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Bioimplantable impedance and temperature monitor low power micro-system suitable for estrus detection

N.Miranda^a, R.Morais^{b,d}, M.Dias^{c,f}, C.Viegas^c, F.Silva^{c,e}, C.Serôdio^{b,d}, J.Almeida^{c,e},
J.Azevedo^{c,e}, M.C.Reis^{b,d}

^aElectric Engineering Dep. – Polytechnic Institute of Leiria, Leiria, Portugal

^bEngineering Dep., ^cVeterinary Science Dep. – University of Trás-os-Montes e Alto Douro, Vila Real, Portugal

^dCITAB, ^eCECAV – University of Trás-os-Montes e Alto Douro, Vila Real, Portugal

^f3B's Research Group – Institute for Biotechnology and Bioengineering, Guimarães, Portugal

Abstract

Based on cyclic physiologic animal bioimpedance and body temperature a new method is being evaluated to predict estrus in dairy cattle with the aim of improving artificial insemination efficiency. Preceding in-vivo tests are being performed with a dedicated system based on the impedance converter AD5933, and a two-electrode configuration bioimplantable capsule. Acquired results will allow the optimal design of an implantable and autonomous low-power system. The implantable microsystem is being designed and simulated employing low-power techniques in a 0.35µm CMOS standard process.

Keywords: Bioimpedance measurement, low-power, artificial insemination

1. Introduction

The future of Artificial Insemination (AI) continues to be promising due to economic profits in herd practice. AI is the low cost option to disseminate the most profitable species. The reproductive efficiency is mentioned to be the major factor that affects production and economic efficiency. In herds that use AI, heat detection remains a serious problem limiting AI success [1]. Most detection methods aren't reliable or are expensive and not suitable in herd practice. Detection method should combine robustness, cost and herd feasibility. These characteristics suggests the need of continuous surveillance and excuse human intervention. To address these issues, the detection device or system must be based on measurement of animal physiologic parameters that depend systematically on estrus cycle [2]. Also, it should be remote and self-powered. Hormonal variations during estrus cycle produces variations not only in animal behavior, but also, in physiologic parameters such as reproductive tissues hydration and body temperature. Both different consequences are systematic and reflect the estrus phase. However, animal behavior is also a consequence of many other factors. As a result, heat detection technique based on animal behavior can produce both false positives and false negatives. In contrast, tissue hydration variations and temperature surrounding reproductive organs can provide useful data to detect heat phase and as a consequence, to predict the AI pinpoint time. Preceding studies reveals systematic electric conductivity variations on bovine vulvar fluids during estrus cycle[3].

Another detection method is based in this characteristic and is performed by inserting a probe on animal genitals. However, impedance variations from animal to animal, disease spreading or anatomic damage risk, and required labor discourage this method[4]. A autonomous implantable bioimpedance and temperature monitor can overcome most problems associated to the reliable detection of estrus [5]. A concept study of a novel estrus detection method based on bioimpedance and body temperature was already published.

Both bipolar and tetrapolar measurement method could be used to perform bioimpedance monitoring. First method is simpler to implement and needs only two electrodes, instead of the four needed for the second one[6]. Except to low frequency bioimpedance measurements, where the capacitive electrode-tissue interface is significant, bipolar method can provide similar accuracy as the tetrapolar one if correct circuitry are applied. Total capsule size and power consumption led us to choose the bipolar method.

This paper describes a impedance and temperature measurement device designed to evaluate both parameters during cattle animal estrus cycle. The purpose of this device is to evaluate the magnitude of bioimpedance and its variations during estrus cycle detecting its minimum value. Acquired data will allow the optimization of a bioimplantable low-power micro-system design regarding the analog front-end that includes the current source and signal conditioning circuits. Experiments are also described and some results from *in-vivo* evaluation on a sheep are presented. The on-going design of the implantable micro-system are also presented.

2. Material and methods

Measurement setup device is composed by an implantable capsule and measuring device connected by cable.

Implantable capsule has two stainless steel ring shape electrodes distanced 8mm and a PT100 temperature transducer. Capsule volume was filled with biocompatible polyurethane and its cylindrical shape with semi-spherical bases was carefully designed for animal implantation.

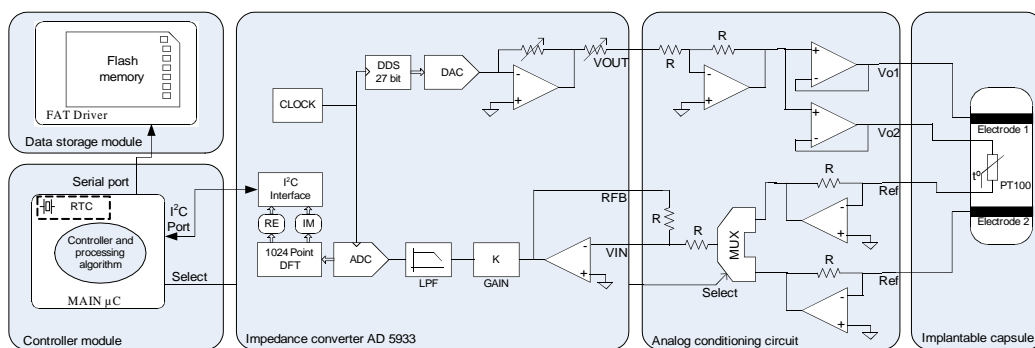


Fig. 1. Measurement setup block diagram.

The experimental macro device is composed by an impedance converter AD5933 (Analog Devices, USA), a analog conditioning circuit, two microcontrollers and a flash memory card. The device core is the impedance converter. It generates a sinusoidal voltage output to be applied on the living tissue and acquires 256 samples from the analog resultant current. An internal DSP computes the DFT of the current samples and, the harmonic 0 corresponds to the complex impedance factor. In this system, impedance converter performs both bioimpedance and temperature measurements.

The analog conditioning circuit reduces the AC amplitude voltage and cancel the DC voltage from the impedance converter output to avoid tissue polarization allowing long term bio-impedance monitoring. Temperature measurements are accomplished by using an embedded PT100 resistive traducer, thermally connected to one electrode. In order to use the same impedance converter and circuitry, an analog multiplexer is used allowing high resolution temperature measurement inherent to the impedance converter. The main microcontroller implements a real-time clock to periodically activate the impedance converter. It also processes the measured data and transmit it to the flash card module using its asynchronous serial port.

The purpose of the second microcontroller is to implement a FAT driver to store data in the flash memory card conveniently in a text or csv file for posterior analysis. Several measurement parameters are configurable such as the output voltage amplitude, sweep frequency points and interval period between measurements. Also, each frequency sweep point can be repeated and the cumulative result is used to improve precision.

System enters in sleep mode between measurements. Analog circuitry and memory card module are completely shutted down and total current consumption in sleep mode is 48µA. Measurement consumption is about 30mA during 15s. A lithium CR2 battery can last almost tree months performing 96 impedance conversions each twenty minutes.

Acquired data stored in the flash memory card is converted to impedance and temperature values though a spreadsheet file. This method allow the use of any resistive temperature transducer and turns the calibration process and data post process more flexible.

3. Experiment and Results

Experiments consists in continuous local bioimpedance and body temperature monitoring of herd sheep and cow females. Measurement region chosen was the vulvar muscle, were the reproductive hormones produce major effect and were the measurement capsule can be easily implanted with fast tissue regeneration and no permanent consequences.

The capsule implantation surgical protocol used was an adaptation of the surgical procedures described by Feldman *et al.* [7] and Smith *et al.*[8] in sheeps. A two centimeter vertical skin incision was made midway between the dorsal and ventral commissures of the vulva and the subcutaneous tissue dissected gently cranially five to six centimeter to position the capsule beneath the vaginal mucosa. The device was maintained in place by a subcutaneous suture that fixed the end of the implantable capsule, near the exit of the cable that connect the capsule to the measurement device. Figure 2(a) shows a final measurement device implementation including the implantable capsule. Figure 2(b) shows the device installation on a sheep to perform the experiment.

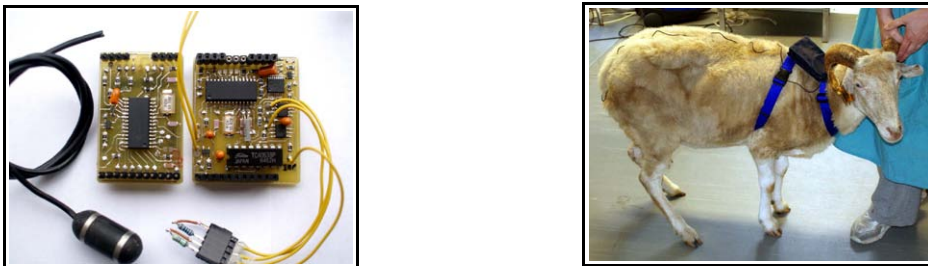


Fig. 2. (a) Measurement device picture and implantable capsule; (b) Measurement device installed on a sheep.

In the first experiment, temperature and bioimpedance frequency sweep were sampled each twenty minutes during two entire estrus cycle on a sheep. From each measurement, temperature and bioimpedance at tree frequency was featured and correspondent diary mean values are presented in figure 3. Bioimpedance data shows two local minimums which corresponds to an entire estrus cycle from June 29 to July 16.

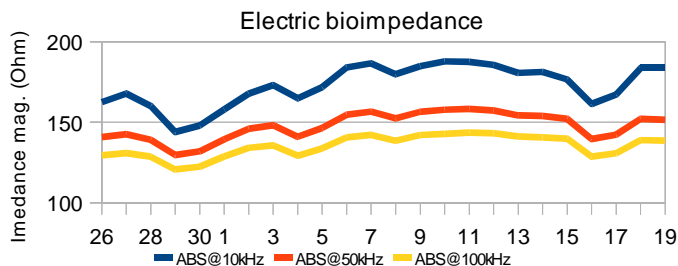


Fig. 3. Sheep bioimpedance absolute value at 10, 50 and 100kHz, from 2008 June 26 to July 19.

Results shows impedance variations are more pronounced at lower frequencies. According to the single cell tissue equivalent circuit model, impedance profiles suggest the extracellular resistance variations are responsible for the observed variations. The intracellular resistance lower global impedance mean and its variations for high frequencies due to the capacitive characteristic associated to the cell membrane.

4. On-going and future work

Physiologic parameters dependent on estrus cycle are now being monitored on cows. Each thirty minutes body temperature and bioimpedance sweep are sampled and stored in a flash memory card using the same experimental macro device.

The implantable micro-system are being designed and simulated in a 0.35 μ m standard CMOS technology. A proposed block diagram is presented in the figure 4.

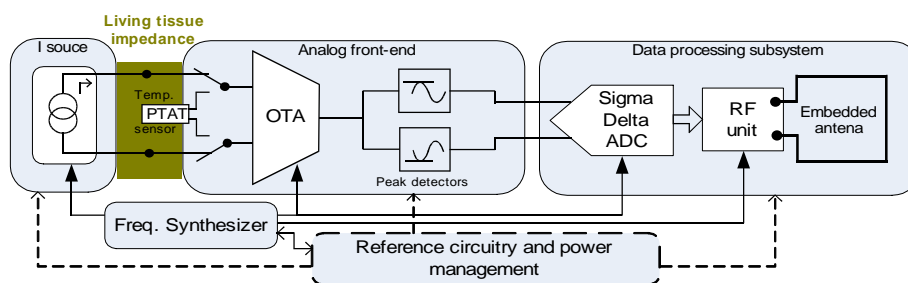


Fig. 4. Block diagram of the proposed implantable micro-system.

Low-power and low-voltage block architectures and design techniques are applied to the current source and to the analog front-end. Most transistors are polarized in moderate inversion to reduce current and keep the required transconductance and bandwidth. Temperature measurement are performed using a proportional to absolute temperature output voltage circuitry, and its signal is multiplexed with the resultant voltage from bioimpedance to be measured. A second-order Sigma-Delta modulator processes the analog signals to digital data to be transmitted through a efficient radio-frequency unit.

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