Investigation of Efficient Wireless Charging for Deep Implanted Medical Devices

Stavros Koulouridis\textsuperscript{1,2}, Sofia Bakogianni\textsuperscript{1}, Antoine Diet\textsuperscript{2}, Yann Le Bihan\textsuperscript{2}, Lionel Pichon\textsuperscript{2}
\textsuperscript{1}School of Electrical and Computer Engineering, University of Patras, Patras, Greece
\textsuperscript{2}Group of electrical engineering - Paris, UMR CNRS 8507, CentraleSupélec, Univ. Paris-Sud, Université Paris-Saclay, Sorbonne Universités, UPMC Univ Paris 06, 3 & 11 rue Joliot-Curie, Plateau de Moulon 91192 Gif-sur-Yvette CEDEX, France
koulouridis@upatras.gr, sofiam@ece.upatras.gr, antoine.diet@geeps.centralesupelec.fr, yann.le-bihan@geeps.centralesupelec.fr, lionel.pichon@geeps.centralesupelec.fr

Abstract—A human tissue-implantable rectenna that is intended for wireless data telemetry and power transmission operation is considered. To that end, a compact-size planar inverted F-antenna (PIFA) that initially operates within the Medical Device Radiocommunications Service (MedRadio, 402-405 MHz) and the industrial, scientific and medical (ISM, 902.8-928 MHz) bands is considered in order to evaluate advantages and disadvantages of radiating versus inductive power harvesting at sub-GHz region. The inductive coupling is carried out in MHz region in order to employ very small (mm-diameter). The scenario considered focuses on implants embedded in depths higher than 10 mm. The analysis is carried out inside the muscle tissue of a cylindrical three-layered phantom representing the human arm. The Specific Absorption Rate (SAR) performance of the implanted system is assessed. The RF-to-DC conversion efficiency is also taken into account.

Keywords—Telemetry, Inductive and Radiating Wireless powering, sub-GHz region

I. INTRODUCTION

On the basis of lessening patient discomfort and reinforcing long-liveness of the device, miniature antennas are integrated into Implantable Medical Devices (IMDs) that can react wirelessly with the external world. Ideally, for such applications, radio frequency (RF) band has been employed as it is offering wireless data telemetry and power transmission at MedRadio (402-405 MHz) and ISM (902.8-928 MHz) bands, correspondingly, is proposed. Considerations of power transfer at MedRadio (402-405 MHz) and ISM (902.8-928 MHz) bands are investigated for wireless biotelemetry purposes. Still, there is research deficiency on the expected advantages. Use of antennas for wireless energy transmission can alleviate such problems. Greater distances, more robust designs, not additional and sensitive external applicators are some of the expected advantages.

Inductive coupling has been heavily investigated as a possible solution for wireless energy transfer. Lately, in order to minimize necessary coils sizes, research has been focused on the sub-GHz regime \cite{4,5}. Indeed, implanted loops of a couple mm radii are proposed. However, frequency of operation is an open issue since for similar geometrical characteristics, proposed region of operation varies from 200 MHz \cite{4} to 900 MHz \cite{5} or even higher. In any case, the use of 1-2 mm radius loops could allow for the coexistence of inductive circuits with antennas in the IMDs since the very small loops would not affect the relative larger antennas. Still, the use of inductive loops requires distances between external applicator and implanted receiver of 1-2 cm \cite{4,5} and therefore placement of the external applicator directly on the body. Moreover, displacement of the external applicator or unwanted misalignment between external and internal system can greatly affect wireless transmission performance.

Use of antennas for wireless energy transmission can alleviate such problems. Greater distances, more robust designs, not additional and sensitive external applicators are some of the expected advantages. Still, there is research deficiency on the investigation of RF wireless power. Wireless energy transfer is realized at 433MHz in \cite{6}, at 2.45GHz in \cite{7,9}, while in \cite{10} a novel miniaturized rectenna for wireless telemetry and power transfer at MedRadio (402-405 MHz) and ISM (902.8-928 MHz) bands, correspondingly, is proposed.

The objective of this work is to investigate different scenarios of wireless power transfer with reference to the 15x15x1.25 mm\textsuperscript{3} rectenna proposed in \cite{10}. A comparison is carried out between inductive and radiating power transfer and advantages and disadvantages are drawn for each approach. The main restriction applied is the embedding of the proposed device in depths larger than 10 mm and the use of frequencies below 1 GHz. As is explained in \cite{11} the use of lower frequency allows for higher power reception especially for depths larger than a cm. As is also discussed in \cite{4,5} the use of sub-GHz region is the optimum for inductive coupling in complex (closer to realistic) human models. The systems feed a ~10kOhm load with DC voltage and hence a rectifier is also sought.

II. GEOMETRY OF THE SYSTEM

The geometry of the proposed implantable slot PIFA is shown in Fig. 1 \cite{10}. The radiating patch is printed on a high-
dielectric substrate (Rogers RO 3210, $\varepsilon_r=10.2$, $\tan\delta=0.003$) of 0.625 mm thickness ($t$) and is covered with an identical superstrate layer. The patch surface and the ground plane have planar dimensions of 13.8 mm x 15.8 mm and 14 mm x 16 mm, respectively. A slot of width $w_2$ and length $l_2$ is opened on the metallic surface in order to tune the antenna at MedRadio band. An L-shaped slot is cut from patch surface for achieving additional antenna operation at 915 MHz for the wireless charging operation. The loaded slot has a non-uniform width of $w_3$ and $w_4$ and $l_3$ and $l_4$ lengths respectively (see Fig. 1). A shorting pin (point S) increases the effective antenna size and further enhances antenna miniaturization (see [10]).

Similarly, using the coils (the external coil is placed very close to the skin), the reception capabilities are also evaluated. Relative position of the external and internal applicators is also registered. The optimum frequency for the inductive coupling is also an open issue and is investigated. A harvesting system is also designed for both systems using off-the-self components.

IV. CONCLUSIONS

Radiating against inductive wireless harvesting is investigated for a novel PIFA operating in the sub-GHz region. To that end the antenna is embedded inside a three-layer arm model. Inductive coupling is carried out with coils seeking the optimum operation frequency. Radiating coupling is applied at 915 MHz while the antenna is also employed for medical telemetry at MedRadio band. Maximum harvested DC power with respect to relative position, misalignments, patient safety is evaluated.

REFERENCES