



# RADIO SCIENCE FOR HUMANITY

## Penetration Depth Enhancement in Breast Cancer Detection at High Frequencies

*Amélioration de la profondeur de pénétration des ondes électromagnétiques à hautes fréquences pour application à la détection de cancer du sein*

I. Iliopoulos<sup>1</sup>, M. Ettorre<sup>1</sup>, R. Sauleau<sup>1</sup>, P. Pouliguen<sup>2</sup>, P. Potier<sup>3</sup>, and M. Pasian<sup>4</sup>

<sup>1</sup>Institut d'Electronique et de Télécommunications de Rennes (IETR), UMR CNRS 6164, Université de Rennes 1, 35042 Rennes Cedex, France, ioannis.iliopoulos@univ-rennes1.fr

<sup>2</sup>P. Pouliguen is with the Strategy Directorate, Direction Générale de l'Armement (DGA), Paris 75509, France, philippe.pouliguen@intradef.gouv.fr

<sup>3</sup>Information Superiority, DGA, Bruz 35170, France, patrick.potier@intradef.gouv.fr

<sup>4</sup>Depart. of Electrical, Computer and Biomedical Engineering, Univ. of Pavia, Pavia, Italy, marco.pasian@unipv.it

**Keywords:** near field, breast cancer, focusing, medical imaging, millimeter waves

**Mots-clefs:** champ-proche, cancer du sein, focalisation, imagerie médicale, ondes millimétriques

### Abstract:

The use of electromagnetic waves for breast cancer detection has been a trending subject for several years. However, the reduced accuracy due to the low frequency of operation is the bottleneck of such systems. Nevertheless, an increase of the frequency results in a decrease of the penetration depth. In this work we investigate a focusing technique capable of increasing the penetration depth of a system for breast imaging with its central frequency set at 30 GHz.

### Résumé:

L'application des ondes électromagnétiques à la détection des cancers du sein fait l'objet de multiples travaux de recherche depuis de nombreuses années. Les techniques proposées souffrent d'une relative faible résolution spatiale en raison des bandes de fréquences de travail. Cependant, augmenter seulement la fréquence de fonctionnement ne permet pas de contourner cette difficulté en raison de la diminution de la profondeur de pénétration des ondes électromagnétiques dans les tissus. Nous proposons ici une nouvelle solution offrant la possibilité de contrôler la zone de focalisation (donc la profondeur de pénétration des ondes), avec une application à la détection du cancer du sein à 30 GHz.

## 1 Introduction

The use of electromagnetic waves for breast cancer detection is an attractive solution due to their non-invasive nature (compared to X-rays) and low cost (compared to magnetic resonance imaging (MRI)). Additionally, it can be physician independent, thus advantageous compared to ultrasound mammography. However, at the typical frequencies where electromagnetic systems are currently designed [1], the achievable resolution is not always adequate to detect early stage malignant regions [2]. A possible improvement to this problem is to scale up the frequency of operation [3]. However, this is accompanied by an increase of the losses and consequently a decrease of the depth from which valuable information can be extracted. In this communication we propose a methodology to focalize the electromagnetic field inside the tissue at 30 GHz (any frequency scaling is possible). To address the problem in a robust way, the breast is approximated with a  $\phi$ -independent planar stratification as illustrated in Fig. 1. The simplified model consists of three layers: skin [4], fat [5] and fibroglandular tissue [6, 7]. Besides a matching layer is chosen with a permittivity equal to the amplitude of the complex permittivity ( $\epsilon_r \sqrt{1 + \tan^2 \delta}$ ) of the skin at 30 GHz.

## 2 Proposed technique

### 2.1 Propagation inside the breast-like media

The planar stratification is illuminated by a uniformly tapered circular aperture. In addition, the aperture is linearly polarized along  $x$  and is located at  $z = 0$  on a  $xy$ -plane parallel to the stratification. For an aperture

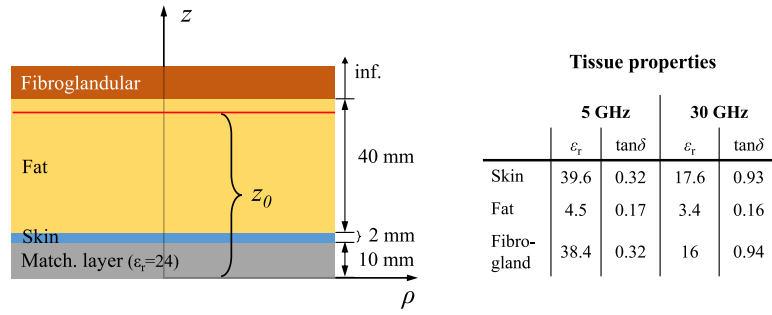


Figure 1: Problem set-up. The red line illustrates the target distance.

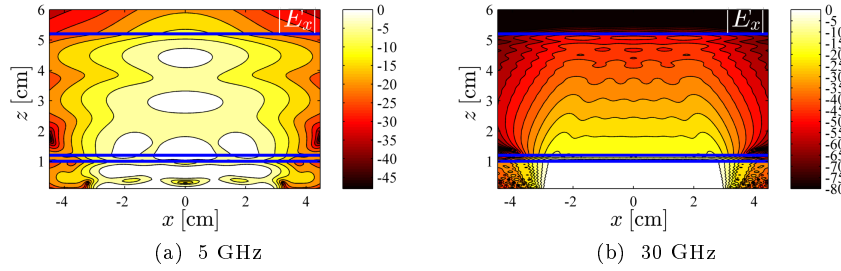


Figure 2: Normalized  $|E_x|$  component in [dB] inside the stratification for different frequencies of operation for a uniformly illuminated aperture of radius 6 cm at (a) 5 GHz and (b) 30 GHz. The blue lines represent the interfaces of the stratification. The fields are normalized to their maximum.

of diameter 6 cm, the field inside the stratification is plotted in Fig. 2 for two distinct frequencies, namely 5 GHz and 30 GHz. We immediately notice the vast difference of the field level inside the body between the two frequencies. In fact, in the case of the lower frequency (5 GHz) the field level around the target distance is about 5 dB lower with respect to the maximum, located very close to the aperture. On the other hand, at the frequency of interest (30 GHz), the field is attenuated by more than 40 dB. Consequently, the possibility to tailor the field at 30 GHz and improve the attenuation rate is of great importance.

## 2.2 Penetration depth enhancement

In order to counterbalance the added losses at the frequency of interest (30 GHz), a focalization of the field is proposed. This can be achieved using different techniques [8, 9]. However in this communication a novel convex optimization method is used, based on the CVX package for MATLAB [10, 11]. By using this method the optimality of the solution is guaranteed [12].

The optimization scheme is able to maximize the field level at a requested distance along the  $z$ -axis. In our case this distance has been set equal to  $z_0 = 5$  cm [13]. The resulting (optimized) aperture distribution is presented in Fig. 3. The field (originating from the aforementioned aperture distribution) behaviour inside the body equivalent media is presented in Fig. 4a. We notice a considerable improvement of the field levels along the  $z$ -axis compared to the uniformly illuminated aperture (Fig. 2b). This is further illustrated in Fig. 4b, where the field along  $z$ -axis is plotted for the two cases. Specifically, a 14 dB increase at the target distance is achieved compared to a uniformly illuminated aperture of the same size. The unavoidable low field values (improved, however, with the proposed technique) are expected to be counterbalanced by the use of dedicated (low noise figure) transceivers for the final system and exposure times of the order of tens of seconds. It should

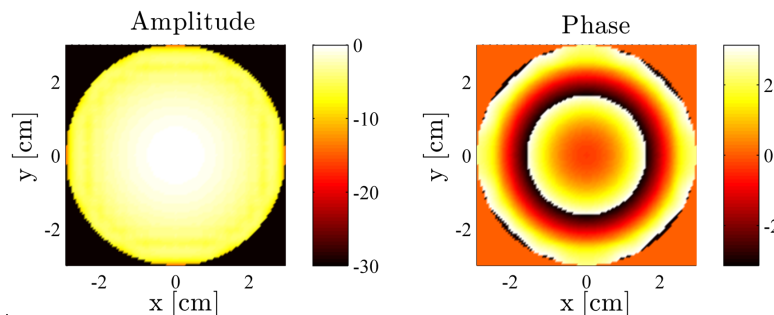


Figure 3: The aperture distribution ( $E_x$  component) generated by the proposed optimization scheme (30 GHz).

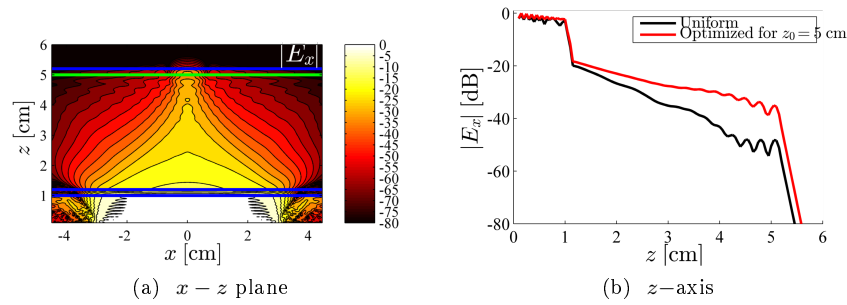


Figure 4: Normalized  $|E_x|$  component in [dB] generated by the optimized aperture distribution at 30 GHz. The improvement (compared to a uniform aperture) at the target distance (5cm) is 14 dB.

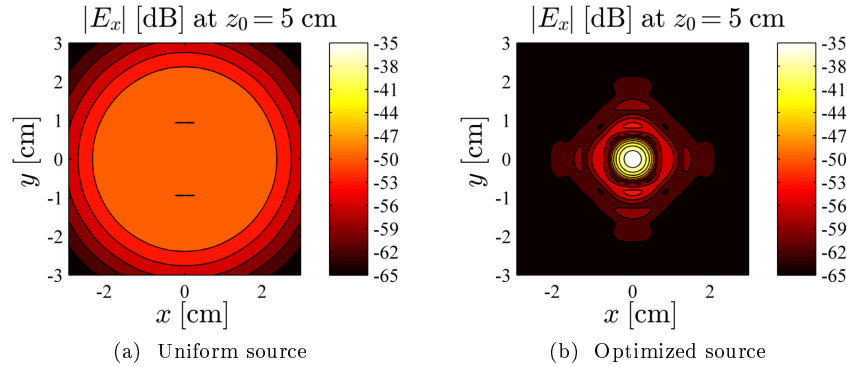


Figure 5: Normalized  $|E_x|$  component in [dB] at the target plane ( $z_0 = 5$  cm) for (a) the uniform and (b) the optimized aperture distribution. The color scale is the same for the two graphs. The contour line interval is 3 dB.

also be noted that the intended technique is best applied for breasts with medium-to-high fat content. Under this condition, the attenuation inside fibroglandular tissue, which is too challenging at such frequencies, can be avoided. Additionally, the contrast between fat and malignant tissue is higher and thus favourable.

However, the increase of the field level along the  $z$ -axis, comes with a decrease of the illuminated area. This is illustrated in Fig. 5, where the field at the target plane ( $z_0 = 5$  cm) is plotted for the uniform and the optimized aperture distribution. The area efficiently illuminated (-3dB from the respective maximum) is 4 cm and 0.6 cm in diameter for the uniform and optimized source, respectively. The impact of this focusing behaviour over cancer detection is currently under investigation.

### 3 Conclusion

The capability to enhance the penetration depth is of paramount importance in high frequency breast cancer scanners. The technique presented here proposes a novel source set-up, capable of increasing the field level along the axis of propagation. This increase on the axial direction generates a focused field at the distance where targets are expected, opening a new horizon towards high precision early breast cancer detection.

### 4 References

- [1] M. Klemm, I. J. Craddock, J. A. Leendertz, A. Preece, and R. Benjamin, "Radar-based breast cancer detection using a hemispherical antenna array: experimental results," *IEEE Trans. Antennas Propag.*, vol. 57, pp. 1692–1704, June 2009.
- [2] N. Nikolova, "Microwave Imaging for Breast Cancer," *IEEE Microwave Mag.*, vol. 12, pp. 78–94, Dec. 2011.
- [3] S. Moscato, G. Matrone, M. Pasian, A. Mazzanti, M. Bozzi, L. Perregrini, F. Svelto, G. Magenes, P. Arcioni, and P. Summers, "A mm-wave 2D ultra-wideband imaging radar for breast cancer detection," *International Journal of Antennas and Propagation*, vol. 2013, Article ID 475375, 8 pages, 2013. doi:10.1155/2013/475375.
- [4] S. Alekseev and M. Ziskin, "Human skin permittivity determined by millimeter wave reflection measurements," *Bioelectromagnetics*, vol. 28, pp. 331–339, July 2007.

- [5] M. Lazebnik, L. McCartney, D. Popovic, C. B. Watkins, M. J. Lindstrom, J. Harter, S. Sewall, A. Magliocco, J. H. Booske, M. Okoniewski, and S. C. Hagness, "A large-scale study of the ultrawideband microwave dielectric properties of normal breast tissue obtained from reduction surgeries," *Physics in Medicine and Biology*, vol. 52, no. 10, p. 2637, 2007.
- [6] A. Martellosio, M. Pasian, M. Bozzi, L. Perregini, A. Mazzanti, F. Svelto, P. E. Summers, G. Renne, and M. Bellomi, "0.5-50 GHz dielectric characterisation of breast cancer tissues," *IET Electronics Letters*, vol. 51, pp. 974–975, June 2015.
- [7] A. Martellosio, M. Pasian, M. Bozzi, L. Perregini, A. Mazzanti, F. Svelto, P. E. Summers, G. Renne, L. Preda, and M. Bellomi, "Dielectric properties characterization from 0.5 to 50 GHz of breast cancer tissues," *IEEE Trans. Microw. Theory Techn.*, DOI:10.1109/TMTT.2016.2631162, to be published.
- [8] S. Kim, J. Ho, and A. Poon, "Wireless power transfer to miniature implants: transmitter optimization," *IEEE Trans. Antennas Propag.*, vol. 60, pp. 4838–4845, Oct. 2012.
- [9] I. Iliopoulos, M. Casaletti, R. Sauleau, P. Pouliguen, P. Potier, and M. Ettorre, "3-D shaping of a focused aperture in the near field," *IEEE Trans. Antennas Propag.*, vol. 64, pp. 5262–5271, Dec. 2016.
- [10] M. Grant and S. Boyd, "CVX: Matlab software for disciplined convex programming, version 2.1," Mar. 2014.
- [11] M. Grant and S. Boyd, "Graph implementations for nonsmooth convex programs," in *Recent Advances in Learning and Control* (V. Blondel, S. Boyd, and H. Kimura, eds.), Lecture Notes in Control and Information Sciences, pp. 95–110, Springer-Verlag Limited, 2008. [http://stanford.edu/~boyd/graph\\_dcp.html](http://stanford.edu/~boyd/graph_dcp.html).
- [12] I. Iliopoulos, B. Fuchs, R. Sauleau, P. Pouliguen, P. Potier, and M. Ettorre, "On the Use of Convex Optimization for Electromagnetic Near-field Shaping," in *2017 11th European Conf. Antennas Propag. (EuCAP) - Accepted*.
- [13] Private communication with the European Institute of Oncology (IEO).