Transforming a Wireless Biotelemetry System to an Implantable System

Shahidul Islam[1], Karu Esselle[1], David Bull[2] and Paul M. Pilowsky[3]

[1]Department of Engineering, Macquarie University, Sydney, Australia
[2]BCS International, 4 Sirius Road, Lane Cove, Australia
[3]Heart Research Institute, Sydney, Australia
E-mail: karu@ieee.org

***Abstract*— The major challenges associated with the transformation of a wireless system operating in air to an implantable version, antenna detuning and biocompatibility, are addressed in a coherent way. An RFID-based biomedical telemetry system designed for free-space operation was chosen as the starting reference. A new, pin-compatible, space-saving antenna with a ground plane was designed, fabricated and tested, to replace the original "free-space" antenna in the active RFID tag without making any other changes to the tag circuit, such that the tag would function well when it is placed under rat skin and fat. Biocompatibility and potential antenna detuning due to rat tissue variations were addressed in the design process, without significantly increasing the tag physical height, by applying a thin coating of biocompatible material directly over the antenna. The operation of the medical telemetry system was successfully demonstrated, with the tag placed under rat skin and fat, and its range of 60-72 cm was found to be sufficient to support medical research experiments conducted with rats in cages. Due to the biocompatible coating over the antenna, antenna matching is very insensitive to changes in tissue dielectric constants and thickness. The footprint of the new antenna is 33% less than that of the original antenna, its measured 10 dB return-loss bandwidth is 100 MHz or 11%, and overall efficiency is 0.82% at 920 MHz.**

Keywords: implantable, biomedical, telemetry, RFID, PIFA, biocompatible, wireless, implanted, compact, antenna

I. INTRODUCTION

Rodents and other larger animals are widely used in medical research for various purposes including studies of breathing, hypertension and cardiovascular systems, the development new treatments for human diseases, and the assessment of new drugs for pharmaceutical trials. During these experiments, it is often necessary to continuously monitor physiological signals that include temperature, blood pressure, pH, nerve activity, electrocardiogram, and blood glucose levels. Wired telemetry systems are widely used for these purposes but skin infections and other problems due to wires being passed percutaneously through the skin often create complications. Although implantable wireless telemetry systems are available, they have limitations such as high power consumption, less flexibility, and high cost. A major disadvantage of current telemetry systems is that the area of the cage is limited, thereby restricting accurate simulation of the natural environment.

To efficiently address the limitations of currently available implantable wireless systems, we started with an extremely low-power wireless telemetry system provided by our industry partner BCS International. This system was designed and tested for operation outside the body, i.e., in air (or free space). The major modification that was required to convert this system to an implantable system was the replacement of its original "free-space" antenna with a pin-compatible and biocompatible antenna, which functions well when placed under rat skin and fat. This presentation will describe the process of this conversion and demonstration of the biotelemetry system operation after conversion. [1, 2]

II. WIRELESS TELEMETRY SYSTEM

Our RFID-based telemetry system consists of two types of units: (a) battery-powered, extremely low-power, active RFID tags that are connected to sensors and transducers and (b) a reader unit (base station) that is connected to a monitoring station via a USB cable. The top view of a tag and the original "free-space" antenna is shown in Fig. 1. A reader unit can be seen in Fig. 2. This system operates in the ISM band around

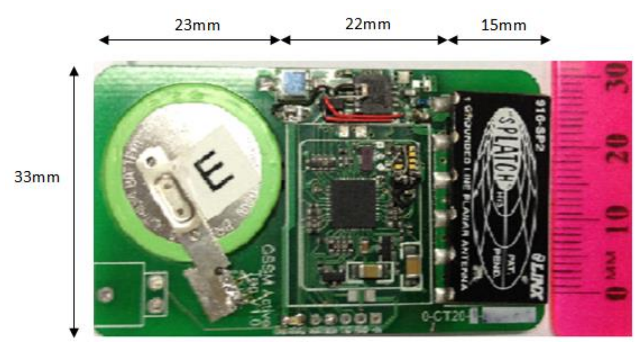

Fig. 1. Active-tag circuit board with the original "free-space" antenna. [1]

900 MHz. The battery-powered tag has a temperature sensor and an ECG sensor and it can be expanded, through a daughter card, to interface with other transducers for monitoring other physiological signals. The tag circuit also includes a Texas Instrument MSP 430F5438A microcontroller, an IDS Microchip AG SL900A RFID chip and a three-axis gyroscope.

The commercial "free-space" antenna in the original telemetry system (Fig. 1) has the dimensions of 27.9×13.7×1.5 mm^3. Its application notes do not allow the system designer to place a ground plane underneath the antenna. The volume below the antenna should be free from metal. The antenna RF terminal is connected to the RFID chip via a lumped impedance transformer network. Other terminals of the antenna are connected to the ground plane of the tag circuit using vias provided in the tag circuit.

With this original antenna, it was impossible to establish a wireless link between the tag and the reader when the tag is placed under a thin layer of rat skin and fat, even when the distance between the tag and the reader is extremely short. This is not due to the attenuation of the radio-frequency waves but instead due to the detuning of the antenna by the rat tissues. Compact antennas typically have bandwidths in the order of 5%. When antenna resonance frequency shifts by 15-20% due to rat tissues, antenna return loss at the system frequency drops to unacceptable levels (e.g., 1 dB).

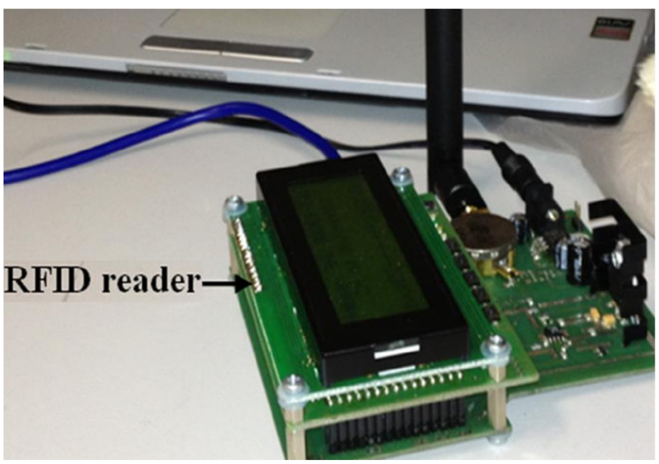

Fig. 2. RFID reader unit. [1]

III. Antenna Environment

Reasonably accurate yet computationally efficient representation of the environment surrounding the antenna is necessary to design antennas that are suitable for implantation. This tag will be implanted under the skin of rats. It is inevitable that there will be a thin layer of fat between the top of the antenna and skin layer. The antenna (and any other parts of the tag that are exposed to rat tissues) should be coated with a biocompatible layer. The tag will be surrounded by muscles etc. These features of a typical rat were represented in our design process using a simplified "rat box" model. The simplicity of the model helped to speed up the computations during design and optimisation.

The rat model parameters were initially set as listed in Table I, for the purpose of antenna design. Considering the uncertainty in these values and potential variations from rat to rat, several parametric analyses were conducted to assess the effects of key model parameters on antenna performance.

IV. Conclusion

An RFID-based active wireless medical telemetry tag unit, previously designed to work in air, was successfully converted to operate under rat skin and fat, by replacing its general-purpose antenna with a new application-specific antenna, which needs 33% less area in the tag circuit board. The operation of this implantable wireless telemetry system was successfully demonstrated in a system test in which temperature was continuously transmitted wirelessly between the tag and the monitoring (reader) station.

Thin layer of Nusil MED-1134 applied to the antenna top not only provided biocompatibility but also acted as a buffer to prevent antenna detuning and hence possible drop-out of the wireless link due to potential variations in skin/fat permittivity or skin thickness between animals. The thickness of the fat layer above the antenna, and hence the implanted position of the tag, is not critical either, for successful operation of the implantable biotelemetry system. Insensitivity of the antenna matching to tissue parameters (dielectric constant and thickness), together with good bandwidth, make this antenna potentially suitable for implantation in other animals as well, that have different tissue parameters.

TABLE I
ANTENNA ENVIRONMENT MODEL PARAMETERS [1]

"Rat box" Model Dimension	Symbol in Fig. 3	Nominal value (mm)
Skin layer thickness	t_1	2
Fat layer thickness	t_2	2
Muscle layer thickness	t_4	50
Coated tag height	t_3	7.8
Length of all layers	L_1	200
Coated tag length	L_2	62
Width of all layers	W_1	60
Coated tag width	W_2	35
Biological Tissue Name	Dielectric const. (ε_r)	Conductivity (σ) S/m
Rat skin	32	0.69
Fat	5.6	0.08
Muscle	58.8	0.84

References

[1] M. S. Islam, K. P. Esselle, D. Bull, and P. M. Pilowsky, "Converting a Wireless Biotelemetry System to an Implantable System through Antenna Redesign," *IEEE Transactions on Microwave Theory and Techniques*, Vol 62, No. 9, pp. 1890 – 1897, September, 2014.

[2] M. S. Islam, K. P. Esselle, D. Bull, and P. M. Pilowsky, "Making a Telemetry System Implantable: Challenges and Opportunities in Antenna Design," *invited paper in IEEE MTT-S IMWS -Bio 2013, RF and Wireless Technologies for Biomedical and Healthcare Applications*, Singapore, 2013, pp. 1-3.