On the development of an imaging system at millimetre-wave frequencies for biological applications: dielectric characterization of tissues and first preliminary results on phantoms

Simona Di Meo[1], Marco Pasian[1], Giulia Matrone[1], Lorenzo Pasotti[1], Luca Perregrini[1], Maurizio Bozzi[1], Lourdes Farrugia[2], Charles V Sammut[2]

[1] Department of Electrical, Computer and Biomedical Engineering, University of Pavia, Pavia, Italy
[2] Electromagnetics Laboratory, Department of Physics University of Malta MSD, Msida 2080, Malta

In recent years, it is growing the interest toward the utilization of electromagnetic waves for biomedical applications. One of the most promising application is the use of microwaves and millimetre waves for diagnostic purpose, in particular for breast cancer detection.

Several experimental campaigns on human *ex-vivo* breast tissues were proposed worldwide to validate the possibility of distinguishing in this frequency range a malignant tissue from the surrounding healthy one. In the framework of a project partially funded by the Italian Association for Cancer Research, and currently supported by the University of Pavia through the Blue Sky Research Project MULTIWAVE, the Microwave Laboratory of the University of Pavia, along with the European Institute of Oncology in Milan, performed two extensive experimental campaigns on *ex-vivo* tissues in 2014 and 2016. These involved more than 300 samples derived from around 100 women of different ages, in the broad frequency range from 500 MHz to 50 GHz. During spring 2019, an *in-vivo* experimental campaign on a relatively small colony of mice is expected to be performed at the IFOM Laboratory in Milan, still in collaboration with the European Institute of Oncology, to validate the *ex-vivo* measurements.

Finally, with the aim of further validating the database on the dielectric properties, the University of Pavia and the University of Malta collaborates in the framework of a wide experimental campaign. This is intended to assess (and possibly quantify), still up to 50 GHz, the statistical difference between the dielectric properties derived from *ex-vivo* samples taken from animals and taken from human beings, in this latter case related to human cadavers.

In addition to these extensive experimental campaigns, in 2016, the numerical (HFSS and Matlab) feasibility study of the mm-wave imaging system for early breast cancer detection was also done by the authors of this abstract. The results of this preliminary study showed that for particularly fat breast and using a circular configuration a resolution in the order of some millimetres is achievable, and a penetration of a few cm can be obtained. In this framework, also several algorithms for image reconstruction were tested and compared, and the high potentiality of the Filtered-Delay-Multiply-And-Sum (F-DMAS) algorithm was shown.

After these two fundamental steps, in the direction of testing the mm-wave imaging prototype on realistic phantoms, different recipes for tissue-mimicking breast phantoms were designed and dielectrically characterized in the frequency range [0.5-50] GHz, involving cheap and not-toxic components. A first attempt of heterogeneous breast phantom, composed by fat-like mixture with the inclusion of a tumor-like mass, was proposed (Fig. 1).

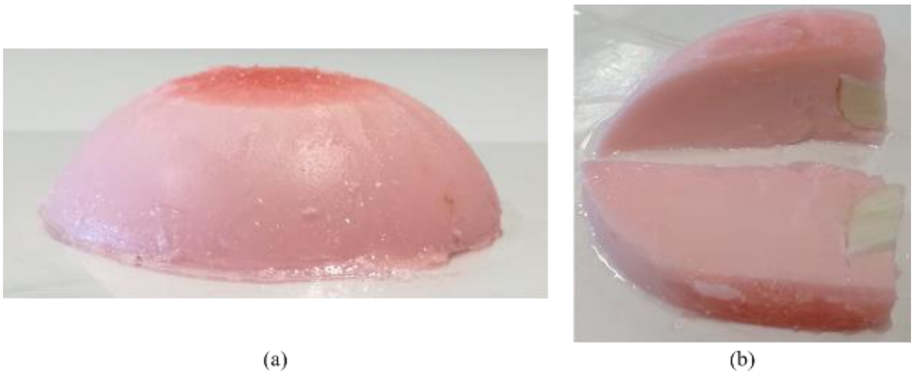

Fig. 1. Lateral view a) and section b) of the heterogeneous breast phantom.

Due to the very promising results related to the comparison between the dielectric properties of the produced phantoms and the ones derived from the experimental campaigns on human breast *ex-vivo* tissues, a first test of the mm-wave imaging prototype was done. In particular, the mm-waves imaging prototype used two mono-modal truncated double-ridge waveguides (PNR180), supported by two microstep actuators, and connected to the Vector Network Analyzer for measurements. By moving the two antennas, a synthetic linear array composed by ten radiators was created, and measurements with a metallic spherical target within the phantom were performed in the frequency range [18-40] GHz. The Stepped Frequency Continuous Wave (SFCW) radar approach was implemented and data were then processed and beamformed to generate the final image, showing that the target can be effectively detected with the developed setup and processing algorithms.

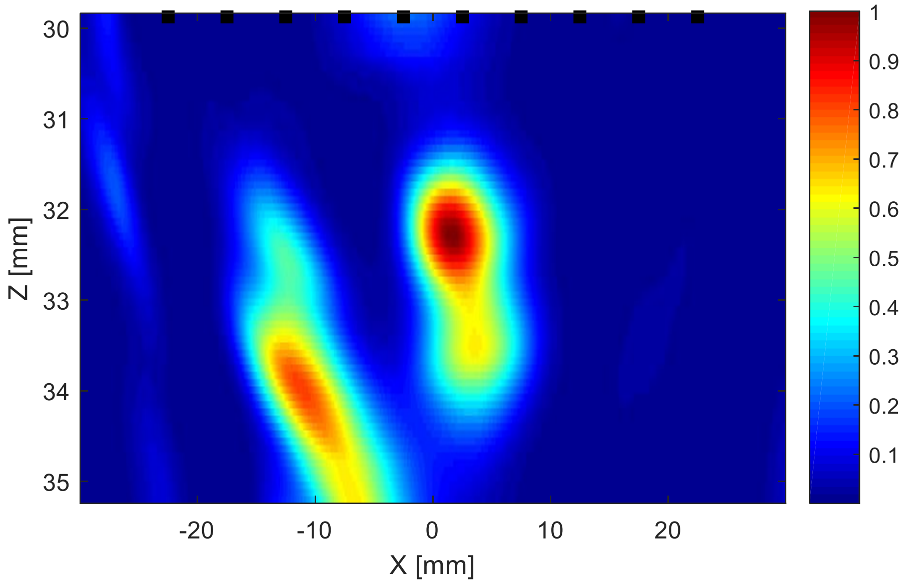

Fig. 2. Reconstructed image of the metallic target embedded in the tissue mimicking phantom material. Black square markers represent the antenna array elements.