The UHF Gen 2 RFID System for Transcutaenous Operation for Orthopedic Implants

Xiaoyu Liu, Joshua R. Stachel, Ervin Sejdić and Marlin H. Mickle
Electrical and Computer Engineering
University of Pittsburgh
Pittsburgh, PA, USA
xil56@pitt.edu

J. Lee Berger
Ortho-tag Inc
Pittsburgh, PA, USA

***Abstract*— This paper aims to develop a UHF Gen 2 RFID system for transcutaneous operation for identifying and monitoring orthopedic implants. The major problems of using existing RFID antennas at UHF band for transcutaneous operation include possible interference with pacemakers and interference with other RFID systems working at the same band. To provide a solution for the above problems, this paper uses transcutaneous near field communication (TNFC) technology based on capacitive coupling between the reader and the tag. The reader and tag both have two electrodes and the energy and signal transmission occurs with the coupling between the electrodes. Both the reader and the tag are impedance matched for maximum power transmission efficiency. A reading range of 4.1 cm is achieved through pork skin using 30 dBm power from the reader. The proposed UHF RFID system is a feasible solution to provide high efficiency for transcutaneous operation while can eliminate an interference with other medical devices or RFID devices.**

Keywords—orthopedic implant; RFID; electrodes; UHF; transcutaneous near field communication

I. INTRODUCTION

A. Smart Implant

Orthopedic implants are a type of joint implant including knee implant and hip implant for joint replacement. Nowadays these implants are very common in orthopedic surgeries for patients who have severely injured joints. Orthopedic implants can be made smart by adding the following two capabilities.

The first capability is the identification of the implant and identification of the patient who is using the implant. This capability can reduce the time and cost in searching for patient and implant information and reduce the risk of counterfeiting as well. Radio frequency identification (RFID) is a technology providing this function which uses radio wave to communicate with a tag attached to the implant and read information from the tag [1]. If the memory on the tag is large enough, all information including implant information, patient information and information regarding surgery can be stored in the tag as a patient registry. RFID tags are commonly used for medical industry for managing inventory and tracking during transportation [2]; furthermore, radio waves are able to travel through tissue and therefore can be applied for transcutaneous operations such as the identification of implant.

The second capability of a smart implant is the function to monitor the implant by integrating sensors on the RFID tag to help diagnose the implant status. The present major problem during recovery period for orthopedic surgeries is the infection of the implant, an ill status difficult to observe and diagnose. A PH sensor is necessary for this case for the smart implant because by reading the change in the PH level, one can tell whether the implant is infected at the early stage. Because identifying early infection and apply proper treatment is considered an efficient way to avoid a second orthopedic surgery to cure the infection, it is believed that RFID tag with sensor applications will have a huge market value.

B. Interference between RFID and Pacemaker

It has been reported interference between RFID devices and pacemakers in some literatures [3] [4] that under some circumstances, pacing signals from pacemakers are missing if there is a working RFID system nearby. The possibility of interference is even higher during the transition period between RF signals. Even though in those literatures the conditions for interference to occur are not identical, it is believed that the radiated power from the RFID system is the main cause of interference when above a certain threshold.

Conventional antennas for the RFID tag and reader are based on inductive coupling for near field communication at low frequency or high frequency [1] [5] and radiation for far field communication at ultra-high frequency [6]. The fundamentals for the antennas are that electromagnetic wave travels through the air or a medium from the reader to the tag. That is to say, the EM wave has a chance to propagate through the air and body to reach the pacemaker and possibly cause interference if the input power is high enough. Therefore, the conventional antennas are not suitable for transcutaneous operations for health concern especially for those with a pacemaker. An alternative solution has to be developed to avoid such interference.

C. The Volume Conduction

The alternative method is to use capacitive coupling which uses electrodes as antennas. The electrodes at the reader side

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generate an electric field inside the medium when RF power is on and the electrodes on the tag are coupled with the electrodes of the reader to capture power for the RFID chip and sensors. Because the medium is tissue, this method is usually called volume conduction, which has been applied previously for transmitting ECG signals [7] and for charging the battery of an implantable medical device [8]. Because the conductivity of human tissue goes high as frequency increases, this technology can be effective for UHF RFID system to transmit power deep inside tissue.

The existing systems using the above method are below or a little bit above 1 MHz, the aim of this paper is to discuss the feasibility of a UHF RFID system using electrodes at 915 MHz for communication, a frequency much higher than those used in the existing volume conduction system. Discussion on the advantages using UHF RFID system toward HF system is in the next section. Different from the existing UHF RFID systems, the proposed system requires its reader and tag in direct contact with tissue to work properly and if not, the tag and the reader will not respond to each other. The proposed system then can be considered as non-radiative because the majority of power is confined within a small area around the implant, and therefore can effectively avoid a possible interference with the pacemaker. Furthermore, the non-radiative RFID system is considered more secured than the existing systems in that the tag is not sensitive to the EM waves from another reader, protecting its data from being stolen or destroyed. The different between the proposed system and the existing RFID systems is illustrated in Fig. 1.

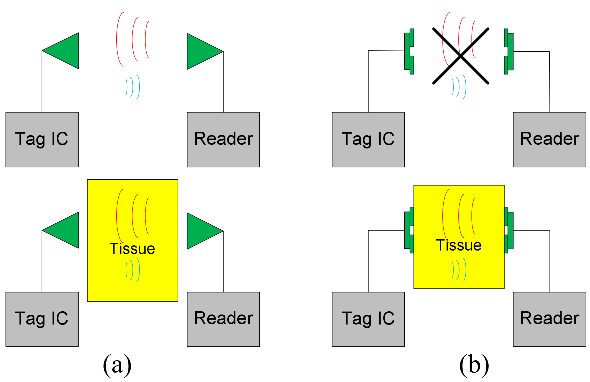

Figure 1. Difference between the existing RFID systems (a) and the proposed method (b).

II. PROPOSED SYSTEM

A. Overview

The proposed system follows the same principle as those proposed for volume conduction in which the major components are two pairs of electrodes, one placed on the surface of tissue at the exterior side and the other placed internally under the tissue but on the implant. The exterior electrodes are connected to the reader and the interior electrodes are connected to the RFID chip and biosensors. To obtain a more reliable communication between the reader and the tag, two matching circuits are added separately at the reader and the tag side to increase the system efficiency. The exterior electrodes and its matching circuit are the components of the touch probe, a package handheld to distribute the RF power into tissue. The interior electrodes, the RFID IC chip and the sensors are on the tag which will eventually be attached to the implant (Fig. 2). In this system, the information regarding the patient and the implant ID is stored in the memory of the RFID chip before the surgery and can be read out by the reader after the surgery is finished. The RFID chip does not only function as a transponder for the information it stores but also works as a host for the biosensors. Due to the technology advancement, the UHF Gen 2 RFID chips supporting sensor applications have already come into the market. The sensors can be powered by the external DC output of the RFID chip and can be communicated through I^2C or SPI interface, which greatly reduces the size of the tag.

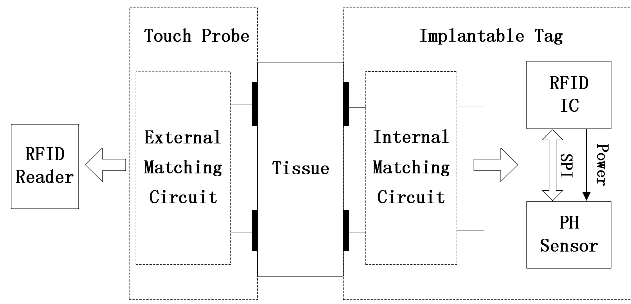

Figure 2. The proposed system.

The system efficiency can be determined by the following equation [6]:

$$\frac{P_{\text{TAG}}}{P_{\text{READ}}} = \tau_{\text{READ}} C \tau_{\text{TAG}} \tag{1}$$

where τ_{READ} and τ_{TAG} are the matching coefficient at the reader and the tag side, with perfectly matching being equal to 1. C is the coupling coefficient between the two pairs of electrodes. The efficiency is of significant importance because it determines the thickness of tissue that RF signal can go through.

B. The Operating Frequency

The operating frequency is one important factor to consider when building the system. As attenuation through tissue increases when frequency goes higher, UHF (915 MHz) system has a much higher attenuation than HF (13.56 MHz) and LF (134 KHz) systems; however, in this paper, UHF RFID system is selected due to several advantages. First, UHF RFID system has a much low probability of interference with pacemakers; second, because orthopedic implants are made of metal, signal degrading around the implant is serious problem for HF and LF systems but has a less effect to the UHF systems; third, the touch probe and the tag can be made smaller in size because of much smaller wavelength. Furthermore, UHF RFID systems follow Gen 2 standards with more industry support for medical compatibility devices such as MRI compatibility RFID ICs.

III. TOUCH PROBE AND TAG

From equation (1), the optimization of the system efficiency is to optimize the electrodes and the matching circuits so that the matching coefficients and the coupling coefficient are maximized. High efficiency can maintain continuously power supply to the tag to maintain a low error rate especially when reading sensor data. The tool used for optimizing the touch probe and the tag is the high frequency structural simulator (HFSS), a finite element analysis tool to study the electromagnetic field distribution between the electrodes. First the knee implant model is created including the tissue around it. The touch probe and the tag are then placed in such a manner that their electrodes are well aligned for optimal signal reception. The optimization then becomes the optimization of the size of electrodes and distance between the electrodes as well as the matching circuits with the efficiency to be maximized.

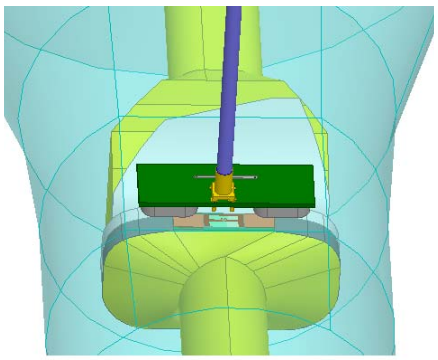

Figure 3. The HFSS model for the touch probe and the tag.

A. *The Touch Probe Design*

For better touch efficiency and better coupling, the electrodes are selected as rectangular shapes, a common electrode shape for direct contact. The distance between the electrodes are adjusted to be as much fit on the knee of an adult as possible. The matching circuit of the touch probe includes a capacitor and an inductor, which is placed on a printed circuit board (PCB) and directly connected to the electrodes through screw. To simplify the structure of the touch probe, inductor is formed by the trace on the PCB, which is a straight wire couple of centimeter long. The capacitor uses a smaller surface mount one at the level of picofarad. The matching circuit is then connected to the RFID reader using a SMA connector. The touch probe is shown in Fig. 3.

Figure 4. The touch probe.

B. *The Tag Design*

The pattern of the tag is shown in Fig. 5, where two electrodes are placed at the two sides of the tag in order to align with the touch probe and the matching circuit is in the middle. The matching circuit uses meander lines to form capacitors as proposed in [9] and uses the long traces on the tag to form inductors. The capacitors and inductors are optimized to match the impedance from the electrodes to the RFID IC. The feeding point of the RFID IC is at the center of the tag to balance the field distribution. The tag is optimized within an area of 20mm by 4mm so that it can be well attached to the front flat surface of the implant.

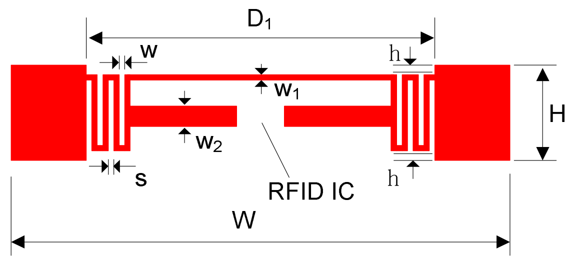

Figure 5. Patten of the tag.

The optimization process of the tag is shown in the following flow chart. To help simplify the optimization process and reduce the human interference, optimetric package from HFSS is used to speed up the simulation. Each control parameter is first assigned a range and the values for the parameter during the optimization process are picked up from the range by a certain step specified by the user. The simulator will scan all possible combinations of the parameter values during the optimization and find out the one that maximize the efficiency. Prototyping and testing will be performed after simulation and the parameters of the tag may need an update if there is a mismatch between simulation and experiment.

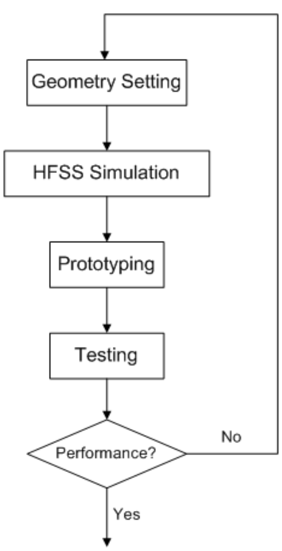

Figure 6. The optimization flow of the tag.

IV. EXPERIMENTS

The experiment platform is shown in Fig. 7. Pig skin is used as tissue in the experiment because its electric properties are close to human skin. The tag is place on a sample knee implant with layers of the pig skin on top. The touch probe is placed right on the pig skins. A simple RFID reader is made to perform the read operation. The reader includes a reader module with a power amplifier connected to the transmitter port. A circulator is used to connect the power amplifier output and the touch probe to the receiver port. An application software is used to control the reader for the operation and to collect the read error information. The tag has an RFID chip that supports sensor applications. For testing the sensor application, instead of a PH sensor, a temperature sensor is integrated into the tag and a heater is used to change the temperature of the pig skin. The maximum thickness of the pig skin that the prototype system could read through for reading the tag ID operation is 41 mm, while this number is reduced to 19 mm when reading the sensor date because of the higher amount of power consumption.

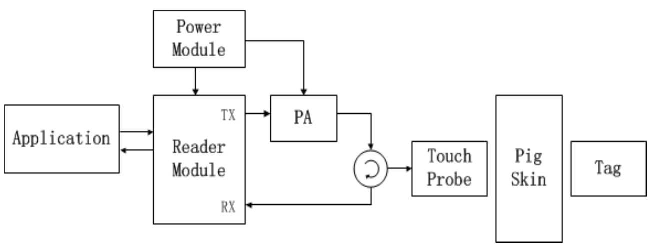

Figure 7. The experiment setup.

To study the possibility of interference between the proposed system and the pacemaker, the radiation pattern of the touch probe in free space is measured (Fig. 8). The gain of the touch probe determines the radiated power of the proposed RFID system using equation (2) [10].

$$P_{\mathrm{RAD}} = G_{\mathrm{ANT}} P_{\mathrm{IN}} \qquad (2)$$

where P_{RAD} is the radiated power, P_{IN} is the input power from the RFID reader and G_{ANT} is the antenna gain which is the gain of the touch probe in this paper. From Fig. 8, the peak gain of the touch probe is less than -15 dB, which is much less than the conventional RFID antennas whose gain is usually 6 dB. Because the radiated power is proportional to the gain, compared with the existing RFID solutions, the proposed solution has a gain more than 20 dB less and therefore has a radiated power more than 100 times less if the RF power from the reader is fixed. As the radiated power is one of the major factors causing a high possibility of interference, the proposed RFID system can effectively avoid an interference with a pacemaker.

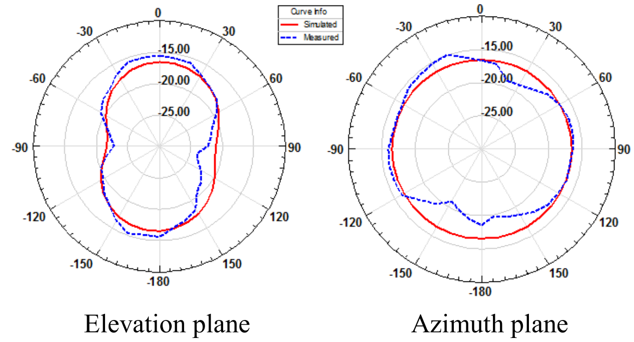

Figure 8. The radiation pattern of the touch probe in free space.

V. CONCLUSION

In this paper, a UHF Gen 2 RFID system designed for transcutaneous operation for orthopedic implants has been proposed in order to avoid interference with a pacemaker. The proposed system uses electrodes and direct contact method for powering the RFID tag and for communication. Optimization process has been performed to increase the overall efficiency and increase the operation range through tissue. The experiment on reading the tag through pig skin has demonstrated the feasibility of the proposed system for transcutaneous operation. The low gain of the touch probe in its radiated pattern also proves that the system can effectively avoid an interference with a pacemaker.

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