

QUANTITATIVE MICROWAVE BREAST PHANTOM IMAGING USING A PLANAR 2.45 GHz SYSTEM

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ABSTRACT

Breast cancer is a global health problem, needing cheap and effective alternative diagnosis methods in order to minimize the mortality. This experimental study is performed in the context of an ongoing collaborative project towards a future planar three-dimensional microwave breast mammography system. Herein the first quantitative image of an inhomogeneous breast tumor phantom, composed by different Triton X-100/water/salt mixtures, is obtained by using the existing planar 2.45 GHz microwave camera.

1 INTRODUCTION

Breast cancer is by far the most frequently diagnosed cancer among women, on a world wide basis [1]. In 2002 1.15 million cases was diagnosed, where 411,000 cases lead to mortality, and those numbers are expected to increase even further in the future. This motivates many groups to search alternative diagnosis methods in order to find the tumor in an early stage and minimize the mortality [2]. Microwave imaging have a potential as an alternative diagnosis modality while the contrast in dielectric properties between the tumor and normal breast tissues is expected between 1.5:1 and 5:1 [3]. Many groups already have showed promising results [2,3], where both radar based [3] and inversed scattering algorithms [2] have been used.

Our work is motivated by the realization of a new planar three-dimensional microwave mammography system which could be an extended version of the existing planar 2.45 GHz microwave camera, at DRE/Supélec. The planar camera was developed in the beginning of the 80's and has later been modified for real-time qualitative imaging with 24 images per second using a spectral algorithm [4]. The use of the Modulated Scatterer Technique (MST) allows performing rapid measurements on a planar 32x32 sensor retina behind the object [5], and thus an extension for a full 3D polarimetric analysis of the scattered field seems to be realistic.

In earlier simulation studies [6], the imaging performance of the planar geometry compared to other existing circular systems [2,7] have been verified for quantitative breast imaging by using a Newton-Kantorovich (NKT) algorithm [8]. The purpose of this study is to follow up the earlier breast imaging investigation [6] by using data provided by the planar camera for a high contrast inhomogeneous object. In the following section, the experimental setup will be shortly described including the breast phantom properties. Section 3 is concerned with simulated and experimental results obtained with the NKT for the breast phantom investigated.

2 EXPERIMENTAL SETUP

2.1 The planar 2.45 GHz microwave camera

The active imaging system, depicted in Figure 1 includes a transmitting horn antenna with exponential profile and a dielectric lens. Thus a vertically polarized quasi-plane wave crosses a 193 mm width water tank, which contains the Object Under Test (OUT). The use of water as surrounding medium improves the spatial resolution by decreasing the wavelength and reduces the multi-paths' effects by introducing losses. During acquisitions the temperature is regulated at 37°C in order to avoid amplitude/phase drift due to electrical characteristic variations of the crossed media. The wave scattered by the OUT is scanned by a planar measurement array called the retina, which is placed at the output of the water tank. The retina is composed of 1024 (32x32) dipoles loaded by PIN diodes sequentially

modulated at 200 kHz. It provides a space sampling of the vertical component of the scattered electric field with a 7.2 mm step, which corresponds to half a wavelength in water.

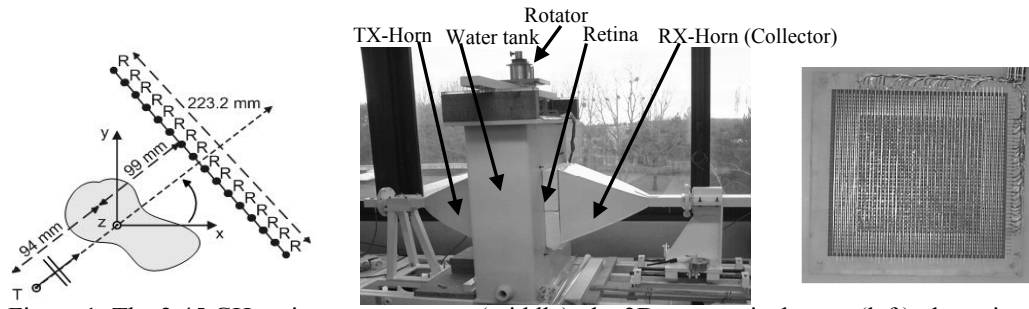


Figure 1: The 2.45 GHz microwave camera (middle), the 2D geometrical setup (left), the retina (right).

Signals scattered by modulated dipoles are gathered by a collector similar to the transmitting horn antenna and applied to a homodyne vector receiver (amplitude / phase measurements). An integration time of several seconds is used during the data acquisition in order to obtain a signal to noise ratio (SNR) around 50 dB, for 1W input power [9]. A multi-view acquisition is controlled by a rotator, which is placed at the top of the system. In the present study 36 angular positions of the phantom are used.

2.2 A Triton X-100 and water based breast phantom

In order to modelize a human breast in a 2D-TM cross section, a 3 mm thick cylindrical Plexiglas ($\epsilon' = 2.73$, $\epsilon'' = 0.01$) structure with 100 mm diameter is used. As shown in Figure 2a, different 2 mm thick Plexiglas tubes are placed inside, in order to simulate tumors of sizes between 10 – 16 mm in diameter. According to the breast tissues Lazebnik *et. al.* reported in[10] that the normal breast tissues may be divided into three different groups dependent on the fat content in the tissue. At 2.45 GHz this leads to three situations: 0-30% adipose tissue ($\epsilon' = 47$, $\epsilon'' = 12$), 31-84% adipose tissue ($\epsilon' = 38$, $\epsilon'' = 9$), 85-100% adipose tissue ($\epsilon' = 5$, $\epsilon'' = 0.5$). Lazebnik *et. al.* proposed a ultrawideband gel breast phantom [11] covering all those situations. However, using a narrowband around 2.45 GHz we'll show that a simpler phantom substance can be used. Herein, a phantom based on the surfactant Triton X-100, salt and distilled water is proposed. The measured complex permittivity, for different weight concentrations are presented in Figure 2b and 2c. Measurements are made by using an Agilent 85070E open-ended coaxial probe at 2.45 GHz, for a temperature of 36.5°C.

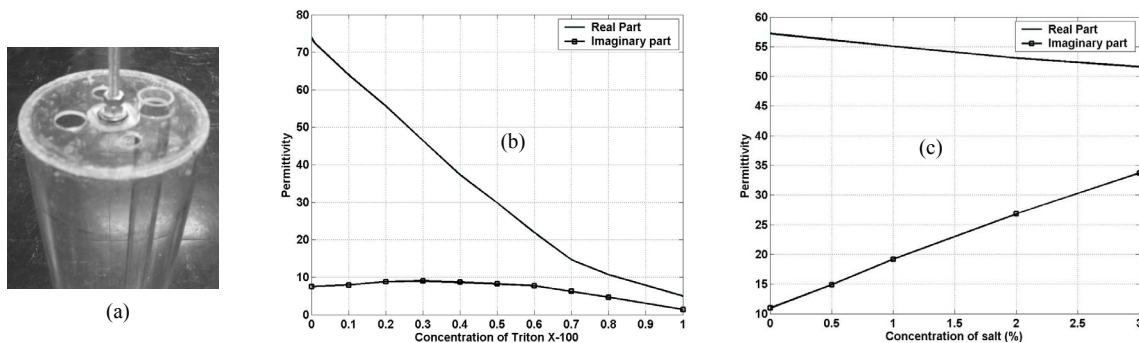


Figure 2: Breast phantom characteristics: (a) Plexiglas breast phantom. Complex permittivity for different weight concentrations of (b) Triton X-100/distillated water mixtures, (c) salt/ 0.2Triton X-100 mixtures

Figure 2b shows that all three tissue types can be covered by using a Triton X concentration of 0.3 (0-30% adipose), 0.4 (31-84% adipose) and 1 (85-100% adipose). Note that salt which increases the imaginary part of the complex permittivity, can be added in order to better fit the low fat breast tissue. Figure 2c shows that the tumor should be well reproduced by adding salt to a 0.2 Triton mixture [3]. Those results will be used in our future experiments. Herein the 16 mm tumor tube is filled with a saline solution whose complex permittivity values is $\epsilon' = 70$, $\epsilon'' = 15$ (6 g/l salt). The breast liquid is a 0.5 Triton X mixture ($\epsilon' = 29$, $\epsilon'' = 8.2$). This value corresponds to an average of the three different tissue groups. The Stogryn model [12] is used for an estimation of the water complex permittivity and gives ($\epsilon' = 73.4$, $\epsilon'' = 7.2$).

3 EXPERIMENTAL RESULTS

3.1 Calibration

In the Newton-Kantorovich algorithm the solution is found iteratively by minimizing the error between the measured scattered field and the computed scattered field from a numerical model. Consequently, the convergence of such an iterative process requires, at least, the numerical model to reproduce as accurately as possible the experimental setup and thus the equipment has to be carefully calibrated. In the studies of homogenous objects performed by Franchois et. al. [13] the system was calibrated by comparison between the measured incident field and the computed one. Another method introduced by Jofre et. al. [7] is to use a reference object for the scattered field calibration. Figure 3 shows an example of the results obtained with this method for a given incident plane wave, on line 15 of the retina. The reference object is a 35 mm PVC cylinder placed at the center of the system during calibration. A good agreement in both phase and amplitude is obtained at the center of retina for 18 elements. However, the data along the borders have large artifacts in amplitude, probably too large to be useful for the reconstruction.

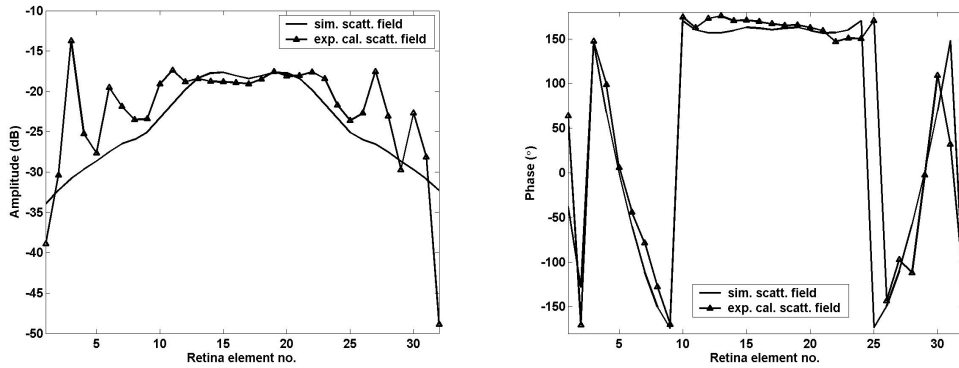


Figure 3: Comparison between calibrated measured and computed scattered field for one view, by using a 35 mm PVC cylinder reference object. Amplitude (left), phase (right).

3.2 Quantitative reconstruction

In order to be sure that quantitative reconstruction of the breast phantom is possible with this amount of data (18 elements x 36 views), the following simulation has been performed. Figure 4 presents the reconstructed complex permittivity, at iteration n°3, from noisy data (SNR=40 dB) for different number of retina elements. As one can see, the number of elements has not a significant effect on the quality of the image. Moreover, the detection of the tumor comes only from the distribution of the real part.

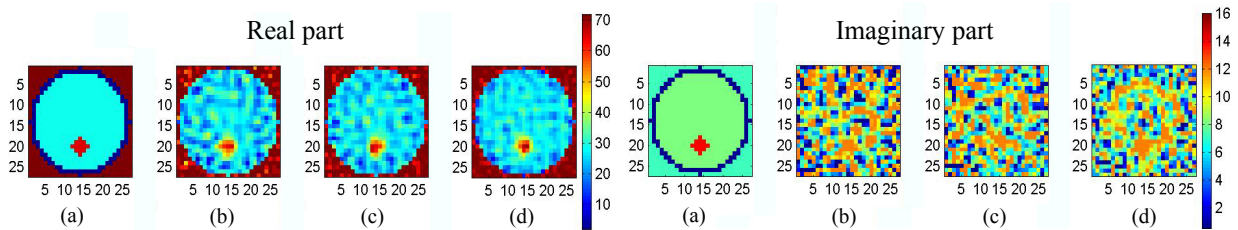


Figure 4: Reconstructed image after three iterations for different number of synthetic noisy data :
 (a) true profile (b) 14x36 data, (c) 18x36 data, (d) 32 x36 data.

Figure 5 shows the results obtained during the iterative process, from the data collected at line n°15 of the planar camera's retina. Concerning the real part the result is very similar to the one obtained with simulated data, the tumor is clearly detectable. Note that the imaginary part distribution contains specific circular artifacts, probably related to the reference cylinder used for calibration. Note that this is the first quantitative image of an inhomogeneous object reconstructed with the planar microwave camera.

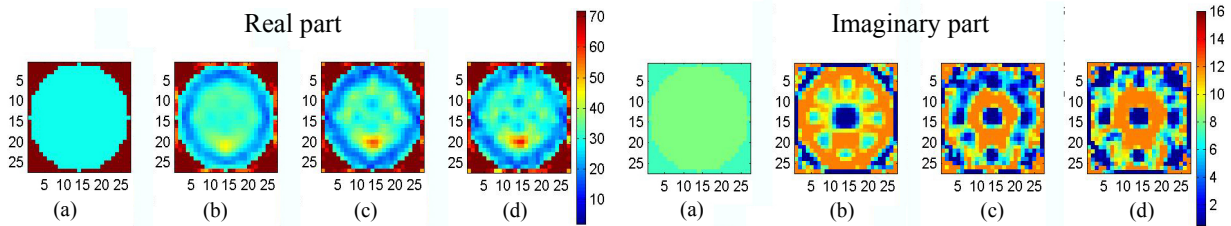


Figure 5: Quantitative reconstruction of the breast tumor phantom with the planar camera:
 (a) initial guess (b) iteration 1, (c) iteration 2, (d) iteration 3.

4 CONCLUSION

In this paper the first quantitative image of an inhomogeneous object using the 2.45 GHz planar microwave camera at DRE/Supélec has been obtained. It has been shown that localization and determination of a 16 mm saline water cylinder is possible through the real part of the complex permittivity distribution. Moreover, a new liquid based narrowband breast phantom has been proposed using a Triton X-100, water and salt mixture. This study fulfills our expectations of an early stage experimental prototype, motivating next steps towards a future planar 3D microwave breast imaging system. Further works will be focused on the improvement of the phantom and the equipment's calibration, and on a better understanding of the detect-ability of a small tumor, with this planar system.

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