present some clinical results at the conference.

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