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Design of a UWB Wide-Slot Antenna and a Hemispherical Array for Breast Imaging

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ABSTRACT

A microstrip, fork fed, wide slot antenna, printed on high permittivity substrate has been developed for the transmission of Ultra Wide Bandwidth (UWB) signals into the breast. The proposed antenna has been developed from an existing design using an in-house Finite Difference Time Domain (FDTD) program. The new antenna is shown to be of a compact size, has a wide impedance bandwidth and good transmission characteristics across the UWB frequency range, using a phantom equivalent to human breast tissue. The antenna is well-suited to its intended application in a breast-imaging array, and an array of 31 of these elements is presented herein for the first time.

I. 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, microwaves are transmitted from an antenna or antenna array, and the received signals containing reflections from tumours are recorded and analysed.

The University of Bristol team is working on multi-static ultra-wideband (UWB) radar for breast cancer detection. The radar system is based on a real aperture antenna array. The team has also developed a realistic 3D curved breast phantom with appropriate electrical properties. Moreover, the experimental system has been built in such way that it can be used with both phantoms and real women.

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], and 16 of these elements were successfully employed for phantom and clinical measurements using a hemispherical array arrangement [5].

Imaging systems such as this are usually limited by clutter, not attenuation, and hence for a multistatic array there are significant advantages in increasing the number of antenna elements. With this aim in mind, the original stacked patch antenna design was abandoned in the search for a more compact radiating element. The element chosen was a fork-fed wide slot design, taking the design in [6] as a starting point but adapted to a higher permittivity medium.

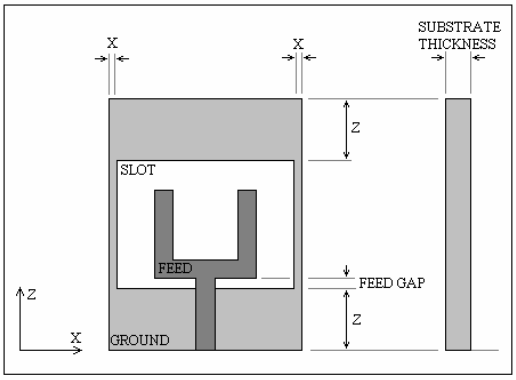

Figure 1. The layout of the developed antenna

Using an in-house FDTD code, the effect that various parameters have on the performance of the antenna were found including the geometry of the slot, ground and feed and the effect of using different substrates. The resulting antenna (Figure 1, Figure 2) is extremely compact and radiates effectively into a high permittivity ($\varepsilon_r \approx 9$) dielectric medium over the desired frequency band from 4 to 10GHz.

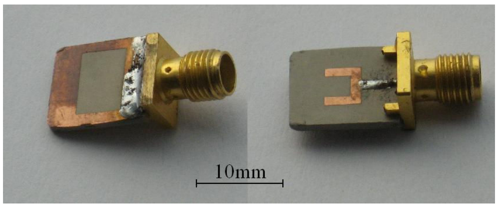

Figure 2: The manufactured antenna, feed and SMA connector

II. Simulation and Measurements of Antenna

The slot antenna was designed and optimised using FDTD simulation. The simulated return loss for this antenna can be seen in Figure 3, along with the measured results. It can be seen that there is good agreement between the two data sets; both show that the -10dB bandwidth extends from around 4 GHz to above 10GHz which is sufficient for this application.

The differences between the two plots are probably due to fabrication tolerances, especially regarding the feed, which is only 0.2mm wide and hence difficult to fabricate accurately.

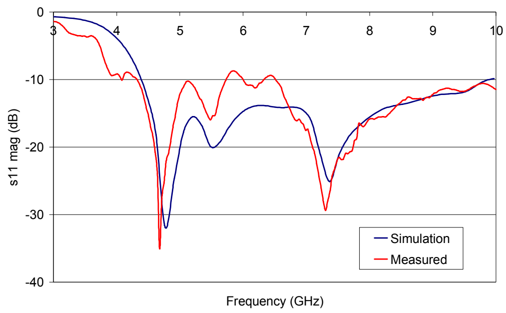

Figure 3: Measured and FDTD simulation of the s_{11} for the small slot antenna

Measuring the free-space radiation pattern of this antenna is obviously pointless and hence the team constructed a facility for measuring the radiation characteristics as they appear when embedded in a medium similar to breast fat.

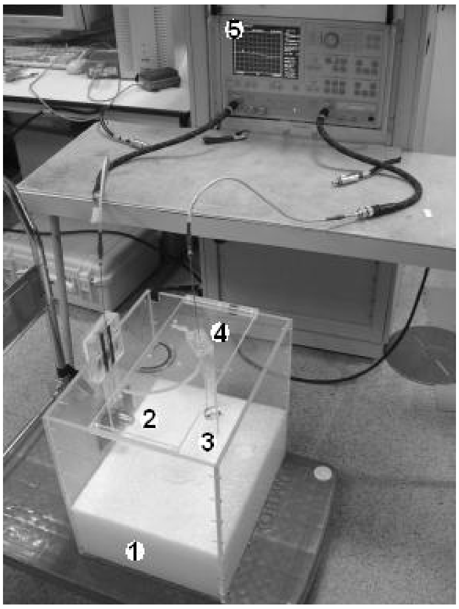

Figure 4: Antenna measurement rig

In the arrangement shown in Figures 4 and 5, both receiving and transmitting antennas are immersed in a large tank of the matching medium/phantom (1). The transmitting antenna (2) is fixed close to the tank wall in a stationary position facing out into the medium. The receiving antenna (3) is mounted on a rig (4) that describes an arc of radius 100mm around a central point at which is the centre of the face of the first antenna. Measurements were taken in the E and H planes using a VNA (5), the chosen plane selected by attaching the antennas to the measurement rig in the correct orientation before immersion in the phantom medium.

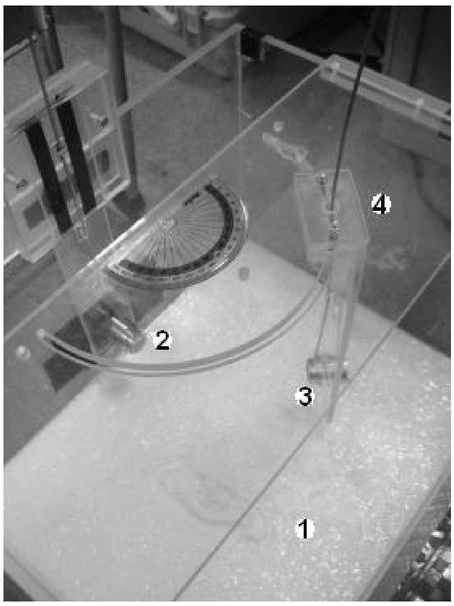

Figure 5: Closer view of measurement set up

There is insufficient space herein to present the full set of wideband radiation patterns recorded during the measurement, but these will be presented at the conference.

The shape of the radiated pulses is of particular concern in this application, and this has been established using the network analyser measurement of the antenna transfer function in the phantom followed by an inverse FFT in order to synthesize a radiated pulse (Figure 6).

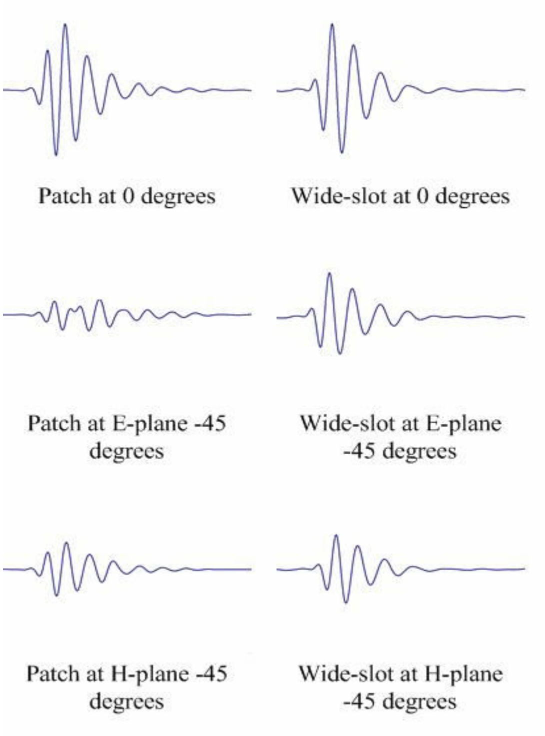

Figure 6: Examples of Pulses Synthesised from Measured Transfer-Function (left: original stacked patch design, right: new antenna)

Figure 6 demonstrates that the slot antenna, in addition to being substantially smaller than the original patch, is also a far better radiating element, especially away from boresight in the E plane, where the transmitted pulse retains greater fidelity to the boresight pulse, and also exhibits very little late-time ringing.

III. Array Design

The smaller size of the antenna enables a significant increase in the number of elements that can be distributed around the available hemispherical surface.

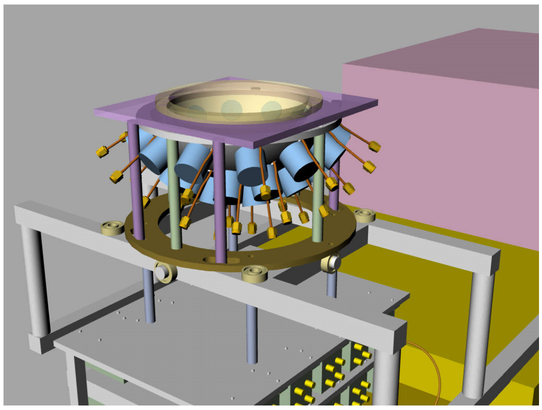

Figure 7: Visualisation of complete array

The Rhinocerous ® 3D modelling package was extensively used to determine possible layouts, paying particular attention to clashes between the feeds of adjacent antenna elements. These are practically impossible to avoid without the benefit of 3D software of this sort. The final design comprised 31 antenna elements.

Each antenna element was supported in a brass housing, that itself was supported by a ABS plastic shell (Figure 9).

Figure 8: Individual antennas and brass housings.

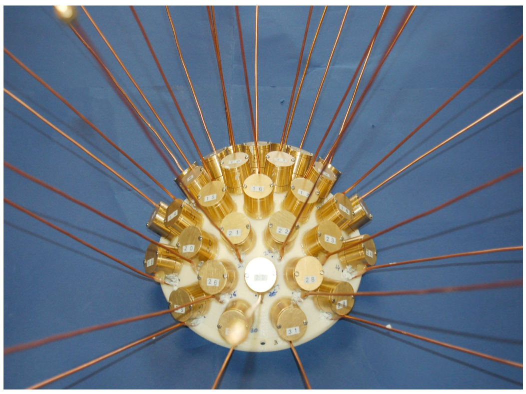

Figure 9: Elements in situ and their feeds (shown from behind)

The array at an advanced stage of construction is shown in Figure 10.

Each antenna feed is taken by semi-rigid coaxial cable to a custom-built switching matrix of Ducommun electromechanical switches, which allow any selected pair of antennas to interface with the two ports of the VNA, while leaving the remaining 29 antennas terminated in 50 Ohm loads.

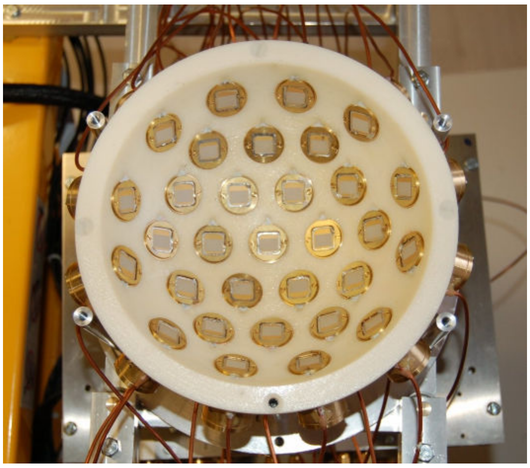

Figure 10: complete 31 element hemispherical array

Both phantom and clinical testing are underway at the time of writing. It will be possible to present these results at the conference.

IV. Conclusions

A design has been proposed for a wide slot antenna that has been specifically developed to radiate UWB frequencies into the breast. The antenna design has both good transmission and input reflection properties and transmits well into a phantom made of a material with a high dielectric constant equivalent to human breast tissue.

The antenna is planar and compact and therefore well-suited to integration into an array. A hemispherical array of 31 of these elements has been presented herein for the first time.

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