Beyond RF Ablation Other uses for RF within the body.

Olive H. Murphy, Mohammad Reza Bahmanyar, Alessandro Borghi, Christopher N. McLeod, Manoraj Navaratnarajah, Magdi Yacoub, Christofer Toumazou

Abstract—The use of high frequencies within the body is commonplace for treatment and imaging, but, other than a few examples very little exists in terms of RF sensors and for communication deep into the body. This paper will give an overview of an RF powered implantable blood pressure sensor for continuous monitoring and in doing so demonstrate the use of RF within the body.

Index Terms—Biomedical applications of electromagnetic (EM) radiation, helical antennas, implantable biomedical devices, biomedical telemetry,

I. INTRODUCTION

CURRENT RF technologies, in particular when used for high speed high data communications, are extremely advanced. With the proliferation of the internet and smart phones, RF ICs continue to be the core of communications system, with further need for faster, smarter, smaller and less battery hungry chips. This multibillion pound industry has fueled entire economies and employs some of the most intelligent and most entrepreneurial minds available.

To date a fraction of this technology has been applied to healthcare - enabling patient tracking [1], wireless endoscopic imagining [2], cochlear implants [3] and indeed RF ablation [4] but the technology for using RF devices as implantable sensors and for communicating with same needs to be highlighted, so that the wider RF community can have a larger impact on the diagnosing, monitoring and treatment of a wide spectrum of chronic illnesses.

Such an example will be presented in this paper which has enabled the continuous wireless monitoring of a deeply implanted blood pressure sensor enabling access to previously unavailable clinical data, and an array of benefits for patients and healthcare providers. While a relatively simple concept complicated by the presence of the body, this project has always remained true to the fundamental principles of RF engineering. An overview of the use of RF will be presented along with the first known wireless pressure data from the left ventricle of the heart of a living swine [5].

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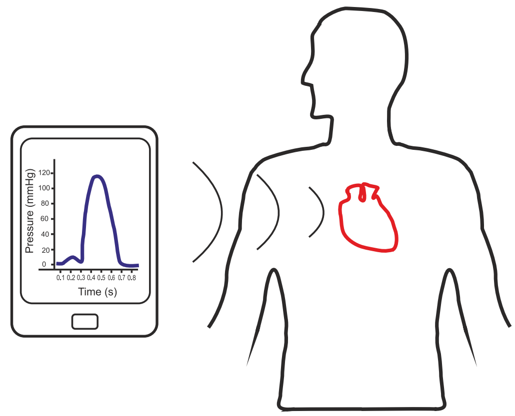

Fig. 1. System overview

II. BACKGROUND

The precise monitoring of blood pressure is key in the treatment of a number of conditions such as hypertension and heart disease [6]. Many studies have shown the effectiveness of continuous monitoring, especially when the patient is allowed to go about their daily lives. There have been some attempts of recording blood pressure using implants in the past [7] but not with the technology presented here.

The system comprises implantable components and external components. Fig.1 presents an overview of the system, whereby an external interrogator powers the implantable passive sensor using electromagnetic radiation; it then listens for the response and interprets an accurate pressure reading.

The location of the high frequency implant is the left ventricle (LV) as seen in Fig.2, the pressure here being vital for monitoring post heart transplant patients and patients with left-ventricle assist devices (LVAD). This information is highly desirable by clinicians and is a vital aid with regards to the treatment and discharge of patients undergoing LVAD implantation [8].

III. RF WITHIN THE BODY

The complexities of working at RF frequencies are well known; however, this is further highlighted when using RF within the human body. Fortunately, this has been studied to some extent [9] so recipes for accurate bio-phantoms for in vitro testing are available, albeit it a tedious and laborious exercise. One advantage of working within the human body is that due to higher permittivities the wavelengths of the frequencies decrease making smaller implantable antennas

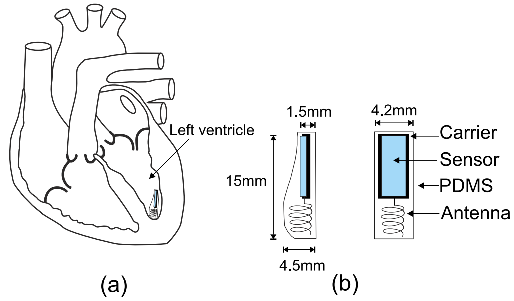

Fig. 2. (a) Location of the pressure sensor in the left ventricle, (b) dimensions of the implantable sensor

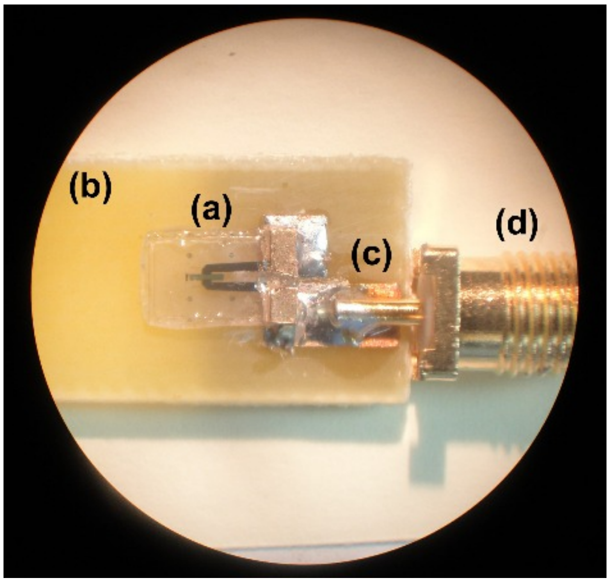

Fig. 3. Assembled (a) pressure sensor on (b) FR-4 test board with (c) transmission line and (d) SMA connector

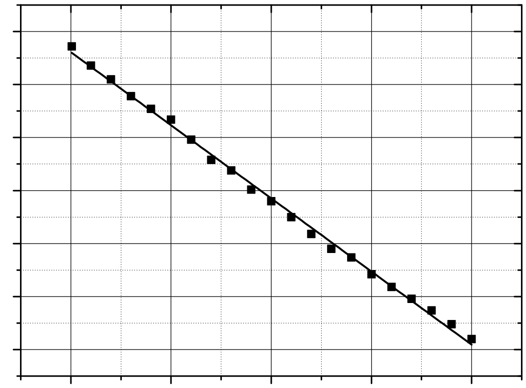

Fig. 4. Plot of the sensor resonant frequency versus pressure

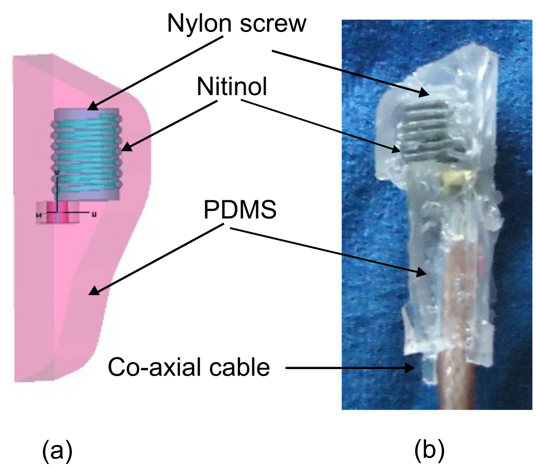

Fig. 5. (a)Pseudo-normal-mode helical antenna wound on a nylon screw, surrounded by PDMS and simulated in a homogenous human body environment (b) photo of the antenna used for tuning in bio-phantom.

possible; however there are many challenges which will be highlighted in the following sections.

A. RF Pressure Sensor

Comparable to a tyre pressure monitor, the implantable blood pressure sensor is based on a surface acoustic wave (SAW) resonator on piezoelectric quartz. SAW resonators are ubiquitous in all RF communications but they are also ideal as implantable pressure sensors as particular cuts of quartz can produce high quality factors and be very temperature insensitive. A SAW resonator is placed at the centre of a thin diaphragm which can deflect with pressure, hence giving a different frequency depending on the applied pressure. Fig. 3 shows a quartz resonator assembled into an implantable pressure sensor and mounted on FR-4 in preparation for testing. Fig. 4 shows the linear response of frequency versus pressure.

Attaining a long term hermetic seal on such a sensor is very difficult so current wafer processing technology is being pushed to the edge to develop a fully hermetic sensor.

B. Implantable and wearable antennas

This system is designed to operate in a Short Range Devices band about 868MHz, ensuring sensors of good quality and relatively small antennas for implanting with the sensor. The anatomical geometry of the cavity into which the sensor is implanted determines the design of the antenna. For placement within the LV a pseudo-normal-mode helical antenna is a good candidate as it offers circular polarization and therefore the exact position of the implant is not required [10]. The shape, thickness and type of insulation is vital and accurate simulations can be carried out before being tested in electro-magnetically correct bio-phantom to mimic the human body. Fig.5 shows the setup when the antenna was encapsulated in polydimethylsiloxane (PDMS) and tested in bio-phantom.

The external wearable antenna is also a key component. Its size, position, polarization and gain are all key components. Using a linearly polarized external antenna is feasible with a circularly polarized implanted antenna, however a dipole is extremely sensitive to its environment while a patch is very stable.

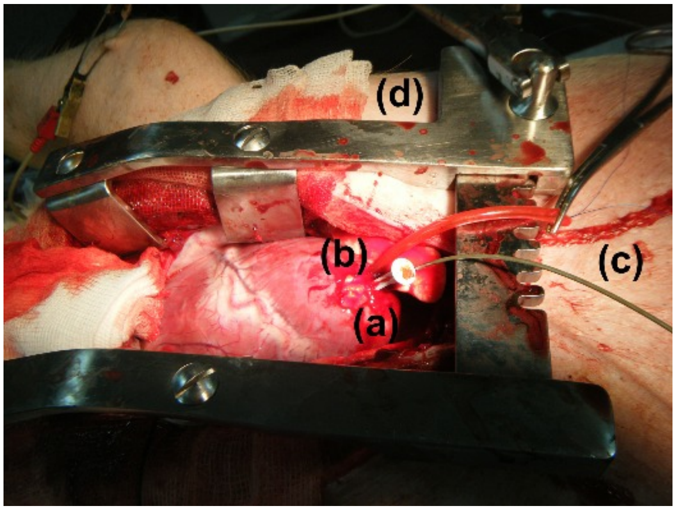

Fig. 6. Anaesthetised mixed landrace pig with (a) exposed LV apex, (b) implanted wireless pressure sensor, (c) catheter-tip transducer and (d) chest spreader

C. RF Interrogation

In theory the method for interrogation appears relatively simple, RF energy at the natural frequency of the implanted resonator is sent in a short burst, then the decaying resonance of the implant is sampled, recorded and translated into a pressure value. However, this method is non-trivial for many reasons. High power levels must be applied as the implant is inherently lossy as well as being deeply implanted. This means the return signal is very low and applying increasingly higher power levels means meeting the spectral regulations is increasingly difficult. While the implanted resonators have excellent Q, this in turn means that the response decays very quickly making it very difficult to sample and decode. Traditionally, when used as a tyre pressure monitor an impedance mismatch between the resonator and the antenna is used as a way of slowing down the decay; however in such an environment power levels are not an issue, therefore impedance matches are necessary at the cost of quicker decays [11].

IV. In vivo measurements

All aspects of the system are measured in electromagnetic bio-phantom using a pressure rig. Then the sensor and antenna was placed in the left ventricle of a living landrace pig along with a catheter-tipped pressure transducer for the sake of comparison as seen in Fig.6. With some simple filtering there is a clear correlation with the Millar catheter-tip transducer as seen in Fig.7.

V. Conclusions

This paper has given a brief overview of a project where RF is the most key component. Its use as both a sensor and as a method of communication is underpinned by a strong understanding of the fundamentals of RF. Future projects can only benefit from further advances in the use of RF within the body for monitoring and commuication.

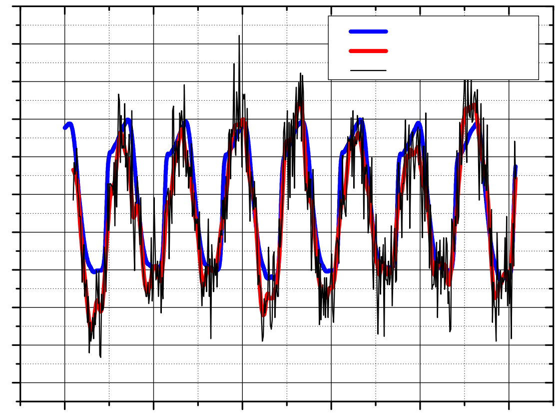

Fig. 7. Left ventricle pressure response versus time

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