Development of a RFID-Based Tunable Power Scavenging System for the Telemetry of Self-sustainable Implantable Sensors

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***Abstract*— This report provides a brief summary of the main outcome of the research project presented to the 2016 IEEE MTT-S Graduate Fellowship for Medical Applications. The research objective of this proposal is to design a self-sustainable implantable wireless bio-pressure sensor system for chronic intra-cardiac pressure monitoring. The research includes the design of a passive wireless pressure sensor system and RFID based power scavenging system for telemetry of self-sustainable sensor with proposed tunable RF components. This report presents the design and modeling of a characterized bio-pressure sensor and the design of tunable RF components applied in self-sustainable RFID-based wireless sensor system**

***Index Terms*—bio-pressure sensor; Tunable RF Components; RFID; Sensor system**

I. Project Introduction

Congenital heart defects (CHDs) is a chronic disease requiring immediate interventions to monitor heart pressure [1. The normal open-heart surgery intervention by intra-cardiac monitoring poses significant risks for infection, microorganism colonization, sepsis, and endocarditis [2]. A novel method providing direct monitor of physiologic intra-cardiac that carries little or no bleeding and infection risks is needed**.**

Integration of radio frequency identification (RFID) with reliable implantable bio-pressure sensor is a promising solution for the telemetry in human body. Making use of recent advances in micro-electromechanical systems (MEMS) and semiconductor technology, the implantable bio-pressure sensor is designed as a series LC resonant circuit with a featured pressure-dependent capacitance. An inductively coupled passive wireless sensor system is designed and modeled for the telemetry of bio-pressure sensor as shown in Fig.1 (a). To overcome the small communication range in passive wireless sensor system [3] and limited battery life, RFID-based tunable power scavenging system is proposed to support the telemetry of wireless sensor in a longer communication range as shown in Fig.1 (b). With the assistant of power scavenging circuits, data processing components can be added to the sensor system to support a longer communication range with the readable digital sensor information [4]. The permittivity of human tissues can be affected by the complicated environment, such as temperature, pH, pressure etc. [5], tunable components such antenna and filter are required to adapt to the working

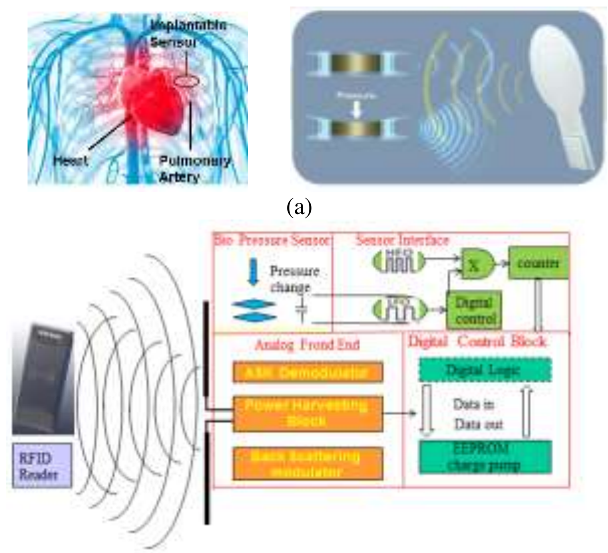


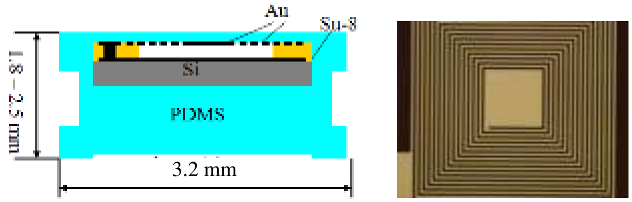
Fig.1. (a) Inductive coupling based passive sensor system (b) RFID-based tunable power scavenging wireless sensor system.

frequency of sensor system to ensure the maximum efficiency. The major challenge of the work is how to design miniaturized high-sensitivity bio-pressure sensor and miniaturized tunable RF components applied in RFID based wireless bio-sensor system. The projects are divided into two major tasks. The first work is the design of high-sensitivity bio-pressure sensor. The second step is making use of an engineered substrate to design compact and tunable RF components integrated with other components in RFID based wireless sensor system. The prototype of the RFID based wireless sensor system based on P2110-EVB design kits from Mouser electronics. The developed miniaturized RF components in the project will replace the ones in the evaluation board and be integrated into the system.

II. Project Description and Outcome

A. *Design of Miniaturized Bio-pressure Sensor*

There are two typical pressure sensors: capacitance-based (CB) or resistance-based (RB) sensors. CB sensor has performed with high sensitive, high resolution and bio-compatibility. However, the complicated 3D structure and



(a) (b)

Fig.2. (a) Side-view of bio-pressure sensor (b) Top-view of bio-pressure sensor

high-cost fabrication processes of the CB pressure sensor are the obstacles for biomedical application. RB pressure sensor performs high linearity in the sensing range. However, the poor performance reliability, sophisticated structure and fabrication processes are still the challenge for medical application. With recent advances in micro-electromechanical systems (MEMS) and semiconductor technology, the micro-fabricated bio-pressure sensor is designed with miniaturized LC resonant circuit which provides a pressure-dependent capacitance to enable noncontact pressure sensing through inductive coupling between two coils. To make it implantable, the bio-pressure sensor is designed within the footprint of 3.2 mm × 3.2 mm and packaged with bio-compatible material-PDMS as shown in Fig. 2. Combined with an inductive readout coil, a passive telemetry system can be realized and used to evaluate the performance of bio-pressure sensor. With applied pressure range from 0 mmHg to 100 mmHg, the response of the pressure sensor shows an average pressure sensitivity of 5.3 KHz/mmHg at a telemetry distance of 10 mm.

B. RFID Based Power Scavenging System

To have an efficient RFID-based tunable power scavenging system for the telemetry of self-sustainable implantable sensors, some blocks in RFID based power scavenging system as shown in Fig.1(b) are replaced by the compact and tunable RF components. These blocks include tunable components for the RFID reader, miniaturized implantable antenna, multistage rectifiers and sensor interfaces from the passive implantable sensor system. Making use of RFID based power harvesting wireless system to decrease the electrical size of an antenna will generally lead to the decrease of its electromagnetic performance. It has been theoretically and experimentally proven that using magneto-dielectric substrates with both high permittivity (ε_r) and permeability (μ_r) is an effective method to design miniaturized antenna with increased bandwidth and improved radiation efficiency. However, there are no natural low-loss magneto-dielectric substrates that could be applied directly for RF components. The project designs an engineered substrate embedded with patterned Py thin film presenting both high and current-dependent permeability, and it has been proved to be an efficient and cost-effective approach to design both of tunable and miniaturized devices without deteriorating the performance [6].

To counter the frequency shift of rectenna in implant sensor system, the transmitting antenna with frequency tunability is preferred to provide the power harvesting circuit with an adaptive and controllable power density. The high-gain and high-directivity tunable dipole antenna is designed on an engineered substrate enabled with patterned Py thin films. Miniaturization of implantable antenna is a great challenge due to fundamental limitations that restrict the performance of antenna with small physical dimensions and the compatibility with rectifying circuit. The planar inverted-F antenna (PIFA), evolved with miniaturized dimension from a quarter-wavelength monopole antenna, is used due to the attractive features such as simplicity, light-weight and easy fabrication with printed circuit board (PCB). Generally for the rectenna in power harvesting system, a low-pass filter is added between the antenna and the rectifier, which can reduce the harmonics induced by the nonlinear diodes from transmitting back to the antenna and thus help improve the efficiency [7]. Defected ground structure (DGS) providing the antenna with RF characteristic of band-rejection property is applied in the PIFA to reduce the size with the reduced number of components. And the size of PIFA is further miniaturized by combining several techniques, including meandered wire, fabricated on engineered substrate embedded with patterned Py thin film, and the usage of DGS. The related research work has been submit to TCMT and will be published within 2017.

III. Education Results and Acknowledgement

I am grateful to the IEEE MTT-S for the support of my research through the award of MTT-S graduate fellowship for Medical Application in 2016. This recognition allowed me a chance to attend IMS2016 that I obtained valuable experience meeting the experts from all over the world and was exposed to the latest academic research in microwave techniques. I was impressed by the development of the modern wireless communication system brought about by microwave technology in industrial exhibitions. My future plan is to be a design engineer in industry and make the cutting-edge technology in research into practical products.

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