Sub-GHz Inductive Power Transmission from Helical Coils for Implanted Medical Devices

A. Diet¹, S. Koulouridis¹,², Y. Le Bihan¹, Q.-T. Luu¹, O. Meyer¹, L. Pichon¹, M. Biancheri-Astier¹
¹GeePs, UMR CNRS 8507, Université Paris-Saclay, Sorbonne Universités.
11 rue Joliot-Curie, Plateau de Moulon 91192 Gif-sur-Yvette, France
²School of Electrical and Computer Engineering, University of Patras, Patras, Greece.
antoine.diet@geeps.centralesupelec.fr, koulouridis@upatras.gr, yann.le-bihan@geeps.centralesupelec.fr

Abstract—This paper presents some measurements and simulations results in which small helicoidal coils are designed, in the idea to provide a RF power transfer for implanted medical devices (IMDs). In such context, the coils should be very small if they are implanted within devices, or even if they are used as an alternate solution combined with UHF antennas (ex. PIFA). The influence of the body and the mandatory small size of the coils bring a difficult technological lock concerning efficiency and measurements accuracy which must validate our simulations. In this paper, a deembedding technique is used to take into account the dedicated test fixture, and further works will investigate the electromagnetic influence of a liquid phantom, modeling the muscle tissue.

Keywords— IMD, antennas, WPT, coils, measurements

I. INTRODUCTION

Implantable Medical Devices (IMDs) offer several advantages for diagnostic and therapeutic purposes including sensing, stimulation, and drug delivery. Since the first implementation of pacemakers in 1958, numerous researches have been conducted around the world to apply the state-of-the-art techniques to the implantable medical devices (IMDs) industry. In order to design smaller IMDs and to reduce potential interaction with the human body, a device with or without embedded rechargeable batteries is desired.

The topic of IMDs is of great interest for electrical engineering scientific community since its wireless powering and communication ability are technical challenges. Additionally, the technical solution proposed for power transfer (as in WPT and RF harvesting topics) and wireless communication (NFC or Far Field) can concerns two key examples whether is considered in-body to in-body or out-of-body to in-body cases of study [1][2][3]. As shown in Figure 1, the body has a complex permittivity which can strongly influence the designs of the antennas. Frequencies investigated for powering and communicating with IMDs goes from HF to UHF because of too high size of lowest frequencies antennas in one hand and too high losses of highest frequencies inside the body in the other hand. The design of antennas for IMDs has some solutions currently proposed such as the use of PIFA antennas [2][3] and the challenge is nowadays to technically combine different RF modes in far field or near field for powering and communicating.

![Figure 1: the two cases of IMDs RF powering or communication](image)

In this paper we focus on the feasibility of a very small coil which can transfer energy at low distance and could be used in one of the two cases in Figure 1. This could efficiently help those of the current IMD designed for which only radiating RF mode is used. The design of such a coil implies that the body influence will be different depending on the frequency and type of biological tissues [4][5][6]. Also the size of the antennas has to be extremely small if implanted and figures of merit should be defined on the efficiency ability of the system [6][7]. However, we can use the antenna size as a degree of freedom for one of them if the case in-body to out-of-body is considered. In the second part of this paper we will present simulation results for such this case, considering an arm for biological tissue. In the third part of the paper we described the design and measurements of small coils, with a diameter of 2.5 mm, at a distance of 10 mm, including the mandatory 2-port deembedding techniques (because coils are smaller than SMA connectors) [8][9][10]. Finally, the last part concludes on further and current works concerning measurement deembedding in phantoms, used for modeling the muscle.

II. INDUCTIVE POWERING SIMULATION

The transmission of a signal between two coils is investigated in the case of an helicoidally coil for the receiver and a loop at the transmitter, in the presence of a muscle tissue
under CST microwaves studio, as seen in Figure 2. The dielectric properties of the muscle simulated, in HF and UHF, are 50 for the relative permittivity and 0.79 S/m for the conductivity.

The simulation and computing of PTE are done in function of the size (radius) of the transmitter loop in presence or not of the tissue. At a fixed distance of 24 mm, the receiver coil is an helicoid of 1mm height, with a diameter of 0.5 mm and has 7 turns. Results are shown in Figure 3.

The simulation results in Figure 3 shows that the presence of the body tissue shifts towards low frequencies the optimal value of power transfer efficiency (i.e. the optimal frequency of operation) and lowers it due to additional losses. Moreover, the design of coils should be investigated by optimizing the shapes of the coil and avoid the presence of a self-resonance in the HF to UHF band of interest (3-300 MHz). In the following part, we designed small identical helicoidal coils for investigating the RF link at such frequencies.

III. Tests with small coils

The design of small coils with a diameter of 1.25 mm and height of 1 mm, are made with thin copper wire and fixed on nylon screws, as shown in Figure 4. Due to the small size of the helicoidally coils, we used a test fixture with PCB in which the connector are at a distance of 2 cm from the coils in order to limit the influence of the metal on the electromagnetic near field generated by the coils, as shown in Figure 4.

The test fixture used will drive us to use a deembedding technique adapted to the unavoidable presence of PCB and lines in HF to UHF frequencies. Some matrix techniques of deembedding are presented in [9][10] for transistor measurements and can be fruitfully used in our case. One method is graphically synthesized in Figure 5 and needs the additional design and measurements of 2-ports “short” and “open” configurations with the same test fixture to be able to compute the matrix equation on admittance parameters.
Measurements are done with a Vector Network Analyzer and S parameters are deembedded and converted towards admittance and impedance parameters under Matlab. An analytical evaluation of the self-inductance of the helicoidally coils is given by Piri et al. in [8], and reported in (2) where K(k) and E(k) are the complete elliptic integrals of the first and second kind, respectively.

\[
L = \frac{8}{\pi \mu_0 R^3} N^2 \frac{1}{k^2} \left( \frac{1}{2} \right) \left( K(k) - E(k) + E(k) \right) - 1
\]

Figure 6 presents the deembedded measurements results for port 1 and port 2. As can be seen in this figure, the measurements deembedded are in the range of the analytical expression with a tolerance of 10% under 300 MHz (upper limit of VHF). In UHF, measurements are not of good accuracy due to the potential self-resonances of coils and or parasitic elements of the test fixture and connectors soldering, even with the deembedded techniques.

The measurements of the previous part show an interesting matching for self-inductance evaluation under 300 MHz with a simple calibration test fixture. Some parasitic are still presents after deembedding and we need to improve the design of the test fixture to be able to evaluate the whole impedance matrix of the 2 coils system.

The design of the coil in the presence of a biological tissue can be fruitfully helped with measurements of the coil inside a phantom made with Triton X, water and salt. This phantom is shown in Figure 7, in which its relative permittivity and conductivity are given in function of the frequency. Nest step of the coils design is so to accurately deembed and retro-simulate to match the characteristics of the medium for optimization of the small coils.

IV. CURRENT WORKS AND CONCLUSION

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REFERENCES