

Semi-Active 866 MHz RFID Implantable Tag Fed by 6.78 MHz Inductive Wireless Power Transfer

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Abstract—The paper presents a compact battery-less semi-active UHF RFID tag powered by an inductive wireless power transfer designed to be implanted into the human body. Communication runs at frequency of 866 MHz whereas powering is performed at frequency of 6.78 MHz to reduce losses. Tag sensitivity for communication was increased by about 21 dB with the help of inductive wireless powering when compared to a tag which did not employ this powering. Communication and powering circuits were integrated within compact structures on the sides of the reader and the tag. The reader side consists of a center-excised Archimedes spiral antenna for communication and a circular loop for powering. The tag side consists of a folded dipole antenna for communication and a rectangular loop for powering.

Keywords—semi-active RFID; inductive wireless power transfer; implantable RFID tag

I. INTRODUCTION

Highly integrated low-power radio frequency identification (RFID) chips enabled the development of implants for wireless monitoring and controlling functions of the human body [1]. The monitored object usually has a passive circuitry (RFID tag with chip) fed by part of power received by communication from a monitoring device (RFID reader).

The semi-active RFID chip can combine powering by the reader and powering by other source. Inductive wireless power transfer (IWPT) can be used to deliver power from this source. The IWPT represents an effective method for delivering power wirelessly from a source to an appliance [2].

The same frequency is usually applied to both communication and powering [1]. A concept using two different frequencies for communication and powering was discussed in [3]. However, the implant described in [3] contains a battery. A concept using three frequencies for forward and backward communication and powering was proposed in [4], but the implant featured in this concept requires a three-dimensional structure.

The RFID in the UHF frequency band enables the use of antennas of acceptable size for implants [5]. However, the considerable dissipation of communication signal power in the human body substantially decreases the read range. This must be compensated by an increase in the transmitted power of the

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reader. The solution of this problem was presented in [6, 7], using a semi-active RFID chip powered by non-electric sources.

This paper describes basic principle of a system which combines a communication scheme based on RFID and a powering scheme based on IWPT for a battery-less tag to be implanted into the human body. More details about the system can be found in [8]. The originally proposed two-frequency solution integrates both communication and powering elements into a single structure with communication running at frequency of 866 MHz (the European UHF frequency band). Powering of the semi-active RFID chip uses IWPT at frequency of 6.78 MHz (industrial, scientific, and medical frequency band) which assures a low dissipation of power transmitted through the tissue of the human body. The design is compact with a tag size suitable for implantation into the human body. The communication sensitivity is increased by 21 dB when the powering is on.

II. SYSTEM DESIGN

The geometry and the arrangement of the system is shown in Fig. 1. The electrical scheme of the reader and tag sides is drawn in Fig. 2.

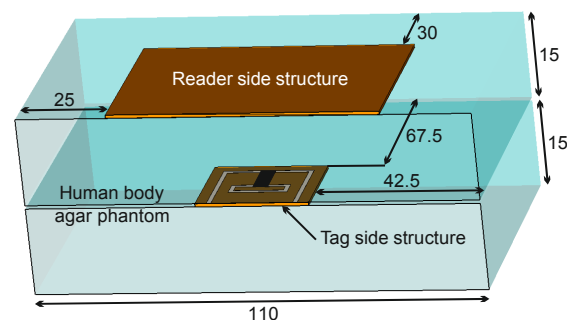


Fig. 1. Cross section of the designed RFID tag powered by IWPT located in the human body agar phantom and the reader side structure on top.

Communication and powering circuits are integrated into compact structures of the reader and tag sides. The reader side structure is comprised of a centre-excised Archimedes spiral antenna for communication and by a circular loop for powering, see Fig. 3. Similarly, the tag side structure consists of a folded dipole communication antenna and a rectangular powering loop, as shown in Fig. 5. Both the structures of the

reader and tag sides are designed on a Taconic RF 30 substrate ($\epsilon_r = 3.00$, $\tan(\delta) = 0.0014$, $h = 0.76$ mm). Additional circuitries are connected between the powering pins of the RFID chip of the tag and the rectangular loop, or, to the circular loop to assure efficient powering by IWPT. Parameters of the RFID reader and the chip are presented in datasheets [9, 10].

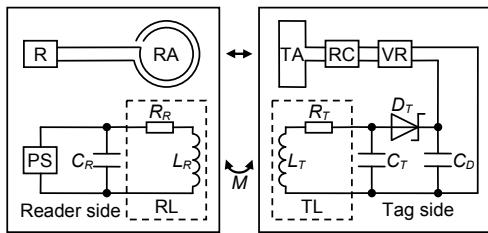


Fig. 2. Scheme of the system (R – Reader, RA – Reader Antenna, TA – Tag Antenna, RC – RFID Chip, VR – Voltage Regulator, PS – Power Source, RL – Reader Loop, TL – Tag Loop).

III. READER SIDE

A centre-excited Archimedes spiral antenna is used for the RFID communication on the reader side, see Fig. 3. The reader antenna properties are optimized for working in close proximity to the human body that is represented in design and measurement by an agar phantom ($110 \times 80 \times 15$ mm³, $\epsilon_r \sim 55$, $\tan(\delta) \sim 0.5$), as shown in Fig. 1. The antenna is expected to be matched to 50 Ω impedance of the reader at the operating frequency of 866 MHz. The antenna is optimized using an IE3D method of moments simulator. The maximum of the radiation is directed to the phantom. A comparison of the simulated and measured reflection coefficients of the antenna is presented in Fig. 4. A highly satisfactory impedance matching at the operating frequency of 866 MHz can be observed. Simulated and measured gains of the antenna have acceptable values -12.2 dBi and -11 dBi respectively.

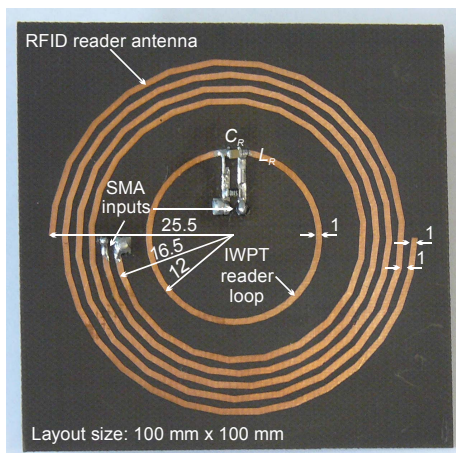


Fig. 3. Layout of the reader side structure.

A circular loop is used as a transmitting element for the IWPT on the reader side, as shown in Fig. 3. A simple loop is chosen since it has little influence on the reader antenna. The measured self-inductance and the resistance of the reader loop have values $L_R = 53.6$ nH and $R_R = 0.066$ Ω respectively. A reactance of the loop is compensated by a capacitor of value $C_R = 10$ nF to form a parallel resonant circuit at the operating

frequency of 6.78 MHz. The resonant circuit assures purely resistive input impedance as seen by the power source.

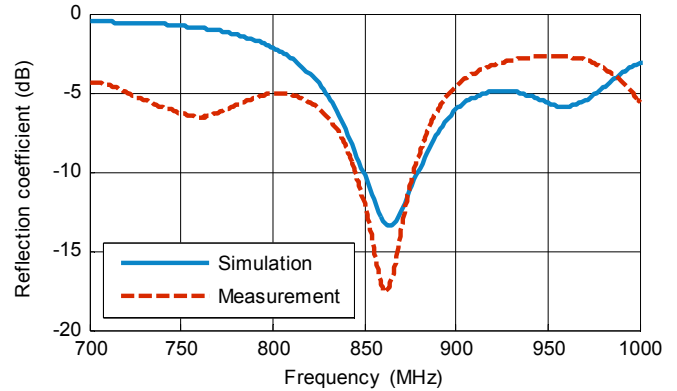


Fig. 4. Simulated and measured reflection coefficients of centre-excited Archimedes spiral RFID reader antenna situated on the human body agar phantom.

IV. TAG SIDE

A folded dipole antenna is used for the RFID communication on the tag side, see Fig. 5. The tag antenna properties are optimized to work in the human body that is represented in design and measurement by an agar phantom, as shown in Fig. 1. The antenna is connected to an RFID chip with input impedance $Z_{CHIP} = 7.4 - j122$ Ω at the operating frequency of 866 MHz in semi-active mode. The antenna is expected to have input impedance $Z_{ANT} = 7.4 + j122$ Ω at the frequency of 866 MHz to be matched to the chip. The antenna is optimized using an IE3D method of moments simulator. The antenna was manufactured and measured as a separate sample, without the chip, fed by an SMA connector to verify the properties of the proposed structure. A comparison of the simulated and measured input impedances of the antenna situated inside the agar phantom, according to Fig. 1, is shown in Fig. 6. Simulated and measured transmission coefficients between the antenna and the chip in semi-active mode at the operating frequency of 866 MHz are 0.75 and 0.87 respectively. Simulated and measured gains of the antenna are -24.9 dBi and -22 dBi respectively, acceptable for this class of implantable antennas [5].

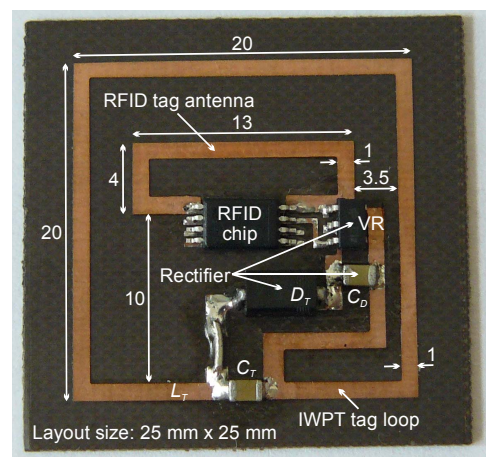


Fig. 5. Layout of the tag side structure.

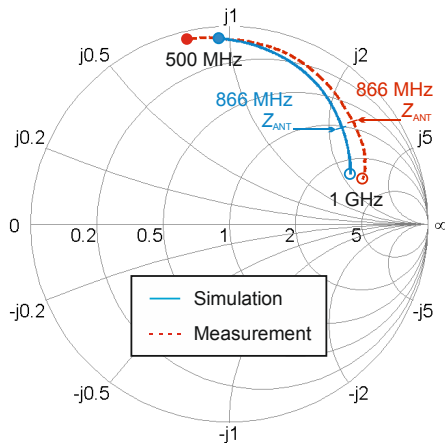


Fig. 6. Simulated and measured input impedances of folded dipole RFID tag antenna in a Smith chart in the frequency band 500 MHz – 1 GHz.

A simple rectangular loop is used as the receiving element for the IWPT on the tag side, as shown in Fig. 5. A simple loop is chosen since it has little influence on the tag antenna. The measured self-inductance and the resistance of the tag loop have values $L_T = 55.9$ nH and $R_T = 0.068$ Ω respectively. The tag loop is coupled to the reader loop by the mutual inductance of value $M = 3$ nH (measured value for the arrangement according to Fig. 1). A reactance of the loop is compensated by a capacitor of value $C_T = 10$ nF to form a parallel resonant circuit at the operating frequency of 6.78 MHz. The resonant circuit assures a sufficient level of voltage for the following simple rectifier which consists of a zero bias Schottky diode D_T , capacitor of value $C_D = 10$ nF, and a voltage regulator connected to the powering pins of the RFID chip.

V. MEASUREMENT OF SYSTEM PROPERTIES

The improvement of sensitivity of the RFID chip is verified by measurements with and without powering by IWPT and the minimum transmitted power by the RFID reader for a constant reading distance is measured.

Operating the RFID chip in a semi-active mode, with powering by the IWPT, allows the chip to increase in sensitivity about 22.7 dB, from -8.3 dBm in the passive mode to -31 dBm in the semi-active mode, according to [10]. It has been verified by measurement that the minimum reader transmitted power is reduced by approximately 21 dB, from 29 dBm in the passive mode to 8 dBm in the semi-active mode, in the arrangement according to Fig. 1. The measured reader transmitted power reduction 21 dB corresponds satisfactorily to the theoretical increase 22.7 dB of chip sensitivity in the semi-active mode. A relatively small difference 1.7 dB is caused by chips manufacturing tolerances and by non-perfect testing in a complex environment.

VI. CONCLUSION

A compact system for an implantable battery-less semi-active UHF RFID tag was designed, fabricated, and measured. This system integrates an RFID communication part operating at frequency of 866 MHz and an IWPT powering part operating at frequency of 6.78 MHz. The reader side structure

is composed of a communication centre-excised Archimedes spiral antenna located on one substrate, together with a powering circular loop. The communication on the tag side proceeds via a folded dipole antenna integrated inside a powering rectangular loop. Efficient performance of the IWPT is assured by the resonant principle and a simple rectifier with a zero bias Schottky diode.

The system is designed to work inside human body tissue represented in design and measurement by an agar phantom. The experiment verified the aim of the design: the sensitivity of the communication of the RFID chip has been improved by about 21 dB when the chip is powered by the IWPT. This allows to reduce significantly the power level of the communication signal, or to increase the depth of the tag placement in the body.

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