Research Networking Programmes

Short Visit Grant ☒ or Exchange Visit Grant ☐

(please tick the relevant box)

Scientific Report

The scientific report (WORD or PDF file – maximum of eight A4 pages) should be submitted online <u>within one month of the event</u>. It will be published on the ESF website.

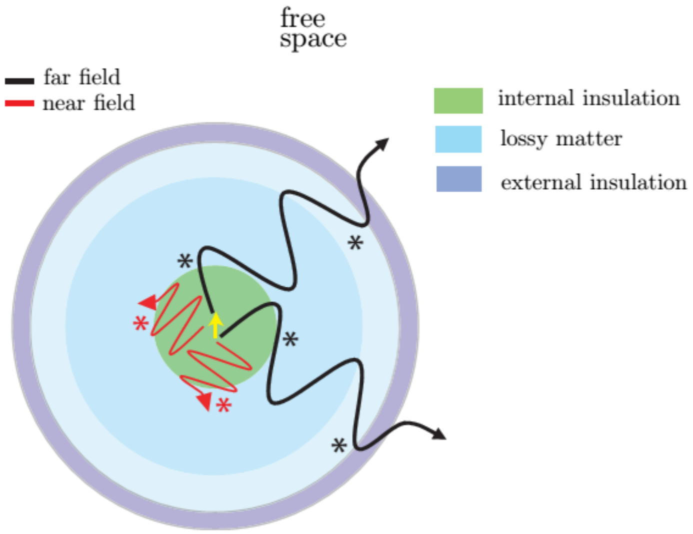
Proposal Title: theoretical investigation on the focalization of implanted antennas

Application Reference N°: 7065

1) Purpose of the visit

Implantable medical devices are very interesting for healthcare services such as disease prevention, diagnosis and therapy. The way to transmit the physiological data from inside the human body to the external world is a key point of such wireless system. The goal of this visit was to investigate the focusing of such implanted antennas towards outside of the body.

For that purpose, we have used an in-house electromagnetic code based on spherical modal expansion so as to derive guidelines for the design of implanted antennas. Indeed, spherical layered structures can be considered as a rough but reasonable approximation of the human body or head as represented below.



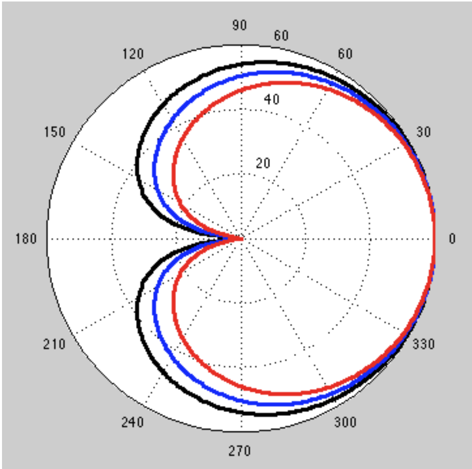
Representation of an implanted antenna in lossy matter with both internal and external insulation

Thanks to this efficient tool, it is possible to quickly obtain physical insights that are of great relevance for implanted antenna designers.

Moreover, it turned out that our spherical harmonics code is also of interest for the design of wearable antennas. The antenna is then outside but in direct contact with the body that strongly affects its radiation performances. The electromagnetic code allows quantifying the influence of the body on the performances of the antenna and therefore it is also of interest for the design of wearable antennas.

2) Description of the work carried out during the visit

A first part of the visit has been dedicated to the extension of the existing electromagnetic code so as to also handle wearable antenna scenarios in addition to implanted antenna ones. The electromagnetic code has been accordingly adapted and the antenna can now be placed either inside or outside of the body. The power absorbed by the body and the radiation patterns can then be computed in both configurations.
In addition to the classical electric and magnetic dipoles, the code can also now handle complex Huygens sources. The latter is composed of crossed electric and magnetic dipoles placed at a complex distance in order to be able to tune the focusing properties of the source as shown in the far field radiation patterns below. A complex Huygens source is an efficient way to mimic realistic antennas such as patches that are typically used as wearable antennas.



Free space radiation patterns of the complex Huygens sources

The implementation phase has been followed by numerical applications in which the power absorbed by the lossy body has been calculated in various configurations detailed in the next Section. The modification of the radiation pattern induced by the presence of the body has also been assessed in various scenarios and for different types of antennas. The goal is to determine what type of antenna is more robust to the presence of the body and therefore most suited to be wearable.

3) Description of the main results obtained

Description of the setting

We have focused our investigation on two frequency bands: MedRadio (Medical Device Radiocommunications Service) 401-406MHz and ISM 2.4 - 2.5 GHz (Industrial, Scientific and Medical). At those frequency, we have considered a lossy sphere to model an equivalent head. The characteristics of this sphere are:

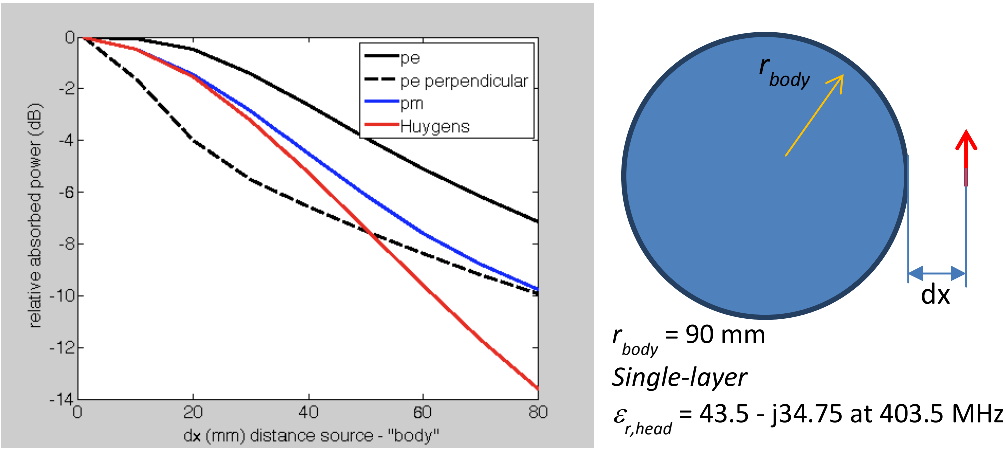
ε_r = 43.5-j34.75, tan δ = 0.799 and σ=0.87 S/m at 403.5MHz and

ε_r = 39.2-j13.2, tan δ = 0.336 and σ=1.80 S/m at 2.45GHz.

Power absorbed by the body model

We have computed the relative absorbed power that is the ratio between the absorbed power and the total power (sum of the absorbed and radiated power). A relative absorbed power of 0dB means that all the power going out of the antenna is absorbed by the body, i.e. that no power is radiated.

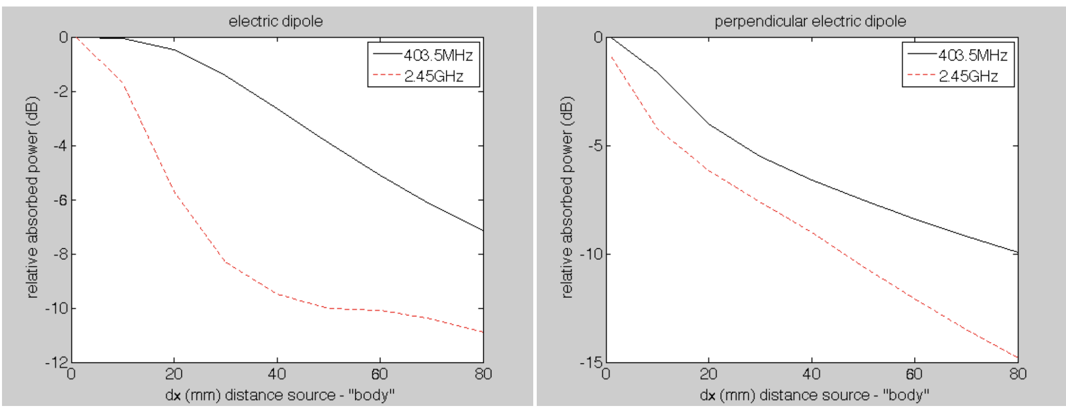
We investigate the influence of the type of source and the distance antenna - head model as reported below.



Influence on the power absorbed by the body of various types of antennas
for different antenna - body distances at 403.5 MHz

As expected, the power absorbed (by the lossy head medium) reduces when the antenna - head distance increases. Moreover the power absorbed by the head is significantly reduced in the case of magnetic dipole compared to the electric one. The high magnetic near field does indeed not dissipate in the head since human tissues have no magnetic losses. Finally, when the electric dipole is oriented perpendicularly to the body, the power absorbed by the body is significantly reduced compared to the parallel case. Indeed, there is then a null of radiation in the direction of the lossy medium.

Similar results have been computed at 2.45GHz and compared to those obtained at 403.5MHz below.



Influence on the power absorbed by the body for electric dipoles parallel and perpendicular to the body at 403.5MHz and 2.45GHz

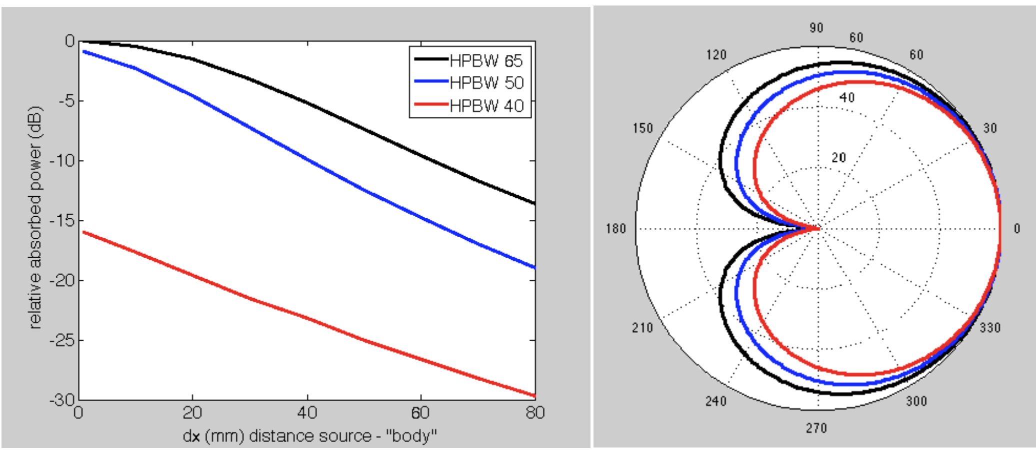
Generally speaking, the power absorbed by the body at 2.45GHz is significantly less important than at 403.5MHz. This can be explained by the loss tangent that is "only" of 0.336 at 2.45GHz instead of 0.799 at 403.5MHz.

Moreover, the skin depth is also a good indicator to quantify the EM power dissipated in a medium. It is a measure of how deep an electromagnetic wave can penetrate into a material. The skin depth δ is computed as follows:

$$\delta = \sqrt{\frac{2}{\mu\omega\sigma}} \approx 503\sqrt{\frac{1}{\mu_r f \sigma}}$$

where μ is the permeability, σ is the conductivity and ω is the angular frequency.
Numerical application yields a skin depth δ of around 27mm at 403.5MHz and "only" 8mm at 2.45GHz. This also explains why the absorbed power is less important at 2.45GHz than at 403.5MHz.

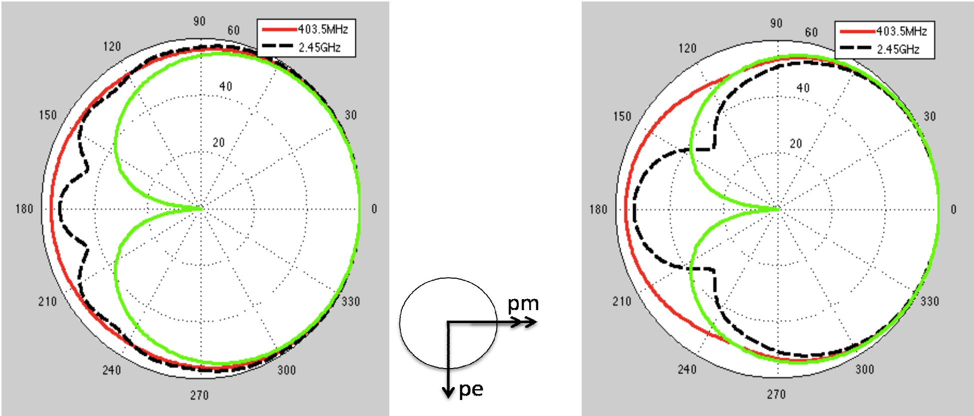
The influence of the antenna focusing properties on the absorbed power has been assessed. Three complex Huygens sources with various Half Power BeamWidth (HPBW): ±40°, ±50° and ±65° have been considered as plotted in the right figure below. In the left figure, it is clear that the *most directive* antenna, i.e. the one that radiates the least towards the body, is the antenna that leads to the minimum absorbed power by the body.



Left: Influence on the power absorbed by the body of various types of Huygens sources for different antenna - body distances at 403.5 MHz.
Right: free space radiation patterns of the three complex Huygens antennas.

Modification of the radiation patterns by the presence of the body

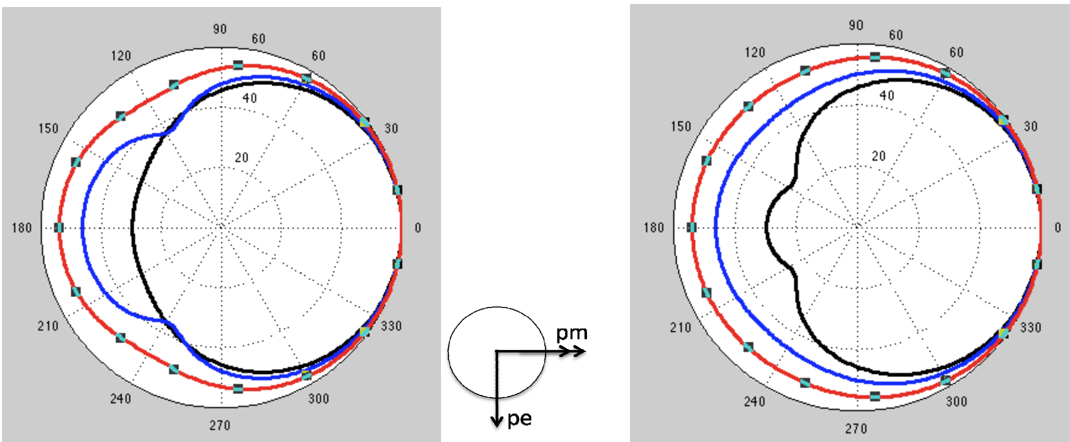
The far field radiated by the antenna without and in presence of the body has been computed at both 403.5MHz and 2.45GHz.



Influence of the body on the radiation patterns for a Huygens antenna placed at 1mm from the body (free space pattern in green), left/right plane containing the electric/magnetic field.

Although the head model is in terms of wavelength about 6 times bigger at 2.45GHz (diameter of about $1.5\lambda_0$) than at 403.5MHz (diameter of about $0.25\lambda_0$), its impact on the radiation pattern is more important. This is very likely due to the skin depth mentioned earlier.

The modification of the radiation pattern by the head model has also been assessed for three antennas with different HPBW. The most directive Huygens antennas have a reduced radiation towards the body and they are consequently less impacted by its presence (see the black patterns).



Influence of the body on the radiation patterns at 403.5MHz for various Huygens antennas (HPBW=±65° in red, HPBW=±50° in blue and HPBW=±40° in black) placed at 10mm from the body

4) Future collaboration with host institution (if applicable)

Newfocus has helped to pursue the existing collaboration between IETR and EPFL as well as to initiate a joint work between IETR and the University of Zagreb. This work on the modeling of implanted and wearable antennas is of great interest for the involved institutions and will continue.

5) Projected publications / articles resulting or to result from the grant *(ESF must be acknowledged in publications resulting from the grantee's work in relation with the grant)*

This short visit was very fruitful. In spite of the small amount of time, the material obtained and shortly summarized in this scientific report has, we believe, a significant degree of novelty.
After compiling and completing appropriately the preliminary results obtained in the framework of Newfocus, we expect in a near future to write a journal paper and disseminate our results via presentations in conferences.

6) Other comments (if any)

I would like to acknowledge Newfocus because this grant was really helpful and well suited to help developing this joint work between IETR, EPFL and the University of Zagreb.