Research Networking Programmes

ESF Research Networking Programme NEWFOCUS
Final scientific report

Project title: **Optimizing the focusing properties of small antennas placed inside a highly dissipative multilayer medium**

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Exchange period: 1 week (3th May 2015 until 10th May 2015)

Host institution: Laboratory of Electromagnetics and Acoustics (LEMA), Ecole Polytechnique Fédérale de Lausanne (EPFL), Switzerland
Host: Prof. Anja K. Skrivervik

Purpose of the visit

Highly dissipative mediums have a severe effect on the radiation properties of antennas when antennas are placed inside such mediums. This is a serious problem in the case when antennas are used like sensors or parts of sensing systems in medical, biological, or similar diagnostic applications where the host medium is not optimal from the electromagnetic point of view. However, despite the losses, the host medium can be used to our advantage if we optimize the position of the antenna and achieve a lens effect that focuses the radiation. Also, by tuning the size and the material of the antenna enclosure we can improve the matching of the antenna and significantly increase the radiation efficiency. Combined effects of the enclosure and position have been relatively marginally discussed in the literature and therefore we have started to develop a numerical algorithm suitable for solving these kinds of problems for spherical type host mediums. The algorithm is based on separate spherical mode decomposition of waves inside the small spherical antenna enclosure and inside the larger host sphere. Initial efforts and first results were obtained in the recent short visit to EPFL by prof. Zvonimir Sipus and we have achieved good agreement with simulations and existing results.

Within this short visit the numerical code was finalized and in collaboration with colleagues from EPFL several practical test cases were simulated to help determining the optimal position and encapsulation of the antenna inside realistic host medium. Also, a prototype was developed on which we started to measure the effects of position and size.

Description of the work carried out and main results obtained

1. Modeling implanted antennas using a spherical model

During the period at the EPFL the research was continued on studying the complex propagation of waves due to sources inside human body (modeled as multilayer spherical structure), in order to optimize antennas for Wireless Body Area Networks (WBANs). The structure of interest is a spherical model of a body with a small implanted air sphere acting as the implanted antenna (shown in Fig. 1.). The goal is for both, the spherical body and the spherical implant to be multilayered in order to study the optimal enclosure for the antenna in different body environments. Each spherical structure can be separately analyzed using spherical-wave modal expansion approach and these two problems need to be efficiently connected.

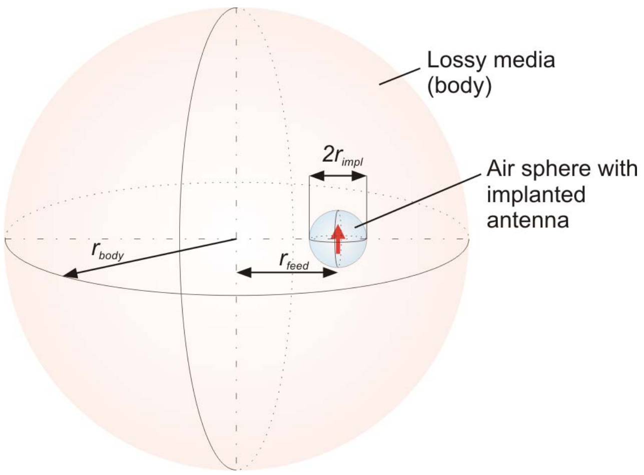


Figure 1. View of the analyzed structure with the excitation moved away from the center.

The EM fields in the implanted antenna sphere and in the outer sphere (human body) are “matched” using the equivalence theorem and it was implemented during a previous exchange visit to EPFL LEMA laboratory. As reported earlier, the total radiated power almost does not depend on the position of the source inside the body. Here total radiated power is found as the ratio of power radiated from body and the power radiated from the implanted sphere which is considered lossless.

This is depicted in Fig. 2. where total radiated power is calculated for a human head model (radius 90 mm, permittivity 43.50 – j34.75 [1, IEEE Head model]) at 403.5 MHz. The air sphere surrounding the small dipole has a radius of 1 mm and both the electric and magnetic dipole excitations are considered.

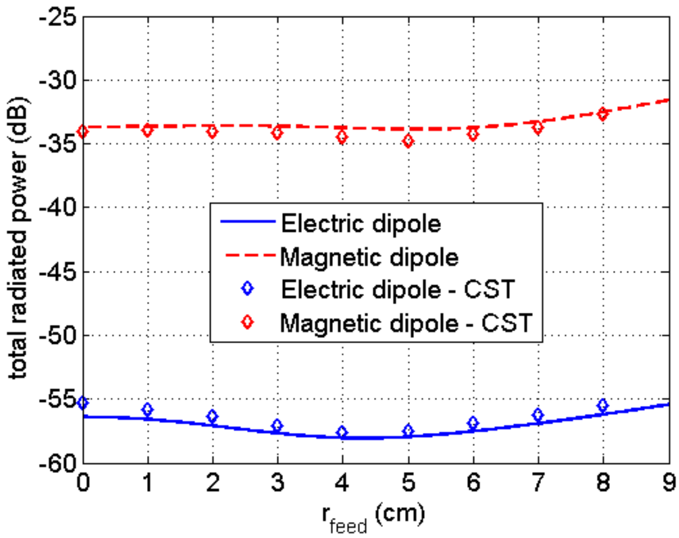


Figure 2. Total radiated power for a spherical body model as a function of the source position.

Within this visit the aim was to learn more about the optimization of the antenna enclosure using the developed code. For that purpose we have first studied the effect of outer layers added on the body. As seen from Fig. 3. different levels of improvement in the radiated power can be obtained for two different thicknesses of (h = 2 and 10 mm) when varying the permittivity of the outer layer. The outer layer acts as a matching layer to the outside air and could be used in scenarios when the receiving antenna is placed close to the body.

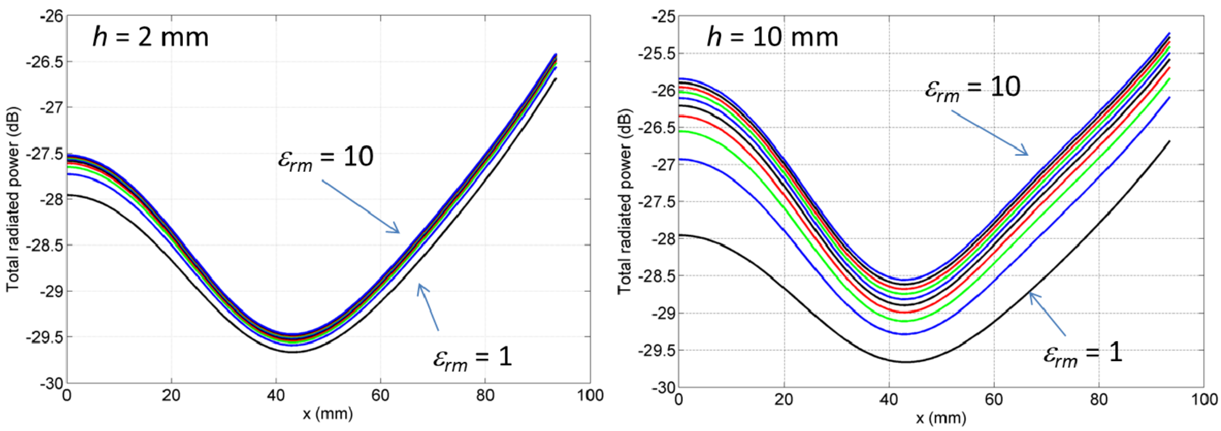


Figure 3. Total radiated power for a spherical body model (IEEE Head model) as a function of the source position ($x = r_{feed}$) for two different thicknesses of outer layer surrounding the body (r_{body} = 90mm, r_{impl} = 10mm).

Furthermore, it was important to verify the effect which the additional encapsulating layer of dielectric around the small air sphere with the antenna has on the overall radiated power. This is a realistic case since only medically allowed materials can be used for implants and these materials can be used to our benefit to improve the radiation efficiency. For this study the developed code had to be improved in order to allow multiple layers of the small antenna sphere. The results are shown in Fig. 4. for relative permittivity of the extra shell varying from 1 to 30, where the thickness of this shell is Δ.

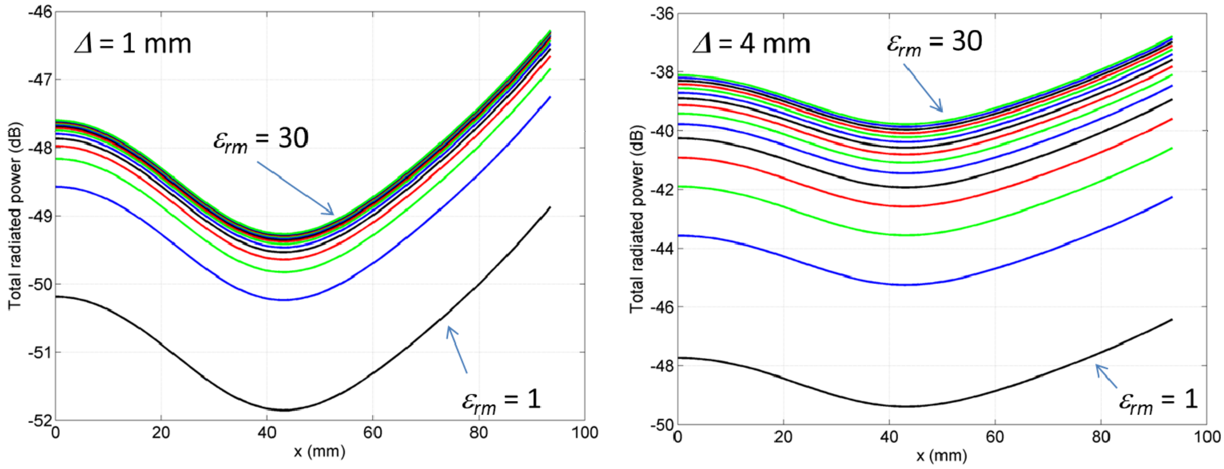


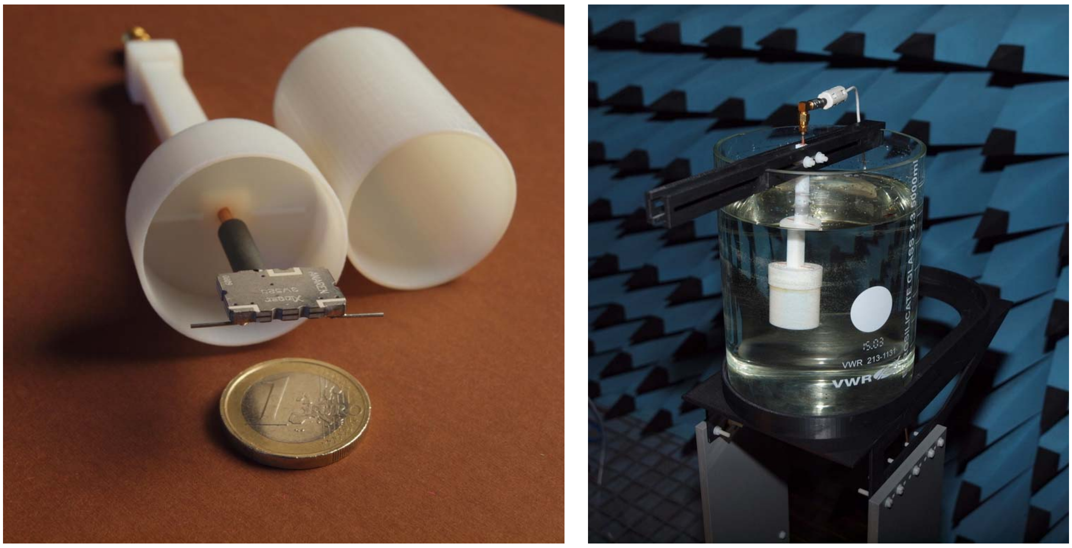
Figure 4. Total radiated power for a spherical body model (IEEE Head model) as a function of the source position ($x = r_{feed}$) for two different thicknesses of additional layer surrounding the small air sphere (r_{body} = 90mm, r_{impl} = 1 mm).

These results have shown that proper choice of materials and thickness can have a substantial impact on the radiation efficiency, which in turn can consequently result in smaller implants, possibility to place receiving antennas further away and similar.

2. *Developing a measurement prototype*

In order to verify our findings and test several realistic scenarios we built a cylindrical prototype of the body using a borosilicate glass jar (inner radius 81 mm, glass thickness 4 mm). The jar was filled with a phantom liquid with the parameters corresponding to the values defined in [1] for IEEE Head model. The enclosure for the antenna was a 3D printed cylindrical cup with the radius of 30 mm in which a dipole with a small balun was placed. Enclosure and the dipole are shown in Fig. 5a. and the complete setup, the jar and the enclosure inside the phantom liquid in Fig. 5b.

First measurement test attempts were made at frequency 403.5 MHz which proved to be very problematic since our balun was not working properly at this frequency. As a consequence, currents were flowing on the feed cables and radiated which was completely masking our measurements. For this reason we decide to move the measurements to a higher frequency (1.1 GHz) and use a different balun.



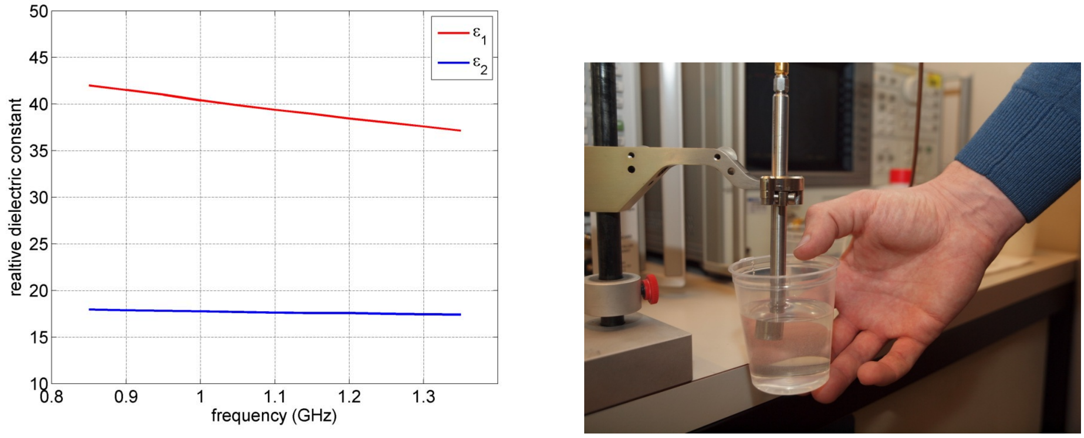
(a) (b)

Figure 5. (a) Photo of the antenna with the balun and the cylindrical enclosure, (b) measurement setup consisting of a glass jar filled with phantom liquid and the cylindrical implant inside.

For the new frequency we had to adjust the phantom liquid which finally consisted of water, sugar and salt. The exact ratios, aimed and obtained values for the permittivity of the liquid are shown in Table 1. and Fig. 6.

Table 1.

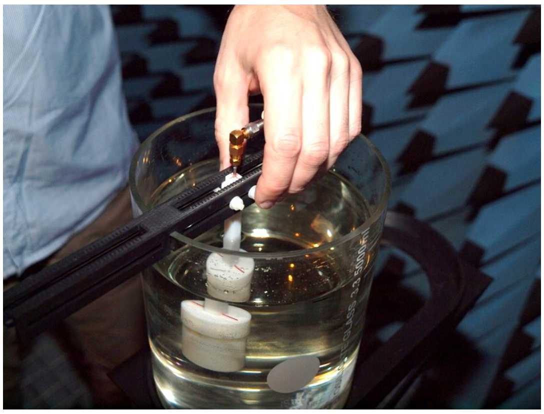
Target values for IEEE head model at 1.1 GHz [1]	Measured values at 1.1 GHz		Ratios of the ingredients [2]	
ε' = 41	ε' = 39.93		H_2O	42%
ε'' = 17	ε'' = 17.61		Sugar	57%
			Salt	1%



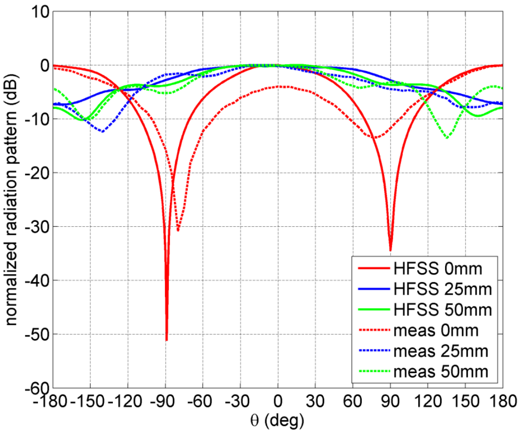
(a) (b)

Figure 6. (a) Measurement results for the phantom liquid, (b) Photo of measuring the sample with the probe.

Due to lack of time since the measurements were shifted to 1.1 GHz we were able to do only a couple of measurements of the radiation patterns (Fig. 7.) for three different positions of the implanted cylinder. The cylinder was moved inside the jar using a 3D printed rail that kept the small cylinder vertically fixed (Fig.7a.).



(a)



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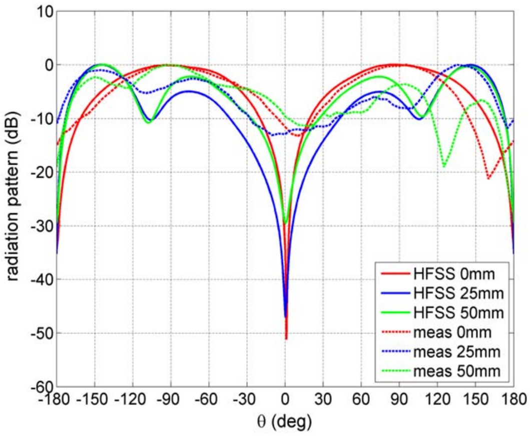

(c)

Figure 7. (a) Photo of the rail system for positioning the antenna, (b) normalized radiation patterns in the horizontal plane for implanted antenna inside the phantom oriented parallel to the approaching wall, (c) vertical to the approaching wall. Comparison with simulated HFSS results is also shown.

The results show only relative agreement with the simulations of the exact model obtained using HFSS. However this is expected due to very low levels of radiated power and the fact that our measurement setup was not designed for 1.1 GHz. Still, once the complete measurement is done we hope to verify our findings based on the spherical model code.

Future collaboration and projected publications

Two short exchanges to EPFL LEMA related to this project have been undertaken and the amount of work and results gathered is quite significant already. In order to complete the picture we are finalizing the measurements after which we plan to publish the results. All publications will acknowledge NEWFOCUS project since these exchanges essentially facilitated this work.

References

[1] Evaluating Compliance With FCC Guidelines for Human Exposure to Radiofrequency Electromagnetic Fields, 97–01 ed. Washington, DC: Federal Communication Commission (FCC) Std. Supplement C, OET Bulletin 65, p. 35, 2001.

[2] Michael Y. Kanda, , Maurice Ballen, Sheldon Salins, Chung-Kwang Chou and Quirino Balzano, “Formulation and Characterization of Tissue Equivalent Liquids Used for RF Densitometry and Dosimetry Measurements,” IEEE TRANSACTIONS ON MICROWAVE THEORY AND TECHNIQUES, VOL. 52, NO. 8, AUGUST 2004.