TEMPERATURE AND PERMITTIVITY MEASUREMENTS USING A CYLINDRICAL MICROWAVE IMAGING SYSTEM

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ABSTRACT

The capabilities of a cylindrical imaging system used in remote thermal sensing and dielectric constant measurements are investigated. The paper presents simulations of absolute and differential reconstructions of bodies within the Born approximation and of stronger diffracting objects. In addition a preliminary experiment is presented.

INTRODUCTION

The potential use of linear and planar imaging systems for non invasive permittivity measurements has been analyzed in some papers [1][2]. The temperature dependence of the permittivity of biological tissues can be used to obtain a differential thermal mapping of bodies. This feature makes active imaging systems attractive for medical diagnosis and control of hyperthermia treatments. Some temperature measurements using planar geometries have been published [3].

A cylindrical system for microwave tomography working at 2.45 GHz has been presented [4]. In this set-up, the body, immersed in water, is illuminated with a cylindrical wave and the measured scattered fields are processed by an algorithm for cylindrical geometries, using the Born approximation to reconstruct a cut of the object [5].

In this paper the use of a cylindrical system for measuring the absolute value of a weakly scattering body permittivity is investigated. Moreover, its ability to sense small local temperature changes inside low and high contrast objects is shown. The limitations of the reconstruction procedure are evidenced by numerical simulations and encouraging experimental results of thermal sensing, using differential imaging, are presented.

NUMERICAL SIMULATIONS

The simulations present several two-dimensional reconstructions using exact scattered fields, obtained under the same conditions prevailing in the cylindrical system, that is a 64 element circular array, 20 cm in diameter, working at 2.45 GHz. The scattered fields produced by concentric dielectric cylinders have been analytically calculated [6].

To assess the validity of the algorithm, a test on a cylindrical weakly scattering object was performed, giving a successful reconstruction of its permittivity and geometry. By subtracting two reconstructions with parts of the body at different temperatures, a differential image showing the thermal increment is obtained.

A more realistic approach would be to apply the same procedure to strong diffracting bodies, where the Born approximation is not valid. Fig.1 shows a simplified phantom model of a human head, consisting of a 15 cm diameter homogeneous cylinder of brain tissue at 37°C, surrounded by a 5 mm thick bone wall. The magnitude of an absolute reconstruction of the object defined as $O(r)= 1-\varepsilon(r)/\varepsilon_0$ is shown in Fig.2. The image does not represent

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the absolute permittivity, because the Born approximation does not apply to this case. Thermal changes in an internal area of the brain could be simulated if the permittivity dependence with temperature was known, but unfortunetely only limited data are available. Some measurements have shown temperature sensitivities of the same order of magnitude than water |3|. For that reason, water sensitivity has been used in imaging local temperature changes on the previous head phantom. Several 1 cm wide rings of different diameters were heated at 39° C and reconstructed. The profile of the differential images (Fig.2) shows clearly the heated area, although the sensitivity of the image to permittivity changes, varies with position depending on the characteristics of the object.

EXPERIMENTAL RESULTS

A basic experiment to estimate the temperature sensitivity on a practical system, conditioned to its engineering limitations, has been carried out. Fig. 3 illustrates the set-up, showing a thin plastic tube, 1 mm thick and 8 mm internal diameter, placed along the array axis. Water from an external temperature regulated tank is pumped through the tube, while the surrounding water is maintained at 26° C.

Fig. 4 shows the differential reconstructions corresponding to three temperature changes. The images are obtained by processing the difference of the total fields produced by the object at temperatures To and T. This is equivalent to subtracting the images, given the linearity of the algorithm. The numerical values of the reconstructions and the temperature changes are found to be linearly related.

CONCLUSIONS

In this work the possibilities of using cylindrical systems in absolute and differential imaging are explored. The obtention of quantitative images is limited at present to weakly scattering objects, although theoretical work is being conducted to overcome this limitation. Differential imaging seems to give the correct shape of the incremental object, but the relationship between quqntitative values of the image and permittivity changes is not straightforward, more work will be necessary to know the real limitations of this technique.

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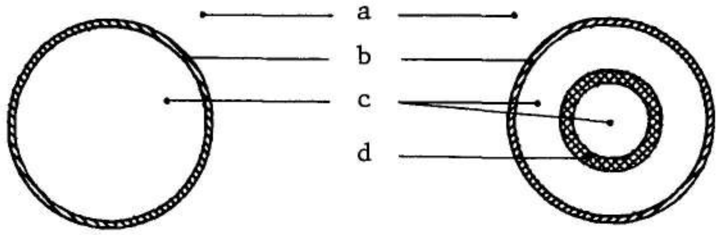


a- water at 37° C $\varepsilon = 73.5 - j6.51$
b- bone $\varepsilon = 4.51 - j0.84$
c- brain at 37° C $\varepsilon = 33.56 - j9.3$
d- brain at 39° C $\varepsilon = 33.22 - j8.92$

Fig. 1. Reference and heated human head phantoms

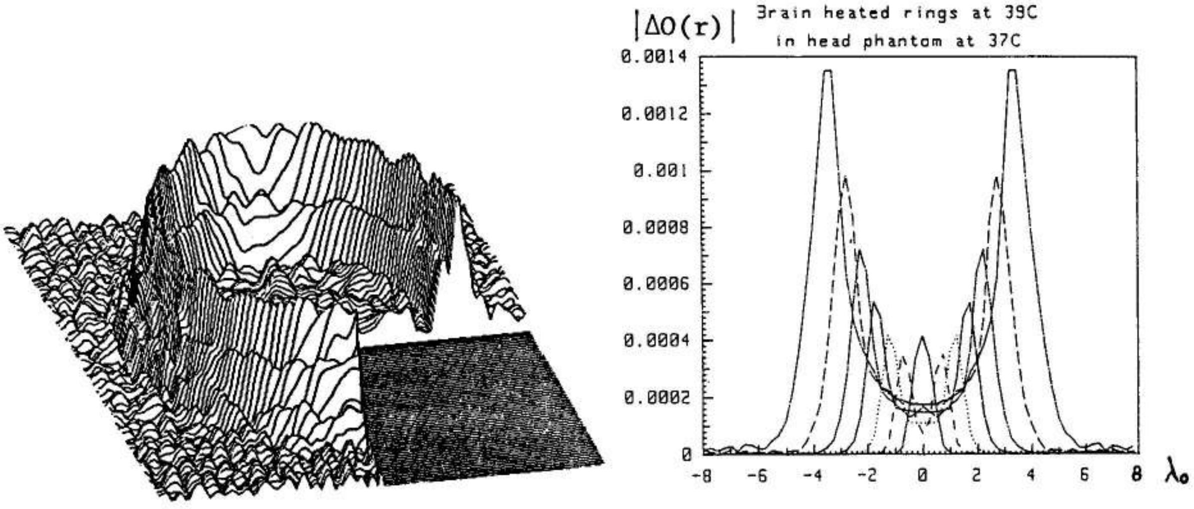


Fig. 2. Absolute reconstruction and differential reconstruction profiles
Actual value $|\Delta O|(39C) = 6.9\ 10^{-3}$

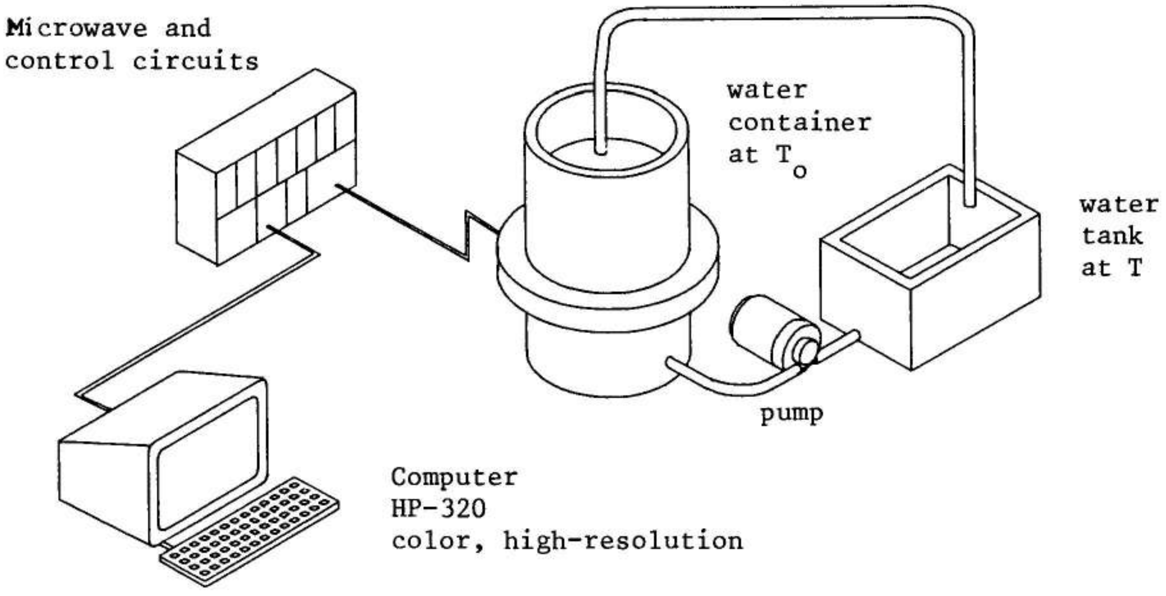
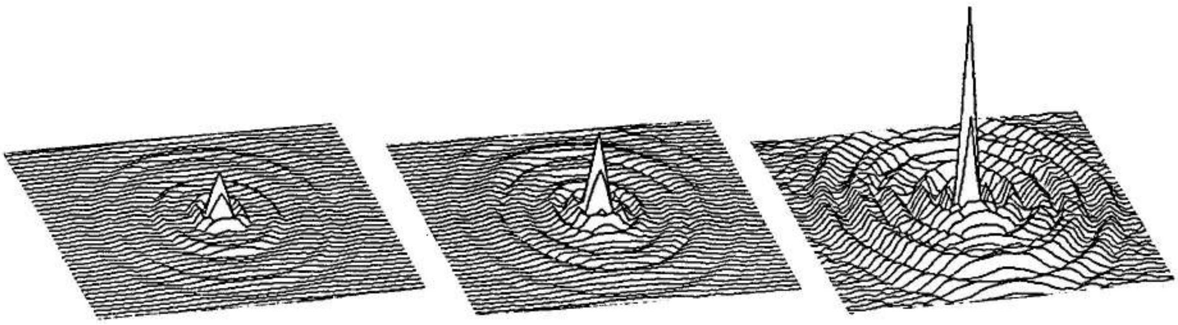


Fig. 3 Experimental set-up for cylindrical
tomography at f= 2.45 GHz.



$T-T_o=2^o$ C $T-T_o=4^o$ C $T-T_o=8^o$ C

Fig. 4 Differential temperature measurements