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Wireless Platform for Multi-Channel Analog Measurements

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Abstract—This paper describes wireless measurement platform, which uses inductive power and data transmission and provides up to four analog measurement channels.

Platform is powered by inductive coupling using the 125 kHz magnetic field. Data transmission is realized by modulating the magnetic field. The platform has up to four 10-bit analog channels. The sample rate of the platform is 237 samples per second, which is divided between the used channels as needed. With 2.85 V supply voltage the measurement platform has power consumption less than 1.5 mW. Nevertheless the end application's total power consumption depends on the measurement set-up. Except for the antenna coil, the measurement platform is made using the commercially available components.

Main target application for the platform is implantable electrocardiogram (ECG) measurement. At this stage ECG measurements are done with one channel. Additional channels are available for example for other ECG channels, temperature or acceleration measurements.

I. Introduction

SOME implantable measurement systems, such as [1]-[4], have been studied. Most of the existing electronic implants, such as cardiac pacemakers, are designed for controlling or augmenting the human physiological phenomena, and measurements are mostly done to adjust those controls. In addition, studies have been done to externally measure the physiological parameters of humans or animals. Some state-of-the-art work in this field is done for example by CardioMEMS. Implantable radio frequency identification (RFID) is widely used in animals and also in some human targeted applications, such as VeriChip's human-implantable RFID microchip [5]. This paper introduces a multipurpose measurement platform for implantable or other wireless short-range measurements. The platform combines the power and data transmission used in low frequency RFID and measurement of physiological or other signals of interest.

In order to reduce the size, weight and complexity of the platform, no batteries are used, but the energy is transferred wirelessly to the device. The platform receives power by means of inductive coupling using the carrier frequency of 125 kHz. The magnetic field used for power transfer is also used for transferring data to and from the platform as suggested in [6]-[9].

The platform has four analog inputs, which can be configured to measure for example electrocardiogram, electromyogram or temperature. The power for the additional measurement circuitry can be fed from the measurement platform. Platform converts the analog signals into digital form and sends data out by modulating the magnetic field.

Platform is accompanied with hand-held, battery-powered reader device, which creates the magnetic field and handles the data communication between the platform and external processing system, such as a personal computer (PC). Nevertheless, further description of the reader device is beyond the scope of this paper.

This paper is organized as follows. Chapter 2 describes the measurement platform. Chapter 3 introduces one of the platform's main applications, electrocardiogram measurement. Platform's power consumption and operating distance are dealt in chapter 4. Final discussion is done in chapter 5.

II. Measurement Platform

Fig. 1 shows the block diagram for the platform. The platform is powered by inductive coupling formed between the antennae of the platform and reader device, which are LC resonance circuits tuned to 125 kHz. Data is transmitted by load modulation within the same magnetic field as power. The same principle is used for example in passive low frequency (e.g. 125/132 kHz and 13.56 MHz) RFID systems [6].

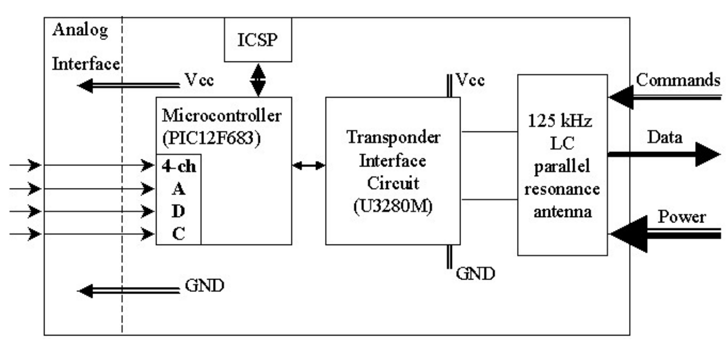

Fig. 1. Platform block diagram, ICs used in the implementation are in parentheses

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A. Implementation

A prototype implementation of the platform was done in order to test and demonstrate the system.

Transponder interface circuit (Atmel's U3280M) is used for voltage rectification and regulation and for bi-directional data transmission. It also includes 32x16-bit EEPROM, which could be used for additional data storage. EEPROM can be accessed through the circuit's two-wire serial communication interface. U3280M regulates the 2.9±0.3 V supply voltage for the rest of the platform from antenna voltage [9]. Transponder circuit modulates the antenna voltage according to the data signal sent from the micro-controller. U3280M has also an output (NGAP) which change its state based on the state of the antenna voltage – NGAP is high when the 125 kHz carrier is present at the antenna, and low when it is not present at the antenna. Commands are sent from the reader device to the platform by switching the magnetic field off for a short period of time. These gaps in the magnetic field and furthermore at the platform antenna voltage is detected as negative pulses in NGAP output of the U3280M [9]. On-board capacitors provide the supply voltage during the field gaps.

The micro-controller (Microchip's PIC12F683, MCU) has an internal 4-channel, 10-bit analog to digital converter (ADC). MCU receives an analog signal from the measurement block and converts it to a digital form. Conversion result is stored as a 16-bit word, in which six most significant bits can be used for identifying the measurement and/or the device itself. Result of the ADC is coded using the differential bi-phase (DBP) coding and sent to U3280M's modulation input. U3280M's NGAP output is connected to MCU's input for receiving the commands sent by the reader device. MCU uses its internal 4 MHz oscillator for the clock source, though with the earlier prototype external 4 MHz resonator was used. There is also the in-circuit serial programming (ICSP) interface on the platform for re-programming the MCU's application code.

B. Data Transmission

Coding for data transmission from the platform to the reader device is implemented using DBP-coding. Changes at the start of every bit, as shown in Fig. 2, can be used for synchronization and error detection. Data is sent with two bytes, high byte first, most significant bit (MSB) first as shown in Fig. 3. Final sample rate was 237 samples/s, yielding the bit-rate of 3792 bit/s.

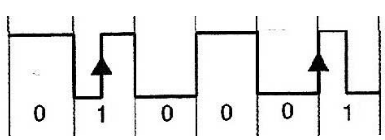

Fig. 2. DBP-coding [6]

High Byte					Low Byte		
MSB Bit 15	...	Bit 10	Bit 9	Bit 8	Bit 7	...	LSB Bit 0
6 Reserved Bits			10 Data Bits				

Fig. 3. Data packet sent by the platform

The sample rate is divided between the used ADC channels. Therefore sample rate per channel depends on the final application. If all the used channels have the same sample rate, the sample rate for each channel can be calculated with (1). On the other hand, for example having one channel for ECG measurement and one channel for temperature measurement, the temperature could be measured once in every second and rest of the time can be given to the ECG measurement.

$$s = \frac{237 \, {}^{samples}\!/_{s}}{n} \qquad (1)$$

where s is sample rate per channel and n is the number of channels.

III. Application Example – Implantable Electrocardiography

One of the major applications for the measurement platform described in this paper is implantable ECG measurement. This chapter shortly describes such an application and some of its essential parameters and in vitro results. Introduction to the prototype of the implantable ECG device is also reported in [10].

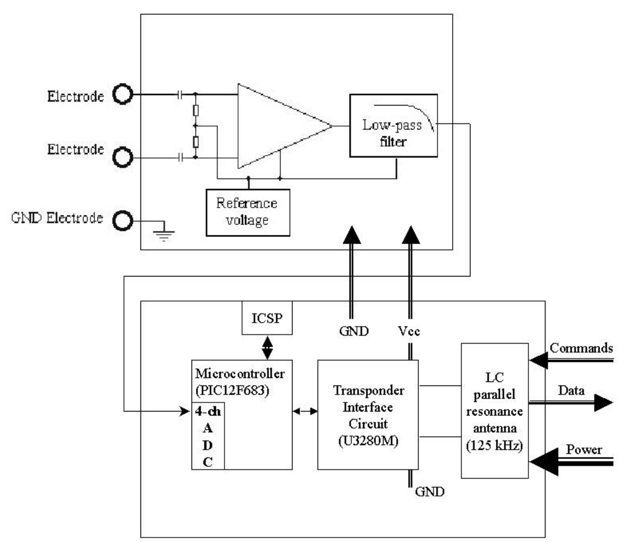

Fig.4. ECG application block diagram

As shown in Fig. 4, ECG amplifier block including high-pass filter at the electrode inputs, differential amplifier, and second order Sallen-Key type low-pass filter, was connected to one of the platform's analog inputs. Measurement block's supply voltage was provided by the platform. Also, the reference voltage with amplitude of half of the supply voltage was fed to the amplifier. Three electrodes, two for measuring and one for grounding, were connected to the measurement block.

Electrodes were placed on the chest at standard points V2, V3, and V4 used in the 12-lead ECG measurements. Resulting output is displayed in Fig. 5.

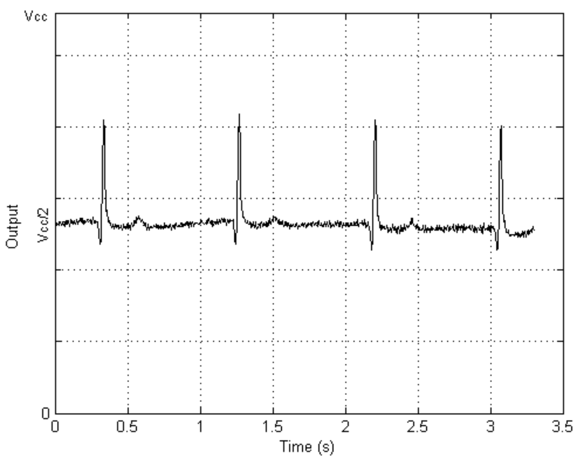

Fig. 5. Measured surface-ECG

IV. Power Need and Operating Distance

First the current consumption of the measurement platform is discussed. From current and measured supply voltage, the platform's total power consumption is calculated. Then the operating distance of the platform is described.

A. Current Measurement

Measurement platform's current consumption was measured with Fluke 87 True RMS multi-meter from U3280M's regulator output with no additional circuitry connected to analog inputs. Since the internal current consumption of U3280M itself was not measured, the total current consumption of the platform (I_{tot}) can be calculated with (2).

$$I_{tot} = I_{CC} + I_{Fi} + I_{FC} \tag{2}$$

where I_{CC} is the measured current consumption which equals 425 µA, I_{Fi} is U3280M's operating current during field supply which is typically 40 µA [9], and I_{FC} is U3280M's FC output's current consumption. FC-pin outputs the clock signal of 125 kHz extracted from the antenna voltage and has a current consumption typically 50 µA [9]. NGAP pin is low only when the magnetic field is not present, for example while sending commands from the reader device to the platform. Most of the time NGAP is at high state, in which its current consumption is –150 µA (U3280M sinks the current into NGAP pin) [9]. Current consumption caused by the NGAP pin is included in the measured I_{CC}. Currents are also shown in Fig. 6.

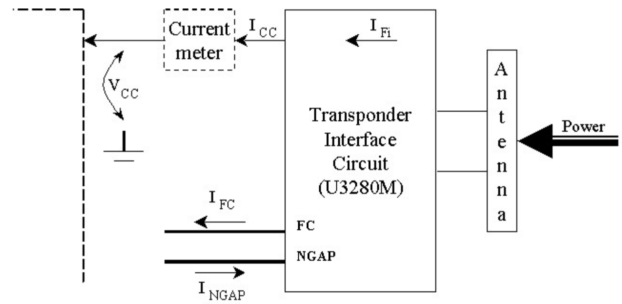

Fig. 6. Currents in the platform

Using (2) and currents mentioned above, the measurement platform's total current consumption is found to be 515 µA. Current consumption caused by the ECG measurement block was measured as 156 µA.

B. Total Power Consumption

Platform's supply voltage is defined as the rectified and regulated voltage which U3280M's outputs at its VDD output. In [9] voltage is characterized as 2.9±0.3 V. Measurements showed that the voltage varied from circuit to circuit and it was typically found to be around 2.85 V. Using the 2.85 V voltage and currents mentioned in chapter 4.1, the total power consumptions of the platform without and with the ECG measurement block were found to be approximately 1.47 mW and 1.91 mW, respectively. Table 1 lists the current and power consumptions for the platform without and with the ECG measurement block.

TABLE I
Platform's Current and Power (VDD = 2.85 V)

	Current	Power
Without ECG Block	515 µA	1.47 mW
With ECG Block	671 µA	1.91 mW

C. Operating Distance

Defining the minimum power consumption of the platform, or its end application, is closely related to its maximum operating distance. Hence, the lower the power need of the device, the greater its operating distance from the reader antenna. Reliable operating distances for platform and ECG application are presented in table 2.

TABLE II
Operating Distance

Without ECG Block	58 mm
With ECG Block	30 mm

During the data transmission, the operating distance is actually limited by the reader device's receiver sensitivity. While distance is grown, errors in data transmission are detected before the platform looses power. Therefore, in a case of ECG application, the maximum operating distance was defined as the distance in which the data transmission is still reliable.

V. Conclusion

This paper introduced the multi-channel measurement platform intended for small-sized, low-power wireless measurements, such as implantable electrocardiogram. Platform has total of 4 analog inputs channels and can provide a supply voltage of 2.85 V to the measurement block attached to it. Power was transferred with inductive coupling at 125 kHz. Data transmission was realized by the means of load-modulation, widely used in low-frequency RFID applications. With the sample rate of 237 samples per second surface-ECG was measured, sent to the hand-held reader device and furthermore displayed in the computer screen.

In the electronics point-of-view, some of the main concerns are the physical size of the platform, higher data rate, and low power consumption. In addition to the platform's power consumption, some of the main issues concerning the operating distance are magnetic field carrier frequency, dimensions and inductances of the antenna coils, and power available for the antenna driver of the portable, battery-operated reader device. Work for using the higher carrier frequencies and also multiple measurement platforms in the vicinity of one reader are now ongoing. Also, miniaturization of the platform and in-vivo measurements with the ECG-prototype coated with biocompatible coating are planned.

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