A Method for 3D Breast Cancer Imaging using Microwave Holography

#D. Smith (1), M. Elsdon(1), M. Leach(1), M. FDO (1), S. J. Foti (2)

(1) *School of Engineering and Technology*
Northumbria University
Newcastle upon Tyne, NE1 8ST, UK
(david.smith@unn.ac.uk):
(2)*Pele Cottage, Wingates, Longhorsley*
Morpeth, NE65 8RW, UK

Abstract

This work describes a technique which has been developed for the detection and imaging of breast cancer tumours. It describes how 3D images can be reconstructed from 2D scalar intensity patterns, or holograms.

An outline of the background theory in described followed by experimental results on paraffin wax breast phantoms

Results demonstrate that this technique is capable of determining the location and extent of the simulated tumours within the breast phantom.

1. INTRODUCTION

The use of microwaves for imaging purposes is currently receiving much attention for a variety of applications.

In the medical area the ability of microwaves to penetrate to considerable depths beneath the skin in a non-ionising safe manner coupled with the large differences in material properties between healthy and malignant tissues has also stimulated much research interest. [1]

The work described here has investigated an approach which focuses upon using an indirect holographic technique for imaging applications. It starts by outlining how 3D images can be obtained from indirect holographic measurements before presenting results on simple breast phantoms containing a simulated tumour. Results are presented showing how single frequency holography can provide an image of the tumour outline. The paper concludes with the description of a proposed technique for reconstructing 3D images from simple holographic intensity patterns.

2. THEORY

Indirect microwave holography differs from direct holography in that only scalar quantities are measured. In direct holography the complex fields scattered by the object to be imaged, E(x,y), are recorded, normally using a vector network analyser. A reconstructed image of the original object can then be obtained from this complex field by techniques such as the back propagation algorithm. [1]

In indirect holography the recorded quantity is the scalar intensity pattern, I(x,y), formed by combining the complex field scattered by the object, $E_s(x,y)$, with a coherently generated reference wave, $E_r(x,y)$. The simplest form of reference wave is a plane wave. In order to obtain an unobscurred image of the object this reference wave is required to have a linear phase shift across the measurement aperture. If this plane wave is introduced along the x-direction the reference signal is of the form

$$E_r(x,y) \quad = \quad E_0 e^{-jk_x x} \tag{1}$$

At optical frequencies this form of reference wave can be obtained by introducing a radiated reference signal at an offset angle to the scattered signal. [2]

At microwave frequencies it proves difficult to obtain a radiated planar reference signal with a linear phase shift. To overcome this problem an alternative approach has been adopted in this work. A synthesised reference wave is derived from the source used to illuminate the object in a manner which enables both the amplitude and the phase of this signal to be closely controlled.

The resultant 2D intensity pattern, I(x,y), formed by combining the two signals, $E_s(x,y)$, and $E_r(x,y)$, is the measured quantity

$$
\begin{aligned}
I(x,y) &= \left|Es(x,y) + Er(x,y)\right|^2 \\
&= \left|Es(x,y)\right|^2 + \left|Er(x,y)\right|^2 + Es^*(x,y).Er(x,y) + Es(x,y).Er^*(x,y)
\end{aligned}
\tag{2}
$$

where $E_s^*(x,y)$ indicates the complex conjugate and

$$
E_r^*(x,y) = E_0 e^{+jk_x x} \tag{3}
$$

Taking the Fourier Transform of Equation (2) produces a pattern in the spatial frequency domain

$$
\begin{aligned}
F\{I(x,y)\} &= F\left\{\left|Es(x,y)\right|^2\right\} + F\left\{\left|Er(x,y)\right|^2\right\} \\
&\quad + F\left\{Es^*(x,y)\right\} \otimes F\{Er(x,y)\} + F\{Es(x,y)\} \otimes F\left\{Er^*(x,y)\right\}
\end{aligned}
\tag{4}
$$

The effect of the linear phase shift is to move the third and fourth terms of Equation (4) by $-k_x$ and $+k_x$ respectively from the central terms. Provided that the spatial frequency extent of the scattered signal is limited the third of fourth term can be separated from the remainder of the pattern. [4] In this case the unwanted terms can be filtered off and the wanted term centralised to give

$$
F'\{((x,y)\} = E_0.F\{Es(x,y)\} \tag{5}
$$

Taking the Inverse Fourier Transform gives us

$$
G\{F'\{I(x,y)\}\} = E_0.Es(x,y) \tag{6}
$$

providing us with the original scattered field of the object at the measurement plane, z = 0.

Having obtained the complex field from a simple intensity measurement we can now obtain a reconstructed image of the original object by adopting a similar approach to that used in direct holography. [5]

Equation (5) provides the plane wave spectrum, PWS, of the original object which can be back propagated through a selected distance, z = -d, to provide an image of the object. [4]

$$
\begin{aligned}
&E(x, y, z = -d) \\
&= \frac{1}{2\pi} \iint E_0.F\{Es(x,y)\}.e^{jkz.d}\, e^{-j(kx.x + ky.y)}\, dkx.dky
\end{aligned}
\tag{7}
$$

Using this approach images can be produced at any selected distance.

3. EXPERIMENTAL RESULTS

An outline of the basic arrangement used for indirect holography is shown in Figure 1

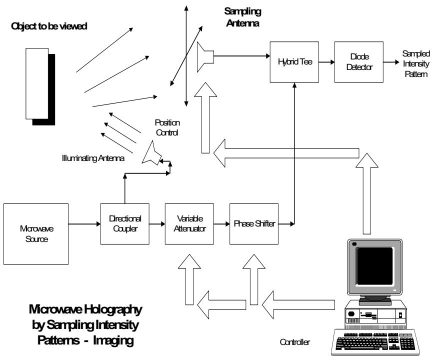

Figure 1 Indirect holographic layout

For general imaging applications the output of the microwave source is split into two coherent parts by the directional coupler. One part of this signal is used to illuminate the object to be imaged, the second part of this signal is used to provide the reference signal. The required form of reference wave, constant amplitude and linearly increasing phase shift can be provided using the phase shifter and variable attenuator.

The signal scattered from the object is picked up by a small probing antenna which can be moved across the scanning aperture. The holographic interference pattern is formed by the combination of the scattered signal and reference signal at the output of the hybrid tee. The intensity of the resultant output signal is recorded using a diode detector or power meter. For the particular case of breast cancer imaging an oil bath immersion system has been utilised, similar to that adopted by other workers in this area. [1] This arrangement significantly reduces the reflection at the air-skin interface. A photograph of the imaging system is shown in Figure 2.

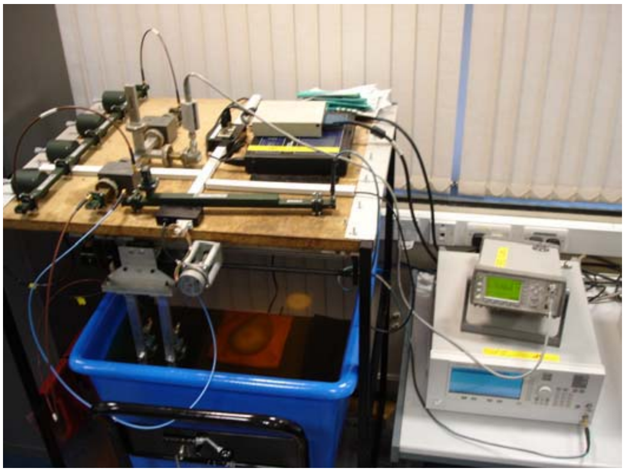

Figure 2 View of Experimental Holographic System

This arrangement allows us to position the antennas above the breast phantom and scan over a 40cm x 40cm rectangular aperture. A crude paraffin wax breast phantom of approximate dimensions, 12cm x 12cm x 8cm, was constructed as shown in Figure 3

Figure 3 Paraffin wax breast phantom

Within the paraffin wax phantom was embedded a simulated tumour consisting of an approx. 4cm dia. Sphere of high dielectric material. The arrangement adopted for holographic imaging is shown in Figure 4 with, $\varepsilon_1 = 13$, $\varepsilon_2 = 2.2$, $\varepsilon_3 = 2.3$. The height of the antenna above the breast phantom was, h = 12cm, with d_1 = 4cm and d_2 = 8cm.

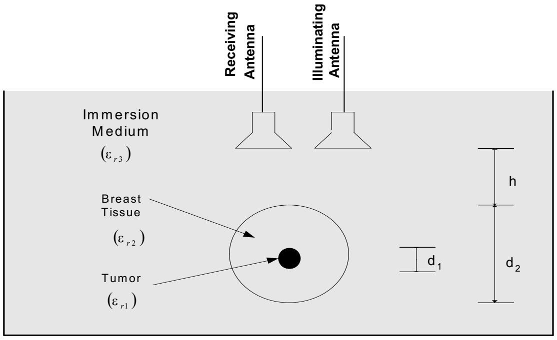

Figure 4 Holographic Imaging layout

Experimental results have been taken at a frequency of 10GHz. at sample spacing $\lambda/2$ in oil with 120° phase shift applied in the x direction between samples.

A sample recorded holographic intensity pattern is shown in Figure 5.

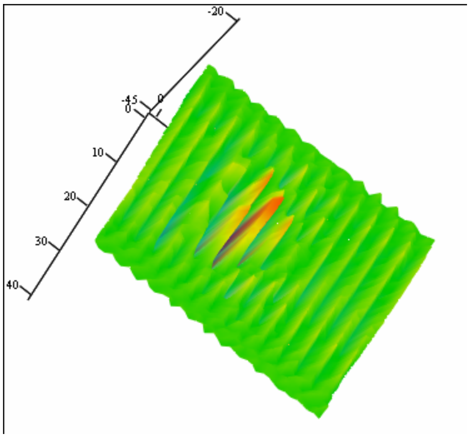

Figure 5 Holographic interference pattern

The linearly varying phase is apparent from the undulating nature of this pattern.

Following the theory outlined in sections 2. this intensity pattern can be Fourier Transformed to give a pattern in the spatial frequency domain as shown in Figure 6

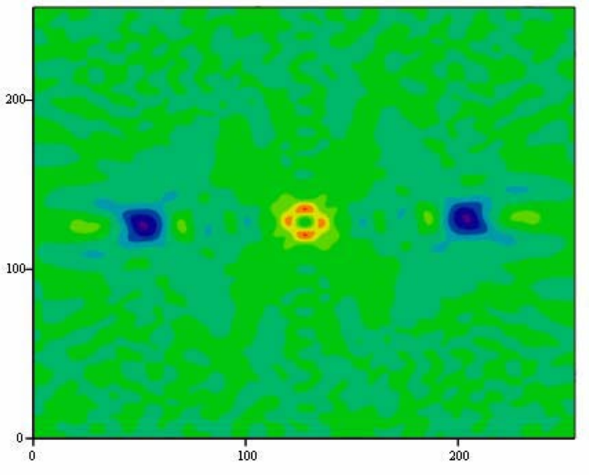

Figure 6 Spatial Frequency pattern of hologram

It was previously stated that a requirement to produce a good image was the ability to separate the outer terms of the spatial frequency pattern from the central terms. Examination of figure 6 shows that the outer terms in this pattern are well separated.

By filtering this pattern and performing an Inverse Fourier Transform with back projection an image of the simulated tumour can be obtained as shown in Figure 7

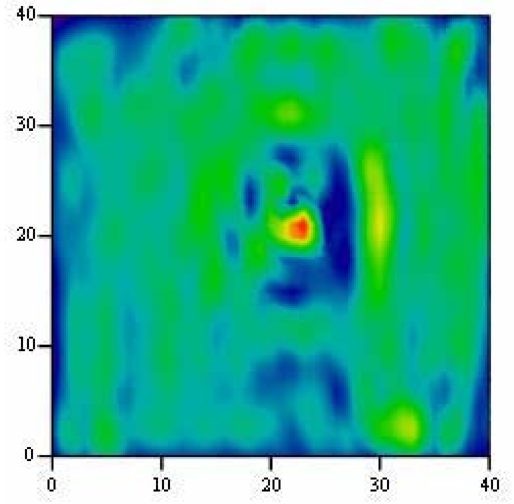

Figure 7 Reconstructed image of concealed tumour

Within this work it is recognised that the use of a single frequency CW signal restricts the ability of this technique to provide good spatial resolution in the third dimension, in this case along the z-axis. A method of overcoming this limitation has recently been proposed. This relies upon the use of stereoscopic holographic imaging. Two orthogonal holograms of the same image are taken and processed as described above. By varying the distance selected for back propagation mage slices can be taken building up an image cube for each of these holograms. These can then be combined to produce a 3D image of the original object.

As a test of this procedure results have been taken using a 5cm dielectric cube as a test object as shown in Figure 8.

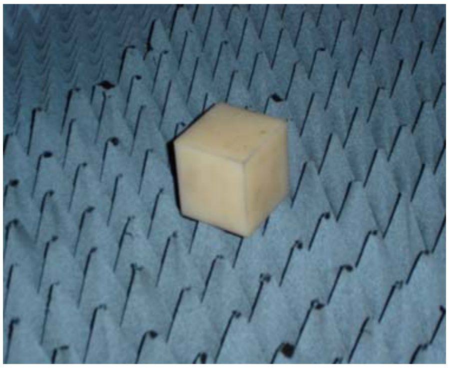

Figure 8 Dielectric Cube for Stereo Imaging

A view of one recorded holographic pattern for the dielectric cube is shown in Figure 9

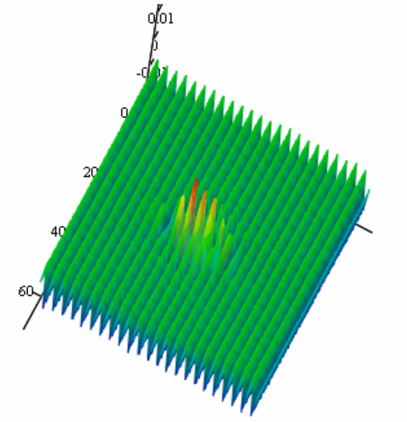

Figure 9 Hologram of Cube

By combining data from both orthogonal holograms a cube of data can be constructed for imaging the original object. Slices through this cube are as shown in Figure 9

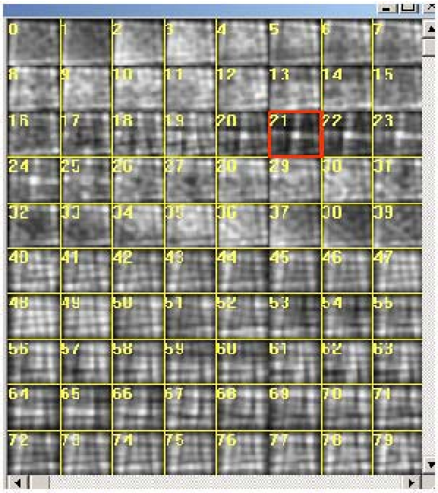

Figure 9 Reconstructed slices through cube

As a final stage in image reconstruction these slices can be gathered together to produce a 3D reconstructed image as shown in Figure 10.

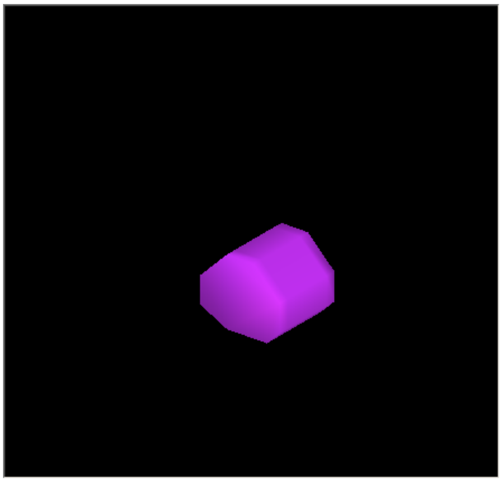

Figure 10 Reconstructed 3D image of cube

4. CONCLUSIONS

This work has outlined how an indirect holographic approach can be applied to breast cancer detection and imaging. An advantage of this technique is that only simple intensity measurements are required. Results on simple breast phantoms have shown that this technique is capable of locating as simulated tumour buried within a breast phantom. Recent work has also shown how the limited resolution in one dimension which results from single frequency operation can be overcome.

ACKNOWLEDGEMENT

The authors of this work acknowledge the support given by Wellcome Trust and EPRSC in carrying out elements of this work.)

REFERENCES

[1] E. C. Fear and M. A. Stuchly, “Microwave system for breast tumour detection”, IEEE Microwave Guided Wave Lett., vol. 9, pp 470 – 472, Nov. 1999

[2] Y. Rahmat-Samii, L. I. Williams, R. G. Yaccarino, “The UCLA Bi-Polar Planar Near-Field Antenna Measurement and Diagnostic Range”, *IEEE Antennas Propagat. Mag.*, vol. 37, No. 6, pp16 – 35, Dec. 1995.

[3] E. N. Leith and J. Upatnieks, ‘Microscopy By Wavefront Reconstruction’, *Journal Of The Optical Society Of America*, Vol. 55, No. 5, 1965, pp. 569-570.

[4] D. Smith, M. Leach, A. J. Sambell, “An Indirect Holographic Method for Determining Antenna Radiation Patterns and Imaging Antenna Fields”, IEEE Symposium 2002, June 16 – 21, San Antonio, Texas, USA 2002.

[5] D. Smith, M. Leach, M.Elsdon, M. J. Fernando, S. J. Foti, “Imaging of Dielectric Objects from Phase patterns Reconstructed using Indirect Holographic Intensity Patterns”, ICEAA-EESC’05, Turin, Italy, Sept. 2005.