An Implantable Microsystem for Electrical Resistance and Temperature Measurements in Cows with Wireless Capabilities Suitable for Reproductive Management

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Abstract: In the cattle breeding industry, where artificial insemination techniques are employed, the successful detection of oestrus onset leads to considerable cost saving in herd management. One of the most reliable approaches is based on the determination of progesterone concentration in milk. However, these methods rely on the biosensor concept where a biological substrate is used in a chemical binding reaction to, directly or indirectly; produce some effect (electrical or light) that is used at the transducer level. These methods present several drawbacks concerning real-time measurements due to the complexity of the reactions involved and reagent/waste handling. Another approach is to combine measurements of electrical resistance of vaginal mucus and temperature to predict estrus. Using a low-power microsystem with wireless capabilities it is possible to take these measurements in-situ and more frequently. The proposed microsystem comprises a second-order delta-sigma modulator for analog to digital conversion and a class-E radio-frequency (RF) transmitter operating in the ISM-band of 433 MHz to transfer acquired data to a collar. Electrical resistance is measured by using a modified Wenner array and temperature by the on-chip temperature sensor. System (including battery and antenna) package is made of a tissue compatible material to allow implantation in the cow vulvar muscle.

Keywords: Microsystem, Wireless, Sensor

INTRODUCTION

Monitoring progesterone levels in milk is an effective method not only of predicting ovulation, and thus time to artificial insemination, but also for detecting pregnancy and fertility problems. Laboratorial measurements, based on RIA (radio-immunoassay) or ELISA (enzyme-linked immunosorbent assay) methodology have allowed oestrus detection with 98% specificity, but these methods require time and specific skills [1]. Several approaches have been developed by researchers to determine progesterone in milk and blood [2, 3, 4, 5]. Other studies have shown that electrical impedance in vaginal mucus may be used to pin point proper insemination time [6]. Decreasing electrical resistance (ER) values were always associated with the onset of estrus. Complementary to the ER variation during the estrous cycle, a temperature variation is also present and can be correlated [7]. The combination between these two parameters not only allows a greater specificity in prediction, but enables the conception of a complete and autonomous microsystem for ER and body temperature measurements, suitable to be implanted in the cow vulvar muscle. To achieve this purpose some key issues have been specially addressed: package (or encapsulation), measurement methods, data transfer and power consumption. All of these key issues are briefly discussed.

SYSTEM OVERVIEW

The specificity of the proposed methodology dictates that size and type of encapsulation is a major concern. For a reliable and long-term operation, the device has to be small, bio-compatible and power efficient. Regarding energy consumption, data transfer is accomplish by using a highly efficient RF transmitter operating in class-E mode to transfer small data packets every half-hour to a receiver device located in the cow collar. Data exchange with a collecting and/or processing station and network issues are not discussed here. Sensor implementation for measuring ER is based on a modified Wenner array. This modification allows measurements of ER using four conductive strips in the perimeter of the package, as depicted in Fig.1.

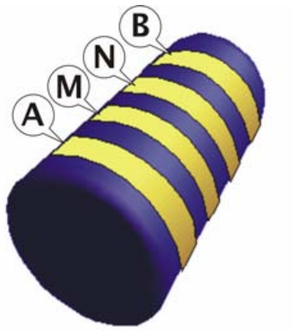

Fig. 1: *Perspective of the proposed microsystem package illustrating the modified Wenner array used to measure electrical resistance.*

In a Wenner array, four equally-spaced electrodes (**A**, **M**, **N** and **B**) are used to measure electrical resistivity. Two electrodes (**A** and **B**) are used to create a current *I* that flows away from or toward each electrode across the surface. The total potential difference between the electrodes **M** and **N** is given by [8]:

$$V_{\mathrm{MN}} = \frac{\rho I}{2\pi a} \quad (1)$$

where ρ represents the surface resistivity (Ωm), *a* is the space (m) between each electrode and *I* the current (A) that flows between electrodes A and B. The potential difference V_{MN} is then applied to a second-order switched-capacitor delta-sigma ($\Delta\Sigma$) modulator, implemented in a fully-differential topology. Fig.2 shows a simplified block diagram of all system.

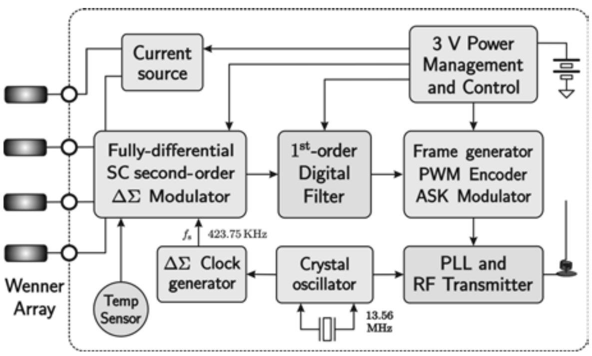

Fig. 2: *Block diagram of the proposed microsystem.*

Measurement of the internal temperature sensor (a PTAT device with an output voltage proportional to the absolute temperature) is achieved by multiplexing $\Delta\Sigma$ modulator inputs. The output of the $\Delta\Sigma$ modulator (bitstream) is then applied to a 1st-order digital filter to provide a 14-bit word. Prior to transmission, data is encoded as a pulse width modulated (PWM) signal and then transmitted by means of amplitude shift-keying (ASK) modulation. The RF frequency (433MHz) is generated by an on-chip frequency synthesizer based on a 13.56 MHz crystal.

DISCUSSION

An implantable microsystem for vulvar ER and body temperature measurements was presented to fulfill the requirements of a low-cost autonomous system to help oestrus prediction. The major advantage of the presented solution is the capability of performing continuous measurements of two correlated parameters during a long period of time without human intervention. Electrical simulations and previous implementations [9, 10] have shown that the delta-sigma modulator exhibits an effective 16.1-bit resolution (98.7dB dynamic range) with an 800Hz bandwidth and the temperature sensor has a 0.05ºC precision. Currently, the complete system is being implemented in a standard CMOS 0.35μ process (AMIS C035M).

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