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Design of telemetry platform system for biomedical pressure monitoring

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Abstract: *The main goal of this work is to fabricate a miniaturized, low power, bi-directional wireless communication system that can be used for in vivo pressure monitoring. The system prototype consists of miniature FSK transceiver integrated with Microcontroller unit (MCU) in one small package, chip antenna, and capacitive interface circuitry based on Delta-sigma ($\Sigma\Delta$) modulator. At the base station side, an FSK receiver/transmitter is connected to another MCU unit, which send the received data or received instructions from a PC through a graphical user interface GUI. Industrial, Scientific and Medical (ISM) band RF (433 MHz) was used to achieve half duplex communication between the two sides. A digital filtering has been used in the capacitive interface to reduce noise effects forming capacitance to digital converter (CDC). All the modules of the mixed signal system are integrated in a printed circuit board (PCB) of size 22.46×20.168mm.*

1. INTRODUCTION

There is a considerable interest in the development of low-power multi-sensor micro-systems for use in implanted [1], ingestible [2] and remote environmental monitoring [3].

For over forty years, implantable telemetry systems have been used for animal experiments and human applications, including measurements of heart rate, ECG, EEG, temperature, pH, and pressure. Recent years, digital RF communication systems have been developed for in vivo pressure acquisition [4], implantable neural recording [5], and functional neurostimulation [6]. The newly developed M2A capsule endoscopes also use radio frequency to transmit video frames from gastrointestinal tract [7].

The development of VLSI and silicon technology makes it possible to produce miniature highly integrated circuits with powerful functions. Also available are the chip-on-board techniques, which use bare dies bounded directly on the PCB substrate to decrease the overall dimension of the circuit board. Double-sided PCB technique could be efficient sometimes to produce very small modules with high efficiency and ease in implementation. These technologies allowed us to develop miniature RF communication systems able to meet extremely strict space demands.

The paper is organised as follows: an overview description of the developed system is given in section two. In section three, the ShockBurstTM protocol used for data communication is described for both transmit/receive modes. The implementation of the capacitive readout circuitry and LABVIEW graphical user interface (GUI) software design are given in the next two sections. In section Six, sample results and power figures are discussed.

2. SYSTEM OVERVIEW

The whole system is made up of two main parts: the miniature RF transceiver and control base station, as illustrated in Figure 1.a. The base station sends commands to switch on the radio and configure the CDC unit, and receives data packets sent by the miniaturized module. The system is half duplex, so data cannot be transmitted and received at the same time. The PCB layout of the wireless module is shown in Figure 1.b. It is composed of four building blocks: transceiver chip, flash memory (EEPROM), CDC and antenna modules. The internal structure of the transceiver chip is shown in Figure 2.

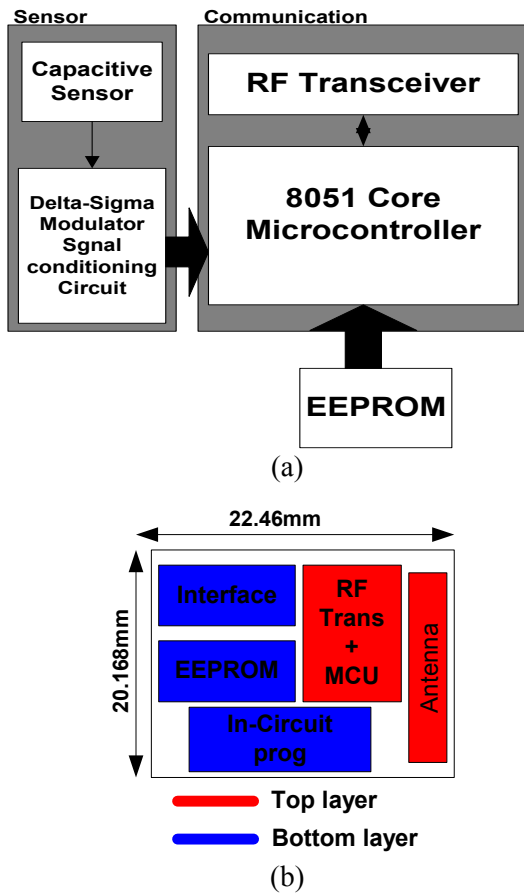


Fig.1. a) Block diagram of the system, b) Board layout of the wireless module

The RF carrier frequency is in the 433 MHz ISM frequency band. GFSK modulation has been adopted in the design with a data rate of 100Kbps and frequency deviation $\pm 50\text{KHz}$. This modulation type results in a more bandwidth effective transmission-link compared with ordinary FSK modulation. The data is internally Manchester encoded and decoded. That is, the effective symbol-rate of the link is 50kbps. By using internally Manchester encoding, no scrambling in the MCU is needed.

Because of the high space restrictions of the application, a special miniaturized 50Ω chip antenna of size $16 \times 3\text{mm}$ has been used. A single ended matching network was adopted between the antenna and transceiver. The supply voltage of the miniature transceiver is 2.7V. The RF transmitted power can be configured by software to be the range from -10dBm to 10dBm .

From Figure 2, the 8051-based MCU with its instruction code stored in 4KB RAM is supervising

the system operation. When powered on, a bootstrapping program is activated and the MCU waits for code to be downloaded from the external serial EEPROM.

The transceiver part is accessed through an internal serial peripheral interface (SPI) unit. Mainly the RF transceiver consists of fully integrated frequency synthesizer, a power amplifier, and a modulator and receive unit. Output power, frequency channels and other RF parameters are easily programmable by the use of on-chip SPI interface.

The power management unit is essential to regulate the power supplied to other parts of the module. Under program control, power management unit can turn on or off the RF transceiver and also provide the system with several low power modes.

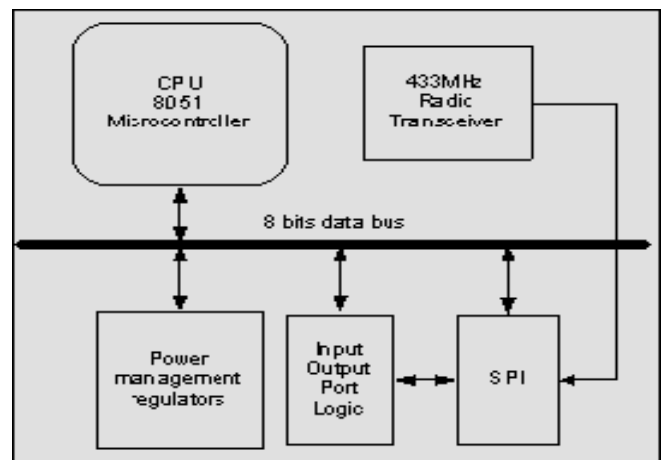


Fig.2. Block diagram of the programmable transceiver module

3. RF COMMUNICATION PROTOCOL

ShockBurstTM protocol has been adopted with RF data transmission/receiving since it provides a high data rate. All high speed signal processing related to the RF protocol has been embedded in the transceiver part. By allowing the digital part of the module to run at low speed, while maximizing the data rate on the RF link, average current consumption can be much reduced. A description of the protocol for both RF operation modes, transmit or receive, are given below.

3.1. Transmit Mode

Figure 3 shows a flowchart of the protocol steps at the transmitter side. Initially when the MCU has a

data for a remote node, the address of the receiver and payload data are clocked into the transceiver through the SPI interface. The speed of interface is set by the MCU. When the radio is powered up, the transceiver automatically generates preamble and cyclic redundancy codes (CRC). A Data Ready (DR) flag is used to notify the MCU when the transmission is completed.

The retransmission feature is used to continuously re-transmit the data packet, which is useful under noisy conditions where error rate is high.

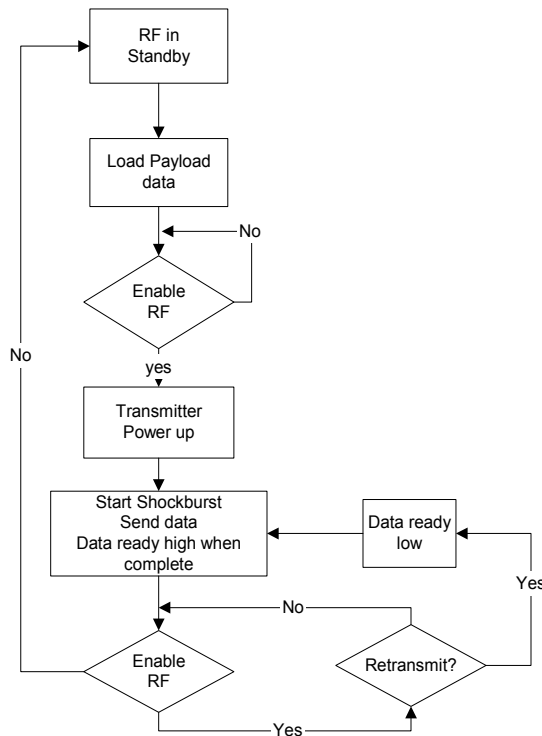


Fig.3. Flowchart of the transmit RF protocol

3.2. Receive Mode

After the receiver is enabled, it will monitor the air for any incoming communication. When a valid address received, data will be checked to have a correct CRC before removing the preamble, address, and the CRC bits. DR will be high to notify the MCU that a correct address and payload data have been received. MCU can then clock out the payload data at a suitable rate through the SPI interface.

It is worth to mention that the transceiver can be switched to operate in either modes or powered down immediately under the software control. Accordingly

an efficient bi-directional communication between the two sides can be achieved.

4. CAPACITIVE INTERFACE UNIT

Capacitive sensors exhibit a change in capacitance in response to a change in physical stimulus. Most of the capacitive systems designed are based on converting the capacitance to voltage first. Then the voltage will be converted into digital domain with high precision analog-to-digital converter (ADC).

In this work, a new approach has been introduced in the capacitive module that employs $\Sigma\Delta$ modulator used in a high resolution ADC to measure the capacitance directly.

4.1. Functional Description

The main functional blocks of the capacitive module are shown in Figure 4. The system consists of on-chip integrated temperature sensor, 24-bit $\Sigma\Delta$ modulator, digital filter, voltage regulator and serial interface all integrated in one module. The system can measure capacitance up to 20 pF with high accuracy ($\pm 4\text{fF}$) and high linearity ($\pm 0.01\%$). The on-chip temperature sensor has resolution of 0.1°C and accuracy of $\pm 2^\circ\text{C}$. The voltage regulator and on-chip clock generator eliminate the need for any external components in the capacitor sensor applications.

The module can operate with a single power supply of 2.7V. The output information from the digital filter will be read by the MCU through a serial interface part.

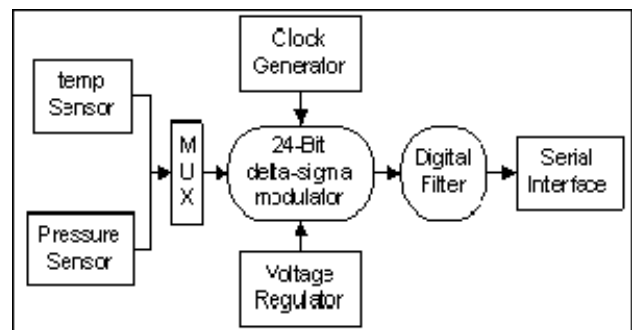


Fig.4. Block diagram of capacitive module

4.2. $\Sigma\Delta$ Capacitance to Digital Converter (CDC)

In our system the $\Sigma\Delta$ modulator has been used, where a fixed excitation voltage is used across a

variable capacitor C_{in} which represents the off chip sensor capacitance as shown in Figure 5. The reference capacitor C_{ref} is periodically switched to the reference input V_{ref} , and along with sensor capacitor will pump charge into the integrator capacitor C_{int} . The output data will represent the ratio between the sensor capacitance and C_{ref} . The digital filter processes the modulator output, which is a stream of 0s and 1s containing the information in 0 and 1 density. The data from the digital filter is scaled and the final result can be read through the serial interface.

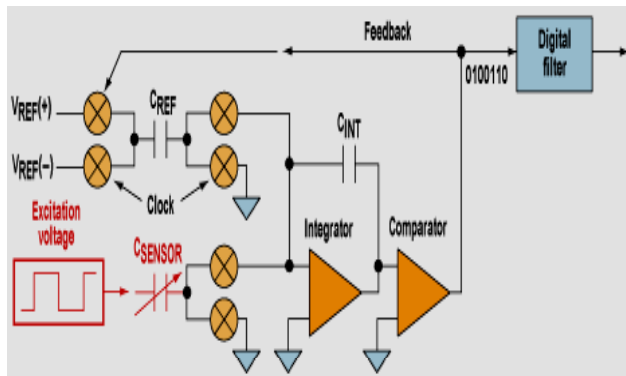


Fig.5. Block diagram depicts the CDC

4.3. Pressure Sensor Development

The capacitive pressure sensors were fabricated using two types of electrodes structures, interdigitated and planer sandwich. Interdigitated arrangement is popular with designers as altering the length of the electrodes can easily change the structure capacitance. Screen-printing technology has been used in the fabrication process.

The dielectric layer consists of a polymer thick film paste, prepared by using polyvinylidene fluoride (PVDF) as the functional material.

4.4. Measuring system performance

The telemetric link and its capabilities to send information have been examined on a test bench as shown in Figure 6. The bench system has been developed to simulate the environment inside the gastrointestinal tract (GI). The system is pumping a fluid with a certain properties inside long tube of 50mm diameter. The rate of fluid flow will generate the required pressure range according to special software designed for this purpose.

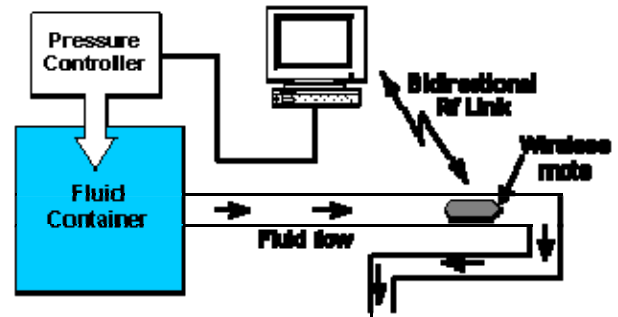


Fig.6. Block diagram of the test bench system

5. DEVELOPMENT OF LABVIEW PROGRAM

LABVIEW software has been used to develop a graphical program for collecting data from an external source at the receiver side and displaying it into viewable charts on a PC. The applied methodology of the program is presented by the flowchart in Figure 7.

The user is required to set a few parameters first that determines the serial interface configuration and other user options. Next, the collected data bytes will be converted to a decimal values and processed, as decided by the user, to get either pressure or temperature value.

6. EXPERIMENTAL RESULTS

The developed wireless system has been tested using the test bench shown in Figure 6. The base station circuit at the receiver side sends start ON and measurements commands. When the commands received, the wireless mote begins to gather either pressure or temperature data, and send it to the base station. The main reason behind selecting the type of data to be sent is to reduce the amount of transmitted data, which leads to save more power. In Figures 8 and 9, sample readings recorded by the LABVIEW software for both changes in capacitance due to pressure and temperature are shown.

The sensitivities of PVDF interdigitated and sandwich pressure sensors have been investigated as shown in Figure 10. A uniform pressure of range 0 to 100KPa has been applied with a uniform change.

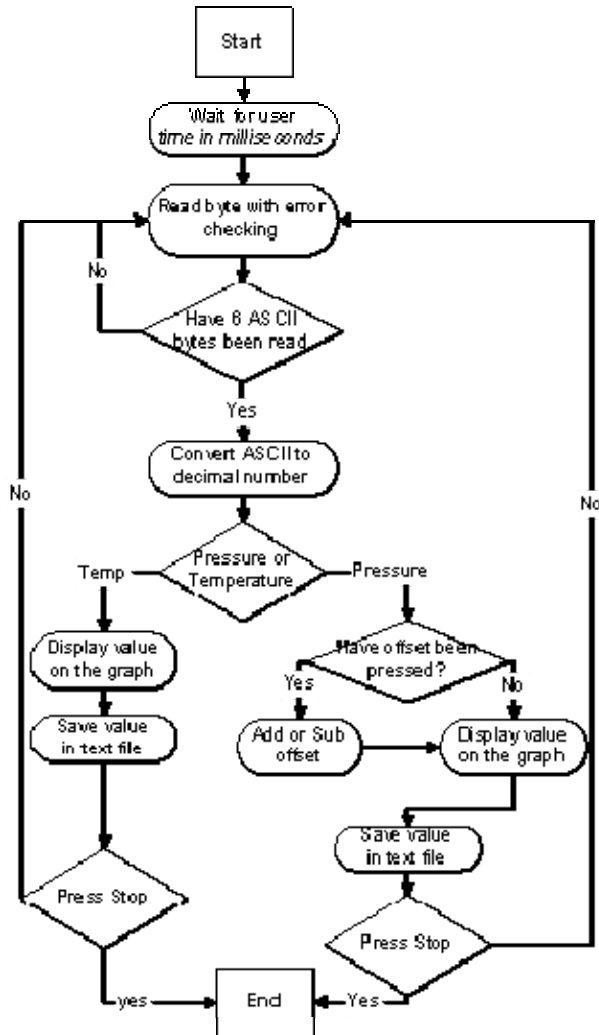


Fig.7. Flowchart of the LABVIEW program.

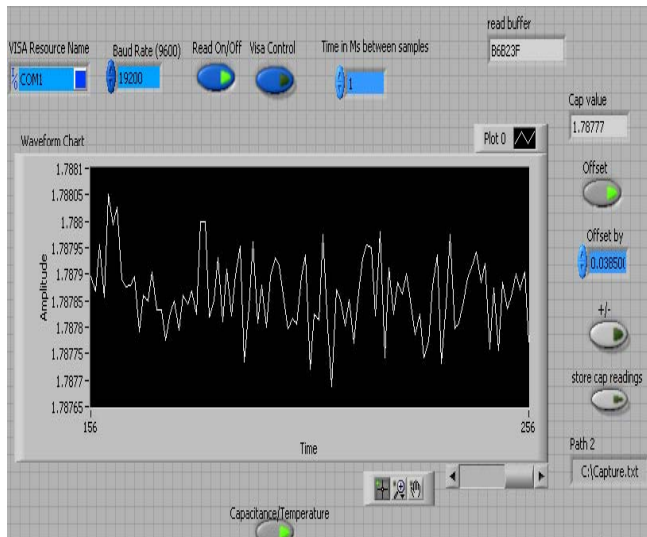


Fig.8. Pressure sensor capacitance change recording

The on-chip temperature effect has been investigated as well for both structures against the same range of pressure applied as presented by Figure 10. From the presented results it can be noticed that the linearity of interdigitated sensor is relatively better. The temperature behaviour of the system for the two types of sensors is identical. Apparently the temperature exhibits a stable performance in the range of pressure less than 70KPa.

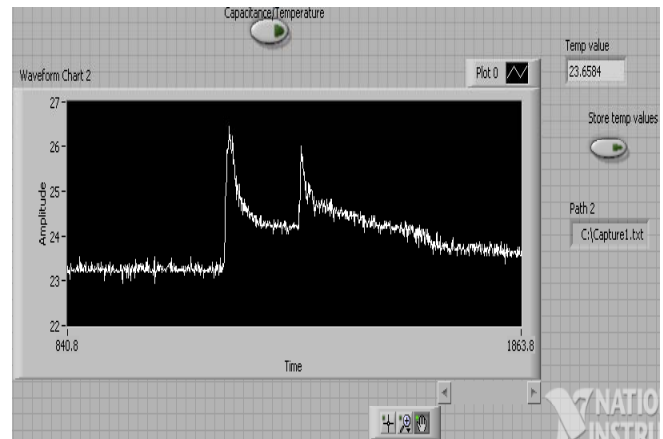


Fig.9. Temperature change recording

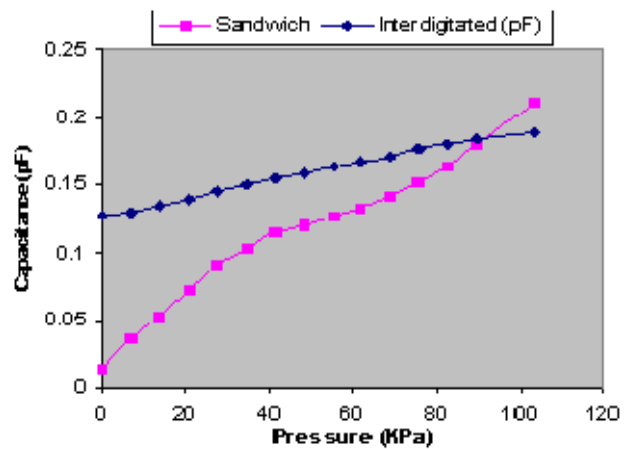


Fig.10. Sensitivity of developed pressure sensors

2.1. Power Usage

Table 1 summarizes the current consumptions of the miniaturized transceiver module for 6dBm-transmitted power. A 3.3V Lithium coin cell battery has been used for powering the miniaturized module. In order to investigate the battery lifetime, the supplied voltage of the battery has been measured for different power transmission as shown in Figure 12.

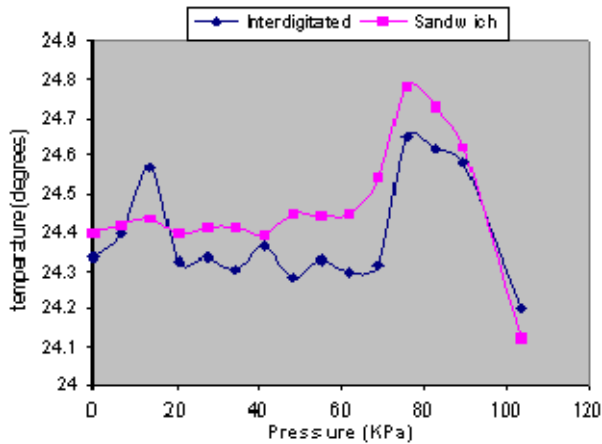


Fig.11. Change of temperature against pressure

It can be noticed that the wireless module could last 11 hours functioning properly with -10dBm transmitted power. One hour less can be obtained with -2dBm , where both 6 and 10dBm transmissions consumes a lot of power in much less operating hours.

TABLE 2. Current consumption specifications

POWER USAGE	CURRENT VALUE	UNITS
Transceiver unit (power down)	2.5	μA
MCU at 16MHz (3V)	2.2	mA
Receiver current	12.2	mA
Transmitter current (6dBm output power)	20	mA
Capacitive interface supply (3V)	700	μA
Total current consumption	36	mA

CONCLUSIONS

The development of a miniaturized wireless module suitable for in vivo pressure monitoring has been presented. Through testing the system in a bench, the reliability and validity of the pressure monitoring are verified. Consequently, the proposed system can supply precise measurements for pressure and temperature signals. A half-duplex bi-directional communication has been established between the two ends of the wireless link taking advantage of the high data rate of the transceiver.

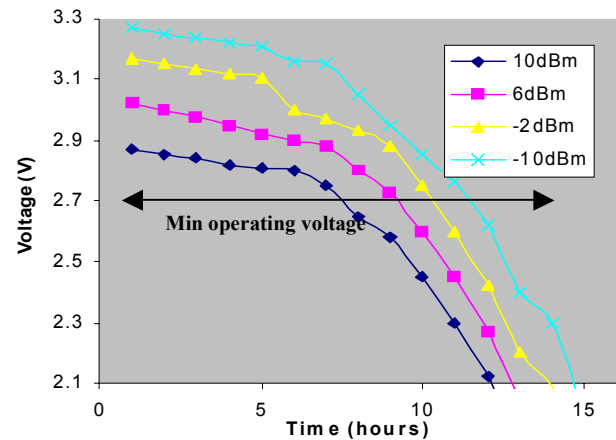


Fig.12. Result of battery test for the wireless module

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