Wideband Microstrip Patch Antenna Design for Breast Cancer Tumour Detection

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Abstract

A patch antenna is presented which has been designed to radiate into human breast tissue. The antenna is shown by means of simulation and practical measurement to possess a wide input bandwidth, stable radiation patterns and a good front-to-back ratio. Consideration is also given to its ability to radiate a pulse, and in this respect it is also found to be suitable for the proposed application.

Introduction

Breast cancer is the most common cancer in women. X-ray mammography is currently the most widely-used detection technique [1], however the X-ray contrast between a tumour and the surrounding tissue is of the order of a few percent – as a result it suffers from a relatively high missed- and false-detection rates and involves uncomfortable compression of the breast. X-rays are also ionising and therefore not generally suited to frequent screening.

Microwave detection of breast tumours is a non-ionising and indeed potentially low-cost alternative. The high contrast between the dielectric properties of a malignant tumour and the normal breast should manifest itself in terms of lower numbers of missed-detections and false-positives. This potential has lead to the exploration of detection techniques based on microwave-radar by a number of groups around the world [2, 3].

Research at Bristol employs a post reception synthetically focussed detection method originally developed for landmine detection [4, 5]. All elements of an antenna array transmit a broadband signal in turn, the elements sharing a field of view with the current transmit element then record the received signal. By predicting the path delay between the transmit and receive antennas via any desired point in the breast, it is then possible to extract and time-align all the signals from that point. Repeated for all points in the breast, this yields a 3D image in which the distinct dielectric properties of malignant tissue are potentially visible.

This process depends on overcoming three problems:

- Achieving high resolution.
- Overcoming the high attenuation in human tissue, to permit the detection of relatively deep-seated tumours.
- Preventing reflections from skin, bones and other anatomical features (clutter) obscuring the signals from tumours.

Achieving high resolutions and good anti-clutter performance requires wide bandwidth operation. The antenna design employed must exhibit good performance, both in terms of input match and radiation pattern over the desired bandwidth.

Furthermore, a compact, low profile antenna design is additionally desirable in order to reduce the complexities of the physical array structure and to achieve a degree of conformality with the body. The wideband bowtie antenna employed at Bristol in the past for landmine-detection research is therefore not ideal [6]. Various different types of antennas are being considered by research groups involved in tissue-sensing applications using pulsed radar techniques, typical examples of such antennas include the resistively loaded bowtie [7], slotline bowtie [8], ridged pyramidal-horn [9], resistively loaded dipole [10] and microstrip Archimedean spiral [11].

This paper presents a low-profile stacked-patch antenna design that can operate over the necessary wide bandwidth for this application. While stacked patch antennas are well-known to have good operating bandwidths, the bandwidths achieved are usually of the order of 20% [12]. The stacked patch antenna presented here has been designed to radiate directly into a medium [13] which has similar dielectric properties to breast tissues, and furthermore achieves a bandwidth of approximately 77%.

As described in subsequent sections, initial antenna design and optimisation were carried out using FDTD techniques. The paper discusses both the FDTD modelling and the subsequent practical measurements conducted in contact with a biological equivalent medium.

FDTD modelling and Practical Measurements

Figure 1 and Figure 2 show the stacked-patch configuration modelled using FDTD. A microstrip line was used to feed the patch, employing electromagnetic coupling through a slot in the antenna ground plane.

Stacked patch antennas are conventionally designed using low permittivity materials, especially for the layer that separates the upper and lower patches, however, appreciating that this antenna was intended to radiate into a medium of ε_r= 9.8 (the approximate dielectric properties of health breast tissue), rather than air, the decision was taken to use higher-dielectric materials.

The antenna therefore consists of two stacked patches printed on a dielectric substrate of ε_r= 2.2 and separated from the ground plane by a second substrate of ε_r= 10.2. A higher dielectric permittivity was chosen as the antenna radiates into a high permittivity medium and to minimise the size of the patches. Antenna dimensions, shown in Figure 2 such as the slot length, slot width, patch sizes and dielectric block sizes were optimised using FDTD techniques to optimise antenna feed matching and near field beam patterns. The initial estimates of patch sizes were each chosen based on achieving a resonance at either end of the desired operating frequency band. Optimised final values for antenna dimensions are shown in Table 1.

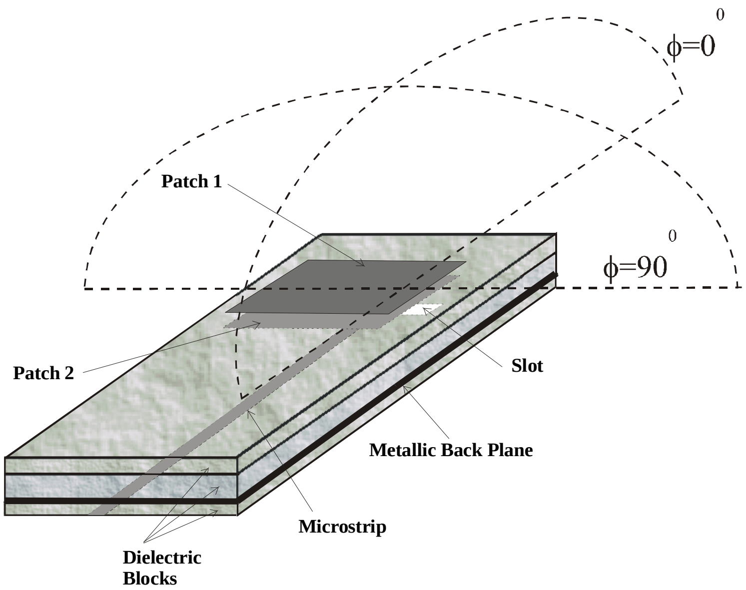
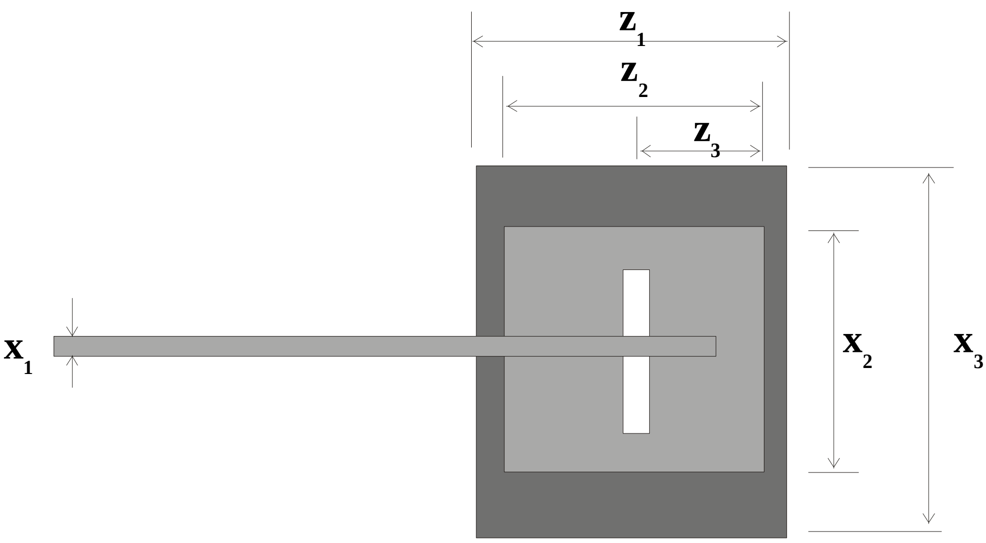


Figure 1 Stacked Patch Antenna



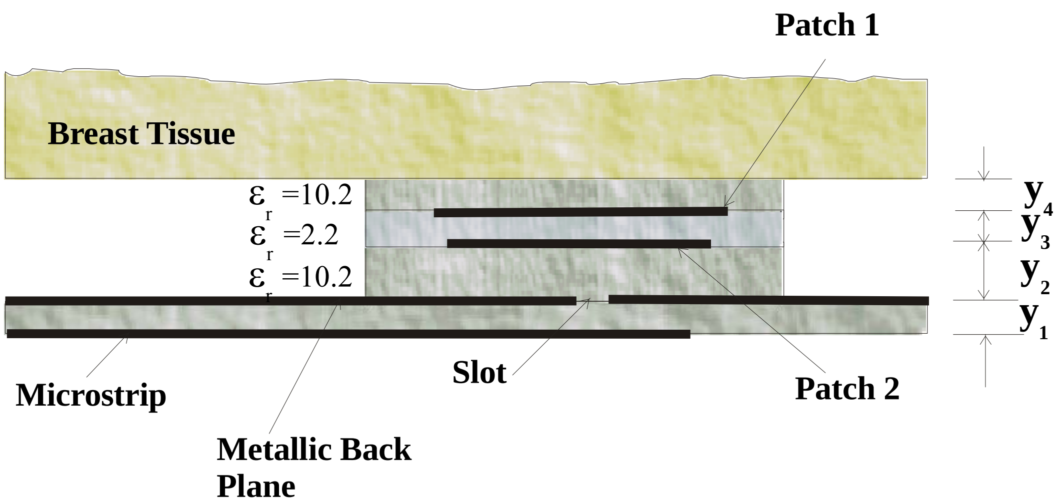


Figure 2 Antenna Configuration

Parameter	Dimension (mm)
x_1	0.66
x_2	6.0
x_3	9.0
y_1	0.64
y_2	1.9
y_3	0.8
y_4	1.27
z_1	6.5
z_2	6.0
z_3	3.0

Table 1 Antenna Dimensions

The antenna input responses achieved through FDTD simulation and subsequent practical measurements are shown in Figure 3. The practical measurements were carried out with the antenna radiating into a dielectric phantom [13]. The antenna was initially designed to radiate into a lossless medium and a good matching was obtained for this case, however one of the FDTD curves in Figure 3 shows the relatively minor perturbation resulting from including 2dB/cm attenuation in the breast medium.

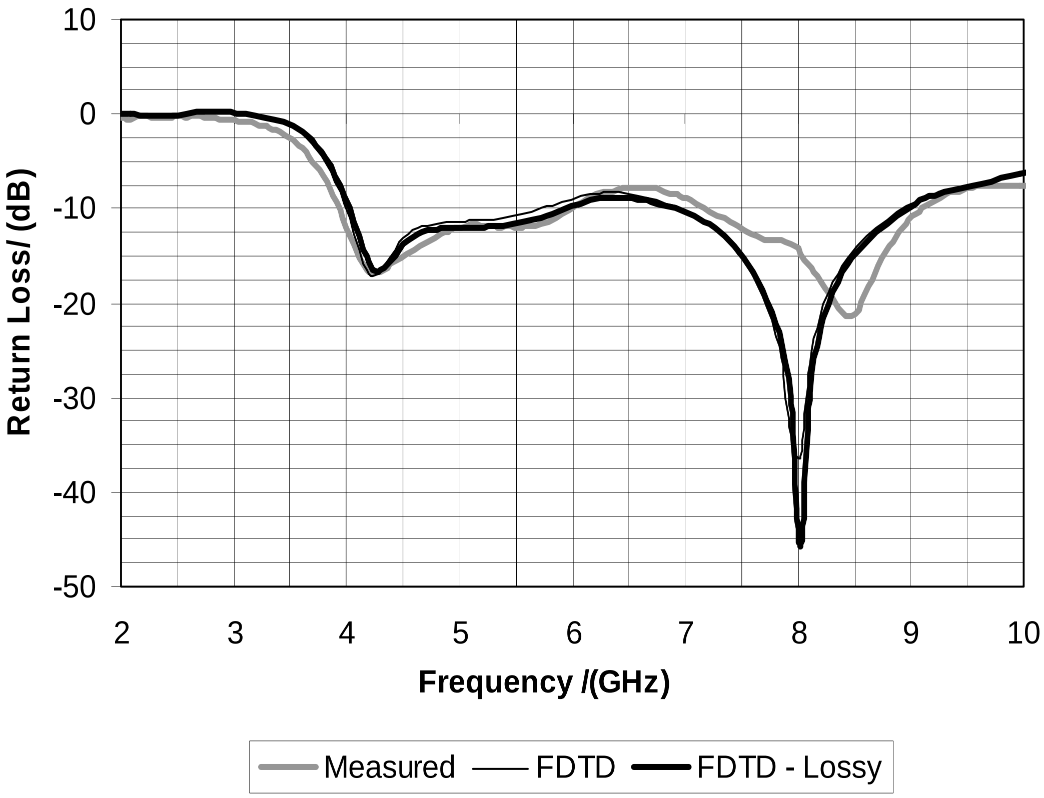


Figure 3 Antenna Input Response

These results show the antenna has a -10dB antenna-feed match from 4 to 9 GHz, with the exception of a small mid-band mismatch at 6.5GHz. Agreement between FDTD and experimental results in Figure 3 is very pleasing, especially given the inevitable manufacturing tolerances involved in defining the patches and feed, and then undertaking the blind-alignment of the different substrate layers.

An input match is only one requirement for the antenna, and stable radiation patterns are also important. The practical patterns measurement is however rather difficult, since the antenna must be measured in the medium, rather than air (as in an anechoic chamber). Given the good agreement obtained in the input response, it was felt reasonable to rely upon FDTD simulations to estimate the pattern characteristics, again assuming radiation into a dielectric medium with $\varepsilon_r = 9.8$.

The far-field radiation patterns of the stacked patch antenna were found by post-processing the FDTD data at specific frequencies. The calculated co-polar radiation patterns for the principal planes are shown in Figure 4 and Figure 5. Cross-polar levels (not shown) were 40dB lower.

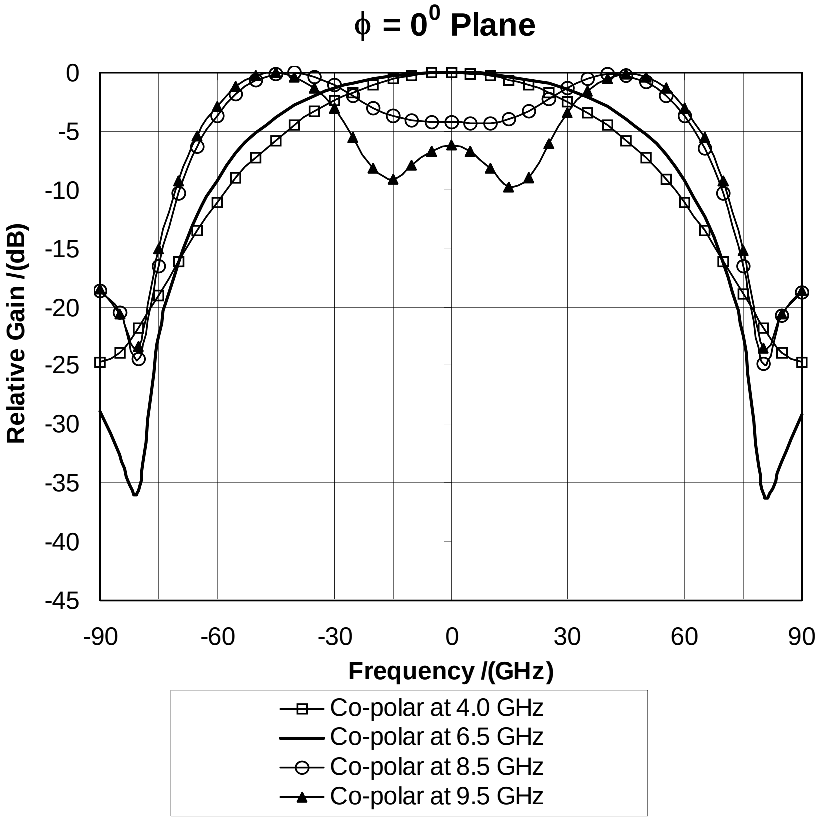


Figure 4 Calculated radiation pattern in the medium for $\phi = 0^0$ plane

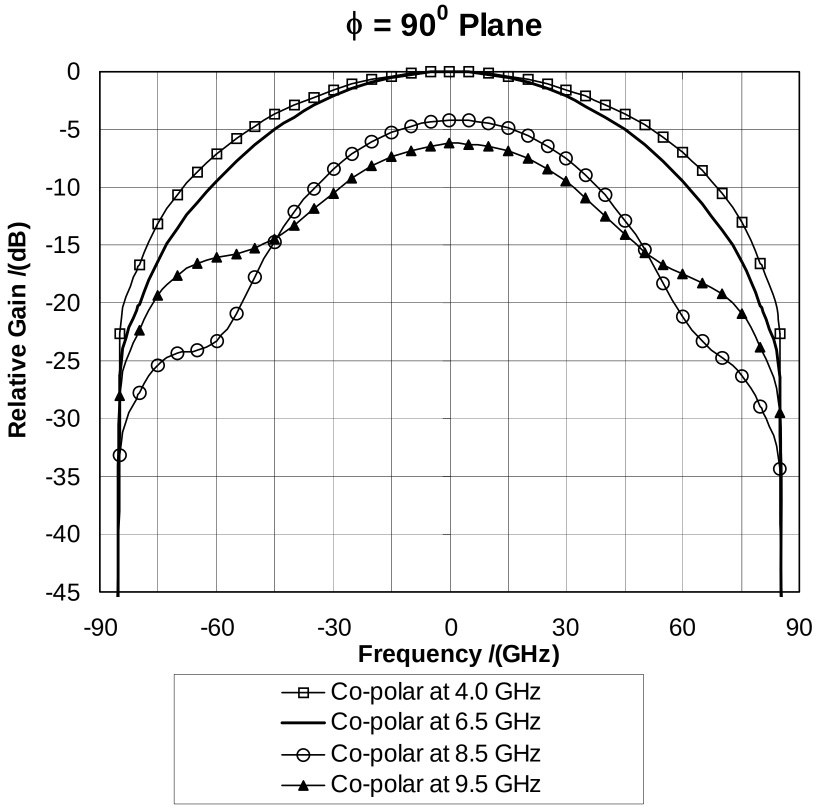


Figure 5 Calculated radiation pattern in the medium for $\phi = 90^0$ plane

Figure 4 and Figure 5 show beamwidths of approximately $\pm 40^0$ in the $\phi = 0^0$ plane and $\pm 30^0$ in the $\phi = 90^0$ plane at the mid-point frequency of 6.5 GHz. The patterns are relatively stable over frequency, although in the 9.5GHz result in Figure 4 (at the far upper end of the frequency range), partial nulls can begin to be seen forming in the pattern. These nulls are due to the separation between the patch and the ground plane, which, with the relatively high permittivity values employed, results in equivalent magnetic currents approximately $\lambda/2$ apart, leading to a boresight null at this frequency. Decreasing the separation improves this situation but results in poor feed-antenna matching.

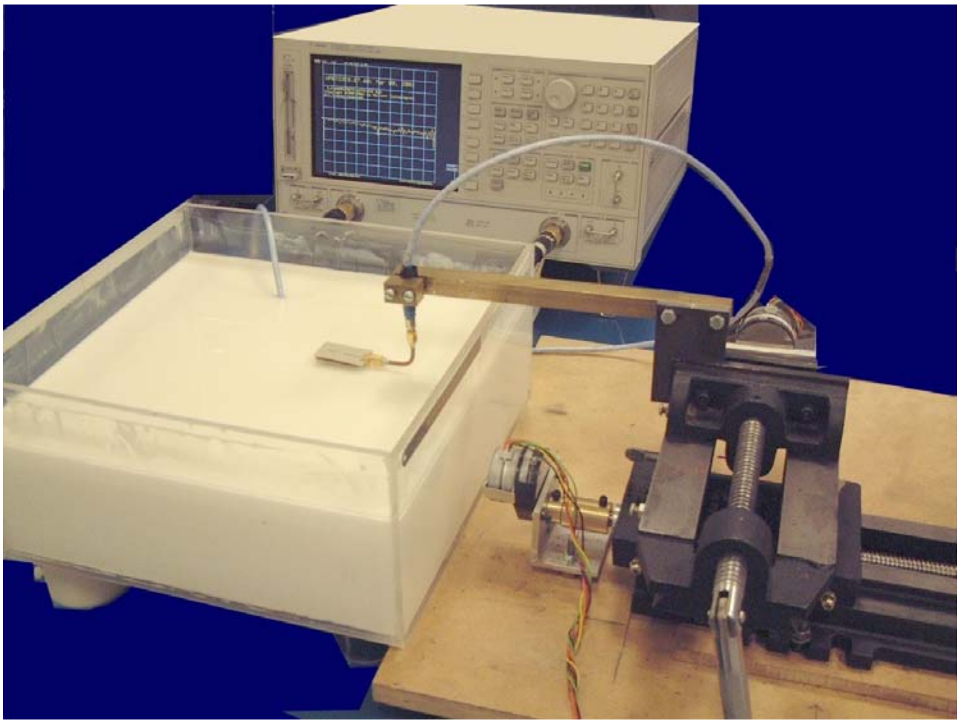


Figure 6 Antenna measurement setup

The radiation characteristics were also measured in a synthetic breast tissue medium [13], where a single antenna was immersed in the medium and a second identical antenna scanned over a horizontal plane at the air-medium interface as shown in Figure 6. This measurement setup includes a stepper motor to control the horizontal movement, Network analyser and a tank containing the synthetic medium. The synthetic breast medium has a relative dielectric constant of approximately 10 over 4 to 10 GHz and the attenuation properties varied from 1 to 3.5dB/cm over this frequency range [13]. Measured patterns at the two principal axes are shown in Figure 7 and Figure 8. Although these measurements were conducted on a plane, rather than on a spherical surface surrounding the test antenna, the patterns clearly demonstrate the radiation properties of the stacked patch antenna.

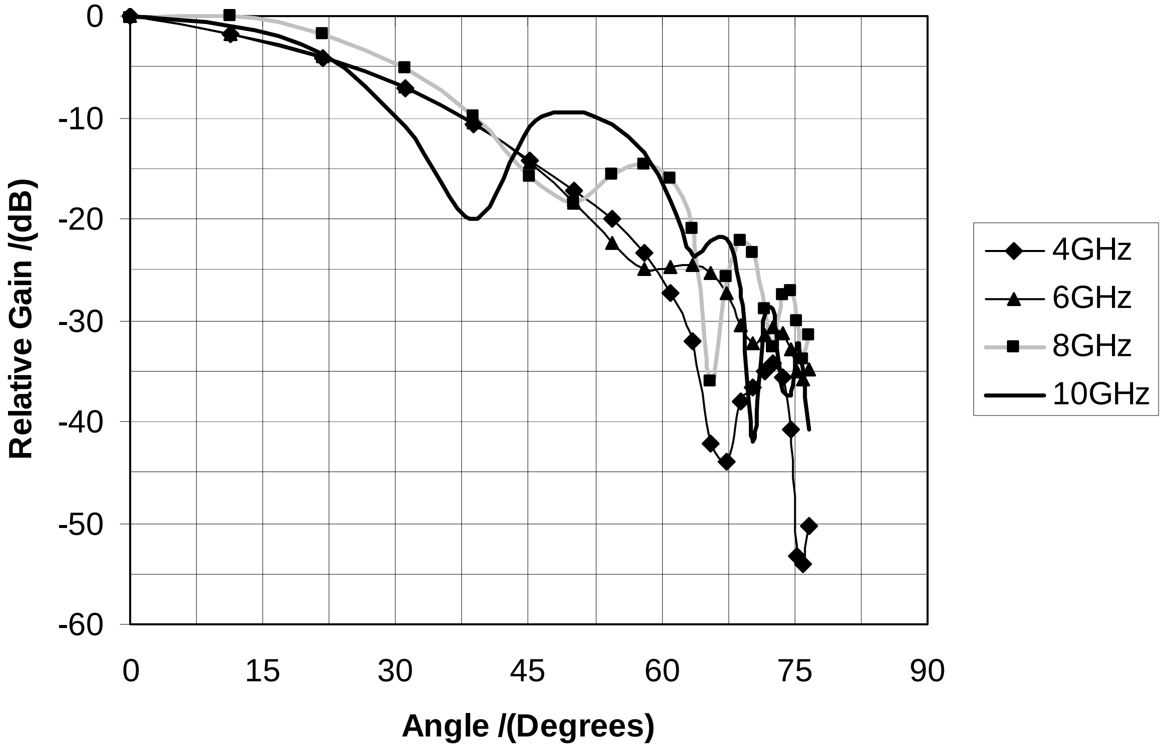


Figure 7 Measured $\phi = 0^0$ plane pattern in synthetic breast medium

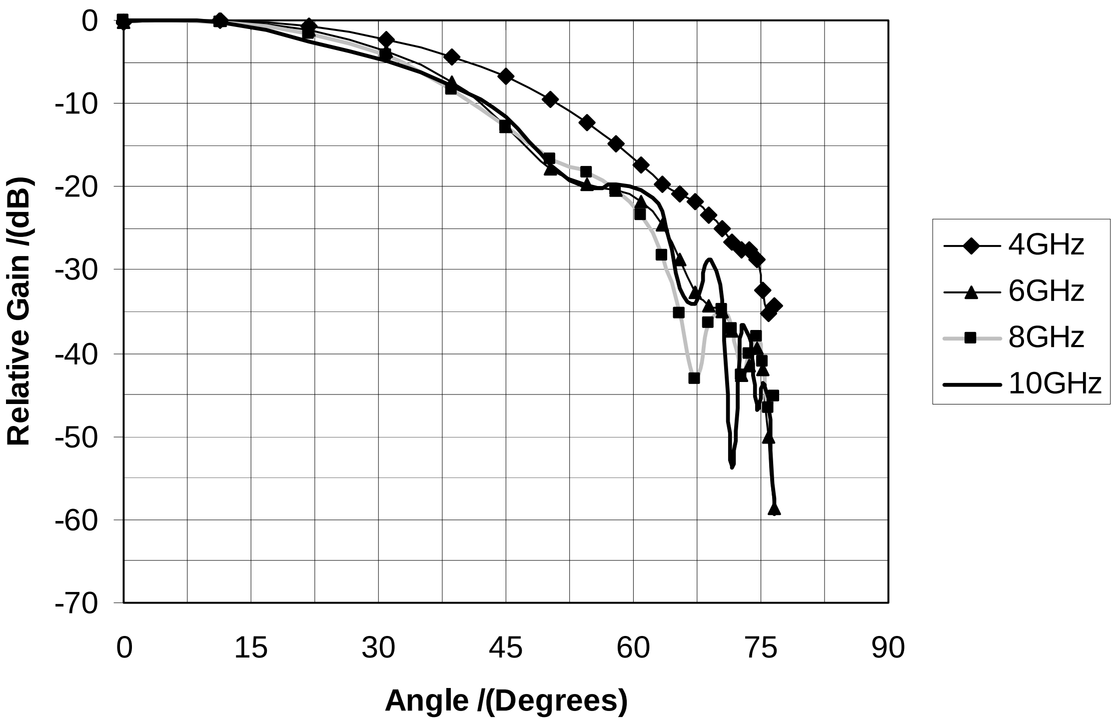


Figure 8 Measured $\phi = 90^0$ plane pattern in synthetic breast medium

The null formation observed in Figure 4 is not seen in Figure 7 because these measurements were conducted on a horizontal plane and hence the radial distance between the antennas was not constant, which, in an attenuating medium, will have a strong affect. Furthermore the experimental measurement was not conducted in the true far-field region. These graphs cannot therefore be directly compared with the earlier FDTD results, however they do confirm the generally-suitable radiation patterns of the antenna. The oscillations in the measured patterns at larger angles and low field levels are believed to be measurement artefacts arising from the imperfect experimental setup, which, amongst other things, was not enclosed in radar absorbing material.

The time domain antenna response was also analysed using FDTD, since time domain performance is important for this type of radar application. The transient fields radiated by the transmitting antenna were calculated at several angular locations in the medium for $\phi = 0^0$ and $\phi = 90^0$ planes are shown in Figure 9 and Figure 10. These radiated signals clearly show the antenna is capable of radiating short pulses with minimal distortion and late-time ringing.

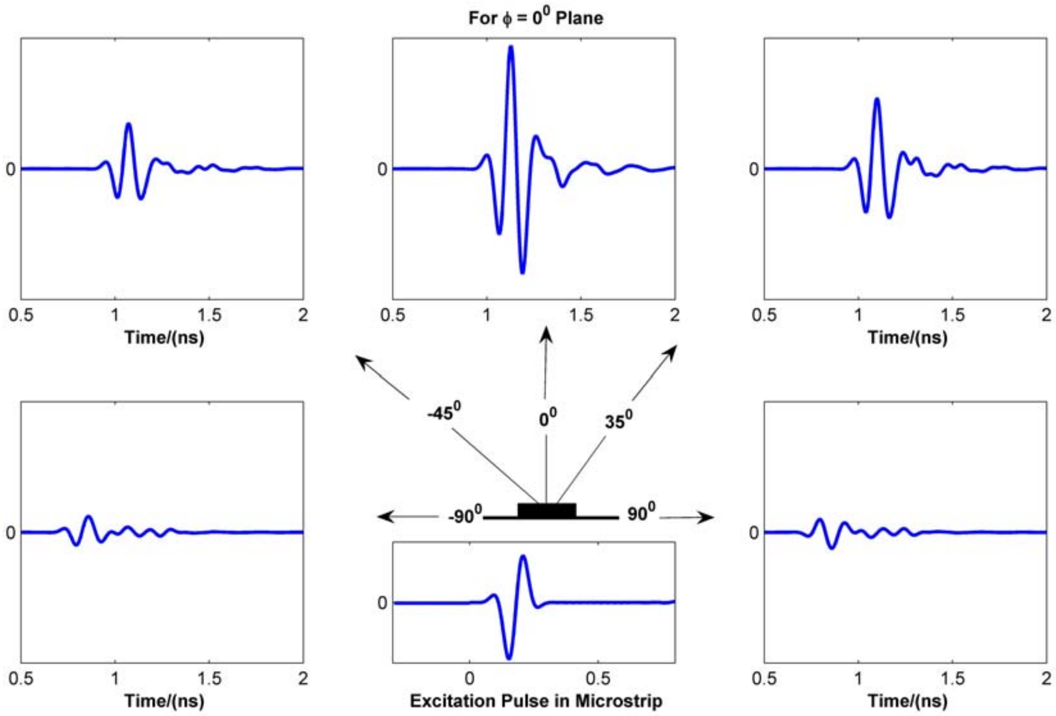


Figure 9 : The calculated Electric field waveforms at 4.5cm from the antenna for $\phi = 0^0$ plane

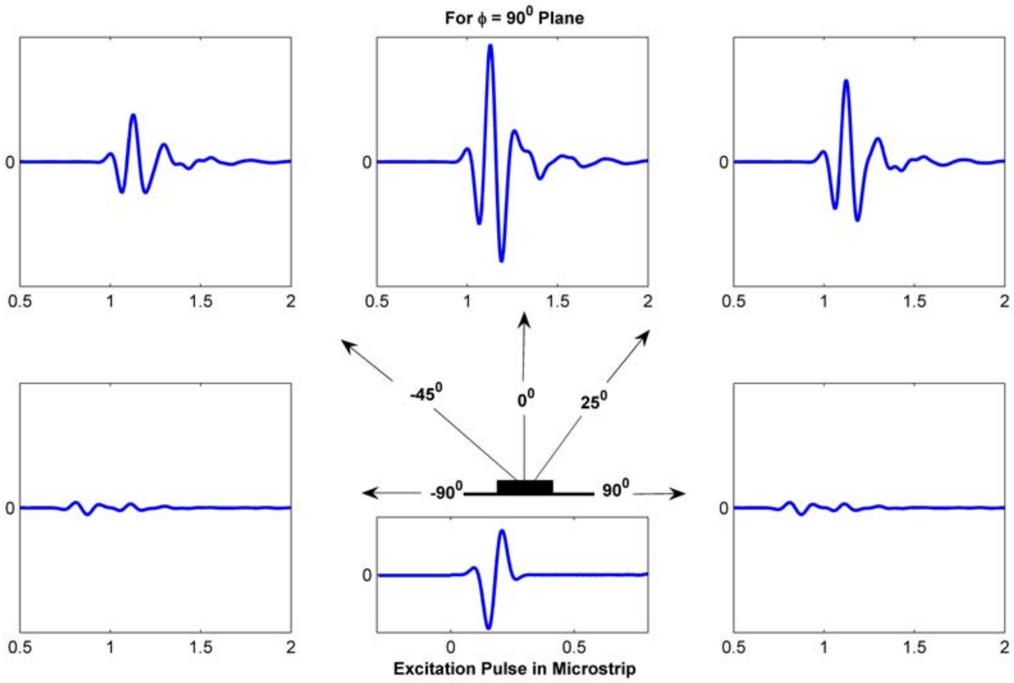


Figure 10 : The calculated Electric field waveforms at 4.5cm from the antenna for $\phi = 90^0$ plane

The stacked patch antenna described is fed through a slot in a ground plane and an obvious concern would be that this slot could also radiate in the unwanted, reverse, direction. The back radiation was therefore compared to the radiation in the desired direction, that is, into the medium, using the existing FDTD model (since an accurate in-medium practical measurement would have been almost impossible to obtain). Signal strengths were compared by integrating the total power radiated in the front and back directions of the antenna at a number of operating frequency, as shown in Table 1.

While an in-medium measurement is impractical, in-air measurements of the front and back field levels were conducted in an anechoic chamber by measuring signal strength levels in the front and back directions (at boresight) as shown in Figure 11. These in-air measurements can only be indicative of the expected performance in the high dielectric medium, since the antenna was not designed for in-air operation, and hence a reduced power level would be expected in the forward direction. Nevertheless Figure 11 shows a 10 to 15dB power difference between the front and back directions, which broadly agrees with the FDTD predictions in Table 2.

Frequency/ (GHz)	4.5	5.5	6.5	8.5	9.5
Power Ratio- Near fields/ (dB)	14.4	18.1	15.2	14.5	11.5

Table 2 Antenna Front to Back Power Ratio

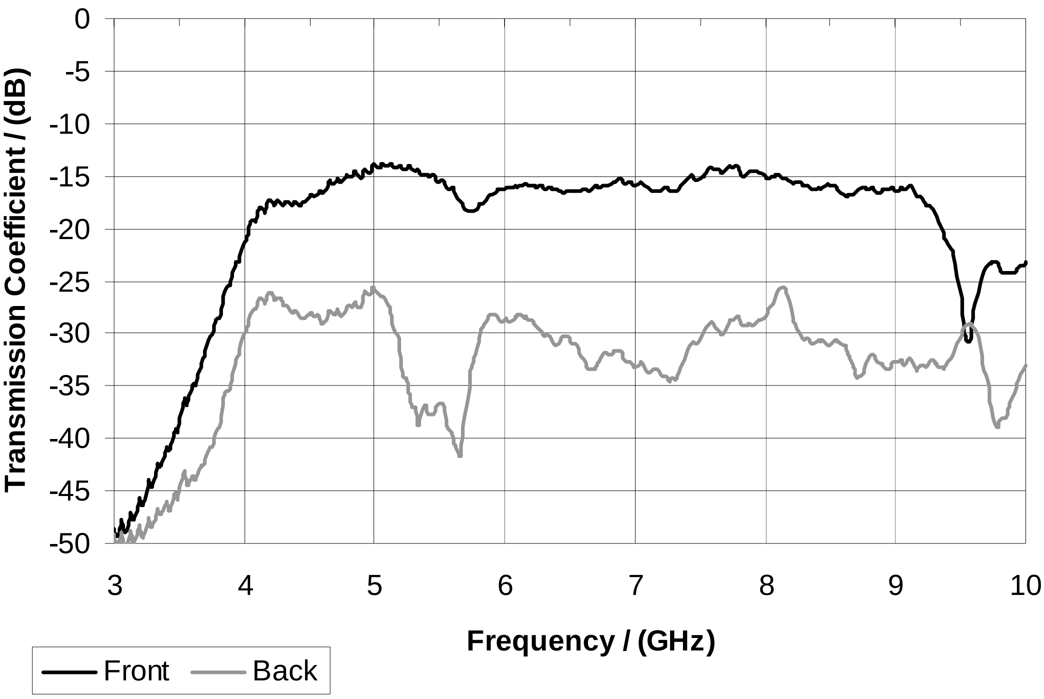


Figure 11 Measured in-air signal strengths in Front and Back directions

Conclusions

A low-profile, wideband stacked patch antenna design for breast tumour detection has been presented. This antenna was designed to radiate directly into a dielectric medium that has similar dielectric properties to breast tissues. It has been shown that this design of the stacked patch antenna produces a bandwidth of approximately 77% and a beamwidth of approximately $\pm 40^0$ in the $\phi = 0^0$ plane and $\pm 30^0$ in the $\phi = 90^0$ plane at 6.5 GHz, calculated using FDTD in a $\varepsilon_r = 9.8$ medium. Measured radiation characteristics in a synthetic dielectric medium have also been presented and these broadly confirm the calculated pattern characteristics of the antenna. The time-domain characterization of the antenna is also presented and indicates that this antenna is suitable for the short pulse radar application considered here.

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