Visibility of breast malignancy by microwave radiometry: preliminary results on a real antenna

S. Iudicello

DISP, via del Politecnico,1, University of Rome Tor Vergata, 00133, Rome, Italy, iudicello@disp.uniroma2.it

Abstract

In microwave radiometry for early detection of breast malignancy a contacting antenna is scanned on the breast surface, while a pressure is exercised along with a deformation. Assuming the antenna at lower temperature than the breast, the results of a numerical modeling show an interesting increase in tumor radiometric visibility in compressed breast. Preliminary results on a real radiometric antenna are presented and compared with the results obtained for an ideal antenna.

1. Introduction

A renewed interest in clinical microwave radiometry can be explained on the basis of the improved performance of both microwave instrumentation and computer modeling of complex systems. During a typical session a contacting antenna scans the surface of a breast. When a thermal anomaly is located within the radiation solid of the antenna, i. e. the volume of breast that contributes almost all the net real power entering the antenna from the breast, the receiver output increases to some amount. The anomaly is radiometrically visible if such amount is larger than the instrumental resolution. In spite of the simplicity of the underlying rationale, measurements on patients may fail because inadequacies of the instruments and presence of artifacts due to spurious radiation. A parametric study on the radiometric visibility of thermal anomalies has been presented in [1]. The results of these investigations show that a 10mm spherical lesion is radiometrically visible by a system with 0.1 °C resolution if it is not deeper than 2.5cm. When a contacting sensor is scanned on the breast a pressure is normally exercised. The breast is deformed so that the distance of a lesion from the contacted surface is lowered while its visibility is changed. While breast flattening has been treated as a negligible effect in the modeling by previous authors, in this paper the breast is intentionally squeezed between antenna and thorax and we estimate the thermal behavior and the corresponding radiometric signal for the deformed breast. Breast compression is routinely performed during compression mammography to an extent that is indicated by regulatory agencies. For the signal S in output to a radiation balance microwave radiometer we shall use:

$$S = \frac{\int_{\Omega} P_d(\underline{r})T(\underline{r})dV}{\int_{\Omega} P_d(\underline{r})dV} \qquad (1)$$

where P_d is microwave power deposition at point $\underline{r} \in \Omega$ when the antenna radiates onto the body in active modality, T is the physical temperature and Ω is the overall volume that is sensed by the antenna. The presence of a malignancy may result in an excess of temperature ΔT as well as in a change ΔP_d within Ω, due to a change in permittivity of tumor tissue with respect to normal tissue. The radiometric resolution (sensitivity) will be denoted by δS. We admit that the radiometric antenna is frontally pressed against the breast, which is squeezed between the planar antenna and the thorax plane, coincident with the pectoral muscle wall (Fig.1). At the interface between antenna and breast a non-penetration condition holds [2]. Owing to this condition breast modeling under compression is not a standard elasticity problem [3]. In Fig. 2 the particle displacement is shown versus its original depth in the undeformed state on a sagittal plane for a 35% net deformation. The displacement is practically linear with depth, with 35% slope. We modeled a tumor as a sphere. The sphere is located on the symmetry axis (z-axis) perpendicular to the chest wall. Tumor-center distance from the antenna contact point in the undeformed state is referred to as tumor depth. For simplicity the mechanical properties of the tumor have been taken coincident with those of the host tissue.

We show that compressing the breast improves the radiometric visibility. As a beneficial effect of the compression, blood flow is reduced thus increasing the tumor over-temperature. Moreover cooling the compression plate and the antenna gives additional visibility to a deep lesion.

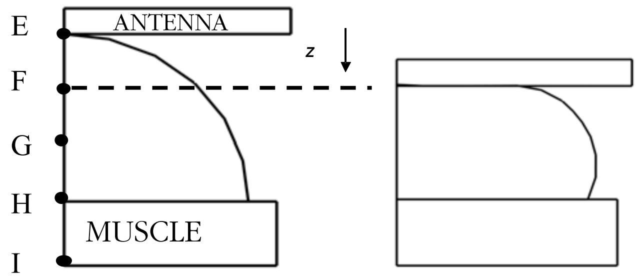


Fig. 1. Geometry of the undeformed (left) and deformed (right) breast on a sagittal view.

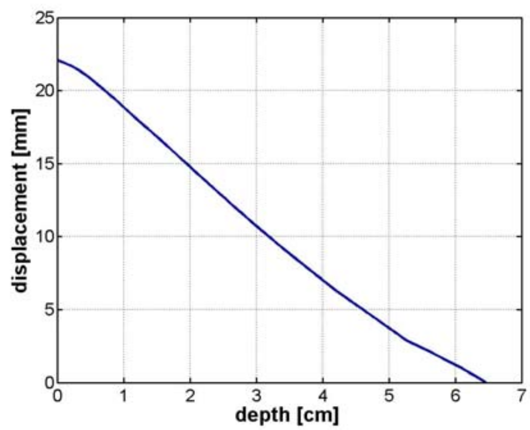


Fig.2. Particle displacement vs. depth on z-axis

2. Thermal and electromagnetics models

In previous work [1], the contact between antenna and breast was ideally confined to a small area and to a very short time interval, in such a way to neglect temperature variations in the breast due to the soft contact with the antenna. Two limiting cases can be envisaged in the presence of large deformations. In a first case the antenna is instantaneously compressed against the breast, while the radiometer takes the data in that instant. No heat exchanges are allowed, so that the temperature of a particle at a point $\underline{x}$ in the compressed state coincides with its temperature at the initial location $\underline{X}$ in the undeformed state. We shall refer to this temperature as adiabatic temperature. In a second case, the radiometric data acquisition takes enough time (about 15 minutes as shown in Fig. 3a) to let the temperature reach the steady state within the deformed breast in the presence of a larger contact surface between antenna and breast. We shall refer to this temperature as steady-state temperature. We expect that the temperature that is sensed by the antenna during a realistic measurement, be between these limiting cases. A tumor may change $T(\underline{r})$ into a new temperature $T'(\underline{r})$ differing by $\Delta T(\underline{r})$ from the normal breast temperature mainly in the tumor volume and in the surrounding tissue. Thermogenesis and angiogenesis are considered responsible for this change [4]. Diagrams of ΔT vs. lesion depth are shown in Fig. 3b) along a line through the lesion center, for a 10 mm tumor centered at 1cm, 2cm, 3cm and 4cm from the surface, in the adiabatic and steady-state cases. The tumor depth is the tumor-center distance from the surface before compression.

A patch antenna for radiometric application has been designed. The geometry is shown in Fig. 4. The geometry of $\lambda/4$ allows miniaturization and gives a regular sensing solid. An open circuit stub is added to improve the 50 Ohm impedance matching at 2.6 GHz. The patch is centered at $z = 0$ plane. We assume the half-space in front of the patch to be filled by breast tissue with dielectric properties as in [1]. We refer to [5] for tumor dielectric properties. The center-band frequency is 2.6 GHz. The antenna has been measured on the breast of volunteers. Insertion loss simulated and measured diagrams are shown in Fig.4. Electromagnetic field computations have been performed by a proprietary FDTD code using Mur absorbing boundary conditions at the walls. The FDTD computation has been repeated in the presence of the spherical lesion with its center at various depths. Contour-level plots of P_d are shown on two orthogonal planes and on a plane parallel to the patch in Fig.5.

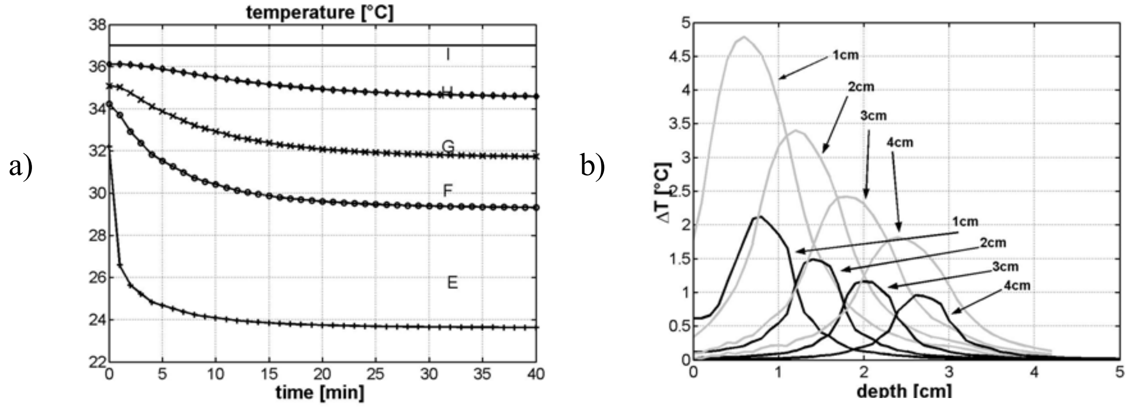


Fig. 3. a) Temperature vs. time at the points labeled in Fig. 1. The curves start for t=0 from the adiabatic values. b) Temperature difference (unhealthy-normal) ΔT for a 10mm lesion and compressed breast. Steady-state (gray line) and adiabatic (bold line).

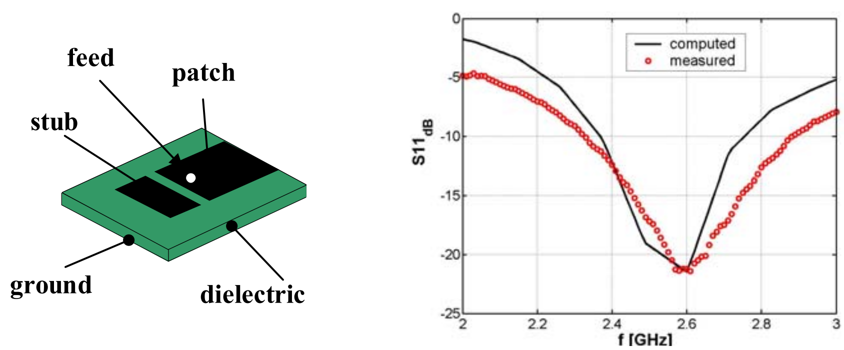


Fig. 4. Rectangular patch (left); insertion loss of the patch antenna in dB (right).

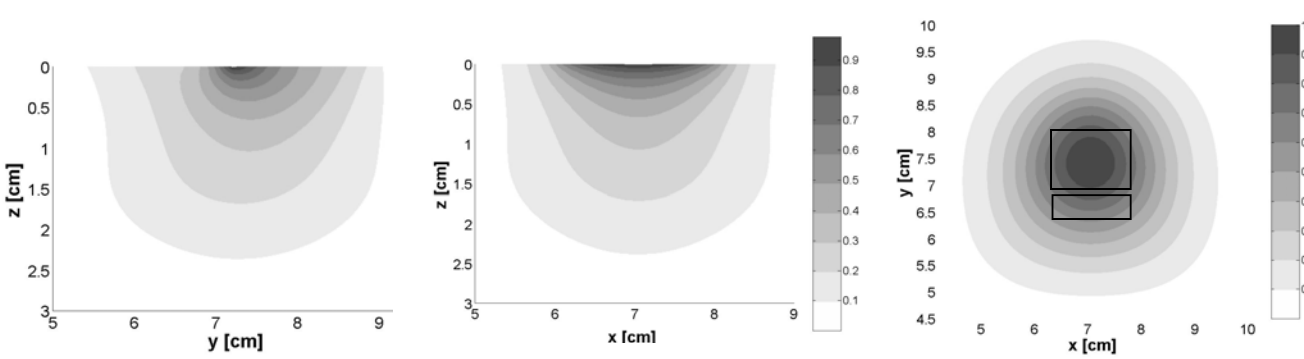


Fig. 5. Contour level diagrams of power deposition at 10mm depth in the breast (right), on a plane parallel and perpendicular to the patch symmetry plane (left).

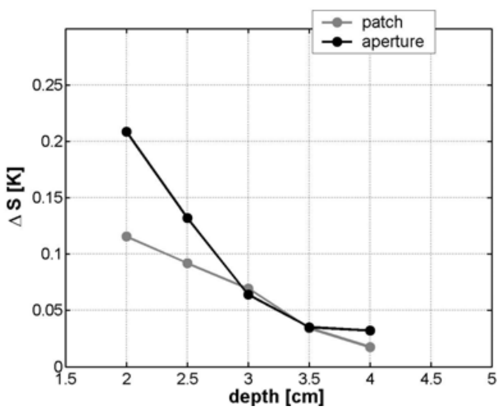
3. Results

The radiometric signal S has been computed by equation (1) after the temperature and power P_d delivered to tissue have been determined within both normal and unhealthy breast. Denote the difference between unhealthy and normal breast signals by ΔS:

$$\Delta S = \int_{\Omega} W'(\underline{r})T'(\underline{r})dV - \int_{\Omega} W(\underline{r})T(\underline{r})dV \qquad (2)$$

where the prime is used for the unhealthy breast. The diagrams in Fig. 6 refer to (a) non-compressed and (b) compressed breast. A tumor is radiometrically visible if the difference signal overcomes the resolution, i.e. $\Delta S > \delta S$ is the condition for a tumor to be visible. A reference value can be $\delta S = 0.1°C$ with 1s integration time. A realistic curve for ΔS of the compressed breast is between the diagrams of adiabatic and steady-state temperature [3]. As expected the visibility of a 10mm tumor decreases when a real antenna is modeled although there is an improvement in the visibility due to compression. We observe from the diagrams that the visibility of a 10mm tumor by the patch antenna increases of about 20% passing from about 23mm (see Fig.6a) in the undeformed breast to a value between 23 and 32 mm in the presence of a 35% compression. (see Fig.6b).

a)



b)

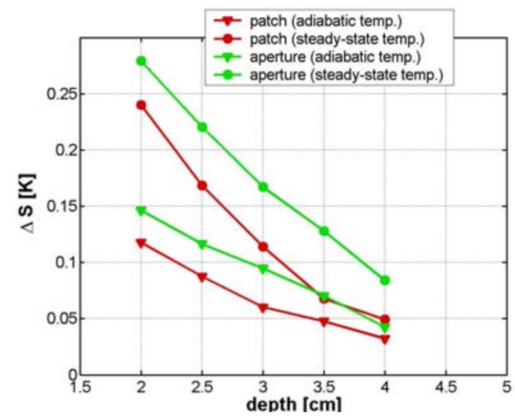


Fig. 6. a) ΔS of a 10mm lesion vs. depth for a 3cm aperture (black line) and for the patch (gray line). Non-compressed breast. b) ΔS vs. depth for a 3cm aperture (green curves) and for the patch (red curves). Compressed breast for 35% net deformation.

4. Conclusion

The problem of tumor visibility in compressed breast has been investigated. A radiometric microstrip antenna has been designed. Its performance has been compared with performance of the ideal aperture antenna that has been considered in our previous studies. The results show that compressing the breast increases the tumor radiometric visibility of 40% and 20% in the ideal and real antenna, respectively.

5. References

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