A THREE-BAND ANTENNA FOR MICROWAVE RADIOMETRY OF BREAST

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INTRODUCTION

Currently, self-examination and regular mammography are the most effective techniques for detecting breast cancer. Mammography reveals occult malignant lesions in asymptomatic women at an earlier stage and in smaller lesions. Despite the value of mammography in revealing breast malignancies, most radiographically identified lesions are ultimately found to be benign on histologic assessment after biopsy. Breast biopsy costs however are important, thus noninvasive methods are needed to aid clinicians in distinguishing benign from malignant breast tissue. Imaging techniques used in conjunction with mammography and physical examination often include ultrasound, CT and MR imaging. Although promising, CT and MR imaging are generally considered too costly for routine use and have other drawbacks. Like mammography, ultrasound imaging relies on the expertise of the technician and the interpretative skills of the radiologist. Promising modalities for aiding clinicians in differentiating malignant from benign breast lesions are classified under electromagnetic non ionising radiation imaging.

Using non ionising electromagnetic radiation for cancer detection in humans has attracted many researchers in the last 25 years. An electromagnetic imaging method can be active or passive. In an active system, one or more antennas radiate onto the body, where the electromagnetic field is scattered by tissue dielectric inhomogeneities and then received by the same or other antennas. In multifrequency active imaging, data are collected at various frequencies and for various locations of the antennas outside the body [1], [2]. Field data are known terms in the inverse scattering problem, whose solution attempts a retrieval of the contrast of an eventual dielectric anomaly with respect to the background permittivity of healthy tissues. Time-domain systems, instead, exploit higher frequencies and wide-band antennas showing some similarity to ground penetrating radar [3], [4]. An anomalous tissue permittivity may be significant of a malignancy.

Passive imaging include infrared and microwave radiometry methods. Both methods detect physiologic tissue response, rather than evaluating anatomic dielectric features. Indeed heat is released from the body on the whole electromagnetic spectrum with a maximum at infrared frequencies. Several physiologic features related to malignant tissue may contribute to the infrared signal, including increased blood flow in the area surrounding a malignancy, angiogenesis, and the release of vasoactive mediators. The infrared imaging system uses a camera that is highly sensitive to infrared radiation in the appropriate spectrum. Computerized systems are designed to show that benign tissue can be differentiated from neoplastic tissue on the basis of the relatively higher strength of the infrared signal in malignant tissue.

Microwave radiometry is based on the measurement of the electromagnetic field spontaneously emitted by a body in the microwave frequency range [5]- [8]. Charged particles in motion are primary sources of incoherent thermal radiation propagating inside the body, where it is partially absorbed and partially irradiated externally. Antennas, located close to or contacting the body collect and transduce the radiation to an electrical current that fluctuates in the receiver's input unit. If we assume the body in local thermodynamic equilibrium, the spectral content of the radiometric signal can be related to the local temperature distribution in the body, allowing its retrieval to be attempted from radiometric data collected at different frequencies and for various antenna positions. A thermal anomaly may be significant of a tumour.

The recently renewed interest in active and passive methods can be explained on the basis of the improved performances of both microwave devices and computer modelling of complex systems [9].

The breast can be considered of possibly larger success than other suggested targets with respect to the early diagnosis problem, because of a larger dielectric contrast between healthy and malignant tissue, a larger penetration depth and accessible location to an external sounding radiation. It allows comparisons between even organs as far as temperature anomalies are explored.

This paper proposes a new multiprobe integrated antenna system for microwave breast radiometry having low profile and able to collect seven independent measures within an area of about 40cm^2. The antennas are arranged in a daisy geometry which permits additional data acquisition by means of a rotation of the system around its centre.

DESCRIPTION OF THE ANTENNA

The proposed multiprobe antenna is allocated according to a circular layout where three 2.6 GHz planar antennas are alternated to 3.5GHz ones having scaled shape (Fig.1). The basic probe is derived from a $\lambda/4$ patch which is shaped to fit a sliced frame. This geometry has been preferred to a standard $\lambda/2$ patch not only for miniaturization purpose, but also to achieve a single-slot receiving mode which yields a well defined sensing spot and therefore enhances the horizontal spatial resolution. The short-circuit at the smaller side of each patch is obtained by a line of posts, while an open-circuit stub is added to tune the resonant frequency and to improve the 50 ohm impedance matching. Antennas are 30° spaced in order to reduce the interaction among contiguous antennas which could deteriorate the transverse resolution.

A circular patch is finally placed within the inner empty space of the multiprobe area. A consistent size reduction and tuning to 1.4 GHz is achieved by means of a shorting pin and three notches yelding a meandered profile.

The antenna layout is sustained by a dielectric substrate having permittivity ε_r=2.6 and thickness 1.6mm. A bolus layer (ε_r=10; σ=0.001 S/m; h=3mm) between patches and tissue permits mechanical and electrical matching to the breast.

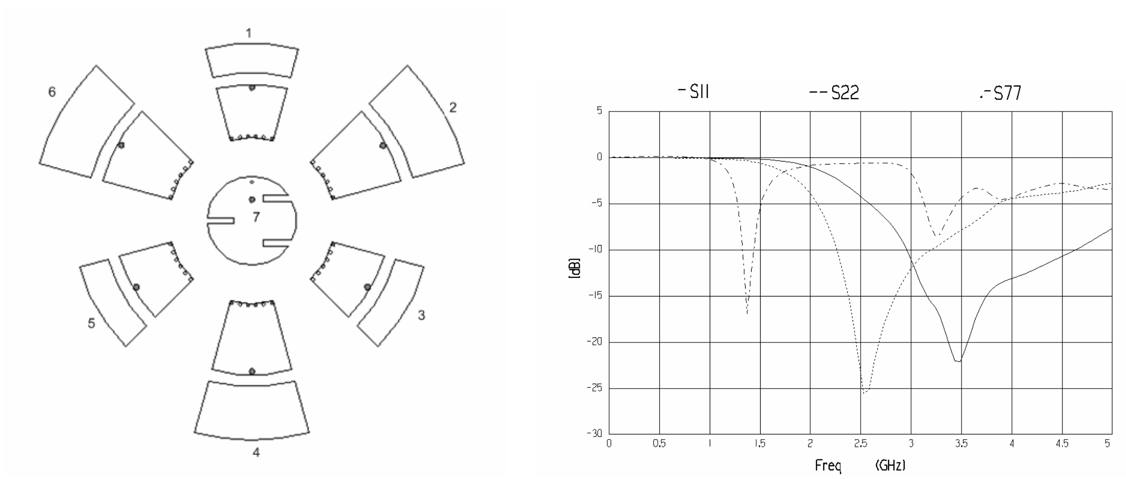


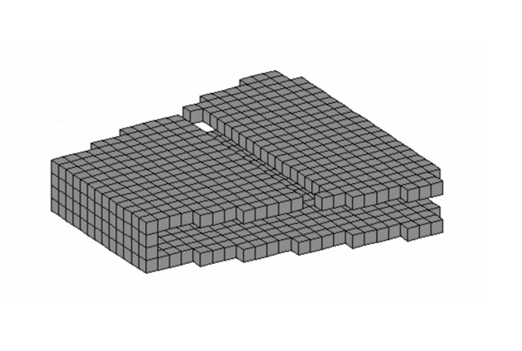
Fig.1: Layout of the multiprobe daisy antenna and amplitude of the S_{jj} scattering parameters

The system is able to collect seven independent measures within an area of about 40cm^2. Additional data can be obtained by a 30° rotation of the antenna around its centre.

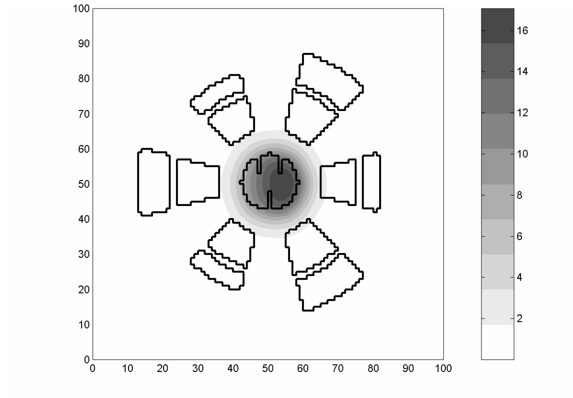
The multiprobe system has been simulated by the Finite-Difference Time-Domain method, where the breast is modelled as an homogeneous half-space. The performance indicator for radiometric application is the *Weighting Function* $W(\underline{r}',f_n)$ at the f_n frequency, e.g. the normalized power density absorbed by tissues when the antennas work in transmitting mode. The radiometric signal g is related to the body temperature and to the weighting function itself by the equation

$$g(f_n) = \int_{body} W(\underline{r}', f_n) T(\underline{r}') dr' \qquad (1)$$

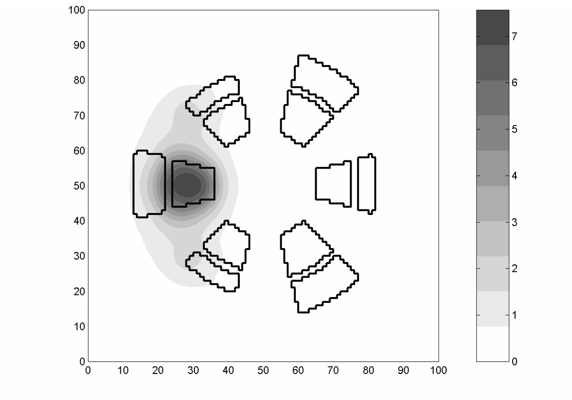
The computed values of the weighting function are shown in Fig.2. It can be appreciated that, in spite of the small inter-antenna spacing, the weighting function at a distance of 8mm from the breast-bolus boundary is rather concentrated in front of the radiating slots at all the three frequencies. The sensibility of the antennas versus depth in the breast has been investigate by evaluating the percentage of the weighting function in a spherical malignant tissue placed at increasing distance from the multiprobe antenna (Fig.3).



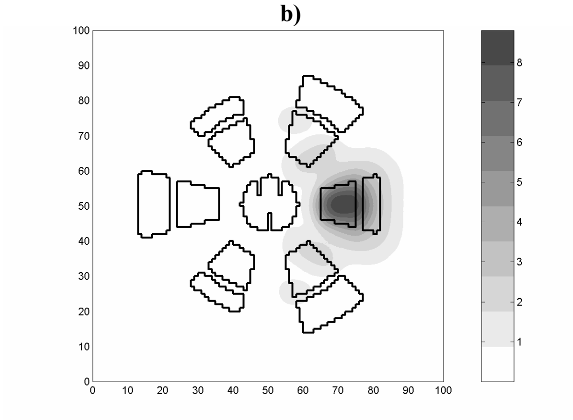
a)



b)



c)



d)

Fig.2 : a) FDTD model of a λ/4 slice patch; computed weighting functions in a uniform breast model at 8mm from the skin at (b) 1.4GHz, (c) 2.6GHz, and (d) 3.5GHz. Greyscales represent weighting functions in arbitrary scale.

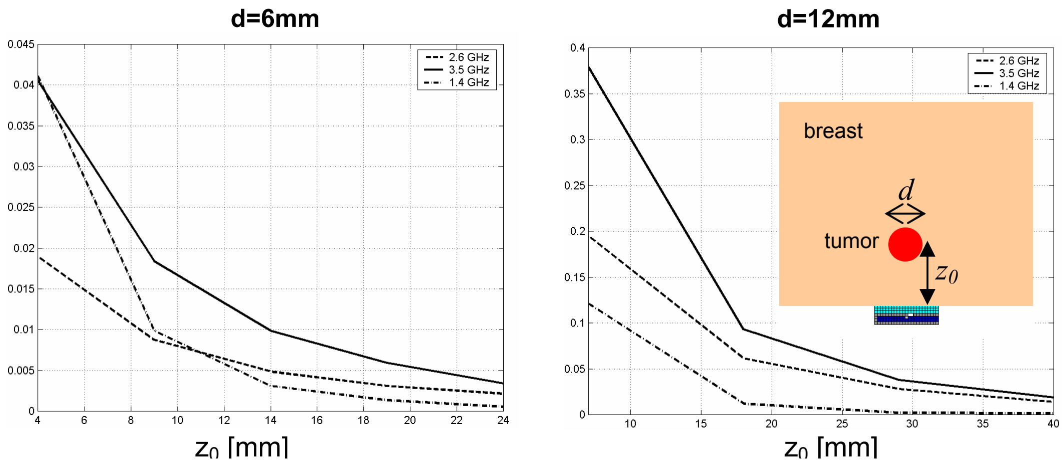
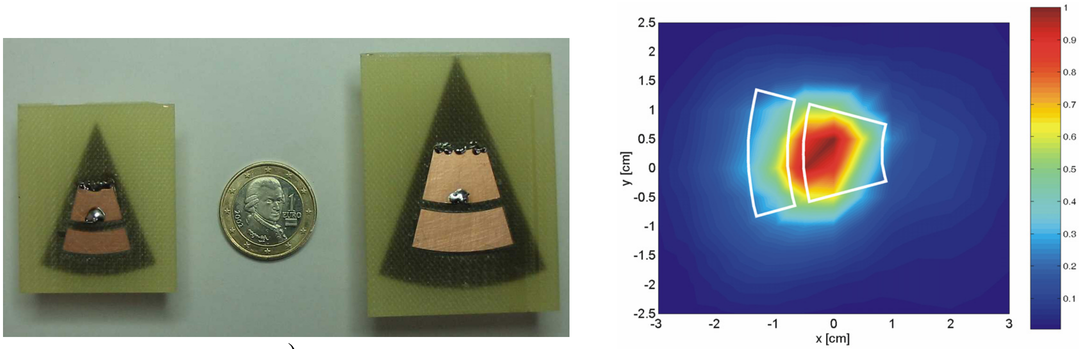


Fig.3 : Percentage of the weighting function in two model of spherical malignant tissue placed at increasing distance from the antennas.

PROTOTYPES AND PRELIMINARY MEASUREMENTS

The performances of two prototype sub-antennas (Fig.4a) have been measured by an experimental set-up comprising a semi-liquid phantom obtained with paraffin oil emulsion, simulating the breast permittivity, and hosted within a cylindrical perspex shell (11cm X 9cm). The electric field has been measured by an isotropic probe. Preliminary measurements of the weighting functions show (Fig.4b) a well localized spot, right under the antenna slot, in reasonable agreement with the simulated results.



a) b)

Fig.4 : Prototypes of the λ/4 slice patches and measured weighting function in a liquid breast phantom. 1.8mm from the air interface

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