Wireless Measurement System for Capacitive pressure Sensors Using Strain Compensated SiGeB

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***Abstract*—A prototype of miniaturized, low power, bi-directional wireless communication system was designed for in vivo pressure monitoring. The capacitive pressure sensors have been developed particularly for the medical field, where packaging size and minimization of the power requirements of the sensors are the major drivers. The pressure sensors have been fabricated using a 2.4 µm thick strain compensated heavily boron doped SiGeB. In order to integrate the sensors with the wireless module, the sensor dice was wire bonded onto TO package using chip on board (COB) technology. The telemetric link and its capabilities to send information have been examined on a test bench. A full pressure range from 0 to 10kPa was generated using either air or water pressure pumped through connected tubes to simulate the environment similar to the one inside the gastro Intestinal (GI) tract.**

I. INTRODUCTION

Wireless data gathering systems have the potential to re-structure the instrumentation used in a variety of industries, including security, health care, and transportation. Looking at wireless sensing technology, both active and passive telemetry are used. Active telemetry systems provide relatively long range bidirectional sensor data transfer [1]. An important example of such active telemetry system is the development of wireless sensor systems that can be integrated into a non-invasive capsule format to perform endoscopic functions within the gastrointestinal tract. Several capsules have been prototyped to date [2-4].

Different physiological parameters, including temperature, pressure and pH can be captured within the GI tract, and the data are relayed wirelessly to a body-worn device (base station). The basic structure of such devices comprises contact or noncontact sensors, an instrumentation circuit, a transmitter, and a power source [5]. There are several key requirements for the ingestible telemetry systems. The capsule production must be cost-effective, as it will only be used once. Low-power consumption is a requirement to minimize battery size and increase operating time. Gastric emptying takes between 0.5–4 h to complete and semi-digested food takes 2–3 h to pass through the small intestine. Once in the colon, gut content moves relatively slowly at approximately 5–10 cm/h. Peristaltic waves in the colon are known as mass movements and only occur 1–3 times per day. Overall, the capsule might take a maximum of 8 h to traverse the upper alimentary tract and the small intestine, while a complete passage through the GI tract might take up to 32 h.

This paper presents a novel wireless prototype developed to measure the pressure caused by the GI muscle contractions. Special capacitive pressure sensors have been fabricated particularly to be used for such application. The paper is organised as follows: In section two, the fabrication of the pressure sensors is explained. An overview description of the developed system is given in section three. In section four, more details about the main components of the wireless prototype are given. In section five, experimental results from testing the sensors are presented.

II. SIGEB PRESSURE SENSOR

The process relies on the silicon fusion bonding of two silicon wafers to seal the pressure sensor cavity and construct the device [6]. Strain compensated $Si_{1-x-y}Ge_xB_y$ layers have been shown to exhibit excellent characteristics similar to those exhibited by simple heavily boron doped layers when used as etch stops in wet chemical etching solutions [6]. In this work, our sensors have been developed based on the advantage of these properties.

A schematic view of the developed sensor is depicted in Figure 1. The device consists of a cavity etched in a thick wet oxide, a fixed electrode and a flexible electrode. When pressure is applied, the flexible electrode deflects towards the fixed electrode and the device capacitance changes. In capacitive type pressure sensors it is this change that is of interest. Rather in pressure switches the value of pressure at which the flexible electrode will touch the fixed electrode is the important parameter.

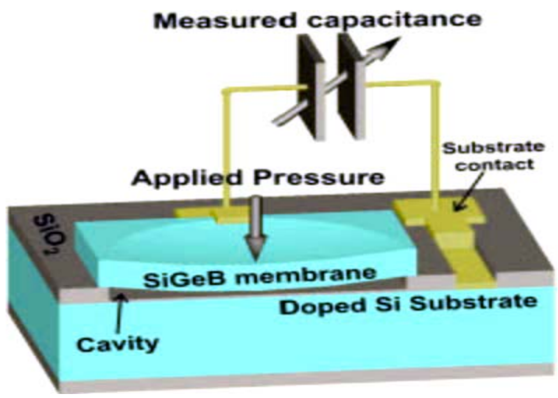


Figure 1. Schematic view of the pressure sensor

In order to integrate the sensors with the wireless module, the sensor dice was wire bonded onto TO package using chip on board technology. A photograph of the packaged sensor is shown in Figure 2. Table.1 summarizes the main technical details of the pressure sensors

Figure 2. Schematic view of the pressure sensor

TABLE I. PRESSURE SENSORS SPECIFICATIONS

Silicon die area	1.1×1.0mm
Baseline capacitance:	4pF
Resolution:	1fF/mbar
Pressure range:	0 - 100 mbar

III. WIRELESS SYSTEM OVERVIEW

The whole system is made up of two main parts: the miniature RF transceiver and control base station, as illustrated in Figure 3. The base station sends commands to switch on the radio and configure the capacitive 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. A photograph of the double-sided wireless prototype is shown in Figure 4.

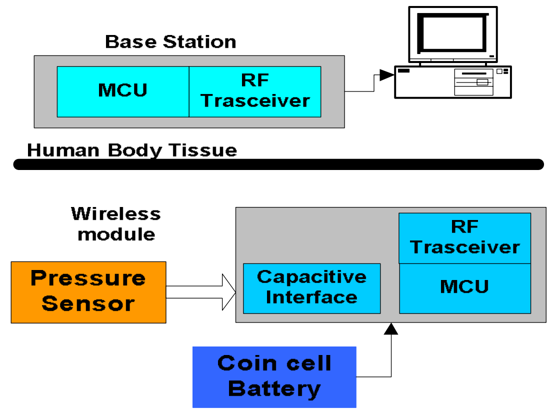


Figure 3. Block diagram of the developed system

The total size of the system printed circuit board (PCB) is 22.46×20.168mm. The RF carrier frequency is in the 433 MHz ISM frequency band. Gaussian Frequency Shift Keying (GFSK) modulation has been adopted in the design with a data rate of 100Kbps and frequency deviation ±50KHz. 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.

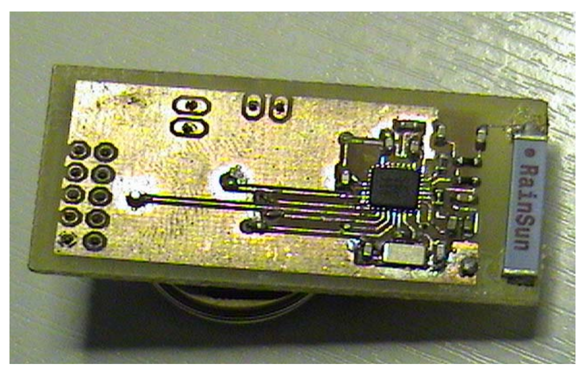
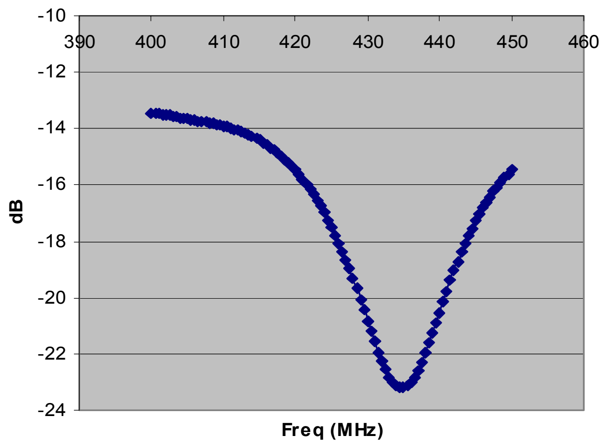


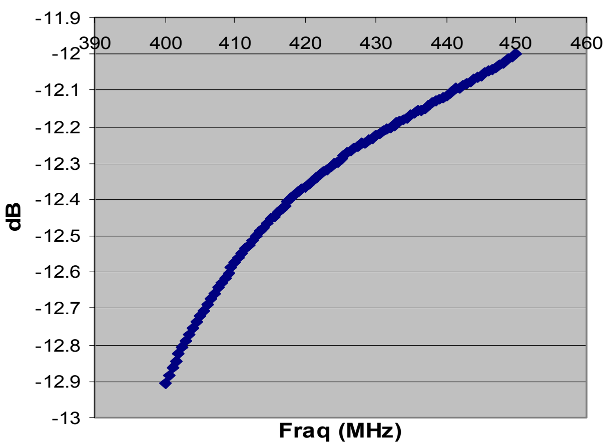
Figure 4. Photograph of the pressure sensor wireless module

A. *Antenna Design*

Because of the high space restrictions of the application, a special miniaturized 50Ω chip antenna of size 16×3mm has been used. A single ended matching network was adopted between the antenna and transceiver. The antenna has been placed carefully on the PCB where few factors like the ground plane, size of the feeding line antenna directivity and enough clearance have been taken first into consideration. A few LC components have been selected to design the impedance matching network which does more than the matching task but also makes sure that harmonic and spurious emissions are kept low and that output power is not decreasing. To have a closer look on how the antenna is impedance matched to RF circuit, the network analyzer 8510 from Hewlett Packard has been employed for this purpose. Figure 5 shows the measured return power patterns for both the RF circuit and the antenna in a narrow band (~70MHz). It is obvious that RF unit display a good power response at the desired frequency.



(a)



(b)

Figure 5. Measured return power loss from (a) the RF transceiver, (b) the miniaturized antenna

B. *RF Transceiver and Capacitive Interface*

Nordic NRF905 multiband transceiver has been selected for the prototype [7], since it has a very small size (5×5mm) with other useful features. 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 RF part has a power management unit which 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.

The new chip AD7746 [8] has been used for the capacitive interface. After experimental testing, it was found to quite suitable for the expected pressure range and provides measurements with a high resolution. This is due to the novel Σ-Δ capacitance-to-digital converter (CDC), which uses fixed excitation voltage across a variable capacitor that form the main core of the chip.

C. *Power Measurements*

A 3.3V Lithium coin cell battery has been used for powering the miniaturized module. The main challenge was to provide enough power to the module to function properly for the complete transit time along the GI. As mentioned before this time can at least 32 h or more depending on health condition of each patient. In some critical conditions this time can reach up to three days (72 h) if the case is severe. Accordingly, many techniques have been applied to reach this target, which is the longest possible operation time. In Figure 6, the supplied voltage of the battery has been measured for 10dBm output power exploiting the effect of introducing the wakeup mode on the battery lifetime.

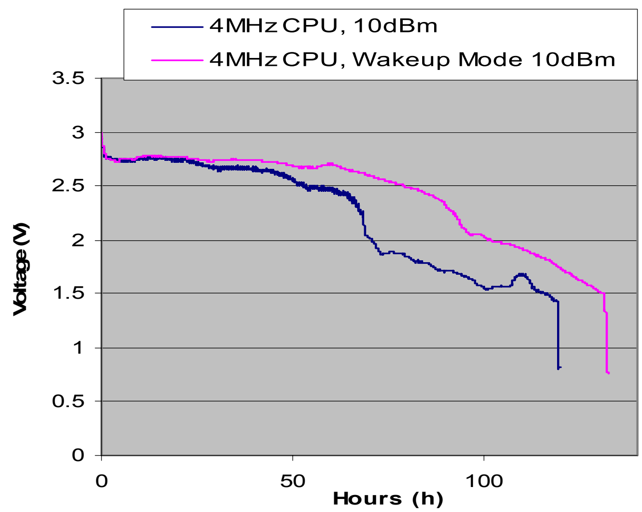


Figure 6. Testing battery life time for the wireless module

IV. Experimental Results

The telemetric link and its capabilities to send information have been examined on a test bench that has been developed to simulate the environment inside the gastrointestinal tract (GI). The pressure sensors have been attached to the wireless module through a special connection to be tested in the GI bench. A mixture of silicon rubber materials has been used to perform one layer packaging for the module. Such layer will have a small impact on the pressure absorption, which can be tolerated at the end by the MCU. A pressure range from 0 to 10kPa has been applied first to examine the sensor response since it's the same range of pressure that could be generated inside the GI tract [9].

Figure 7 shows a sample result for the sensor sensitivity against pressure.

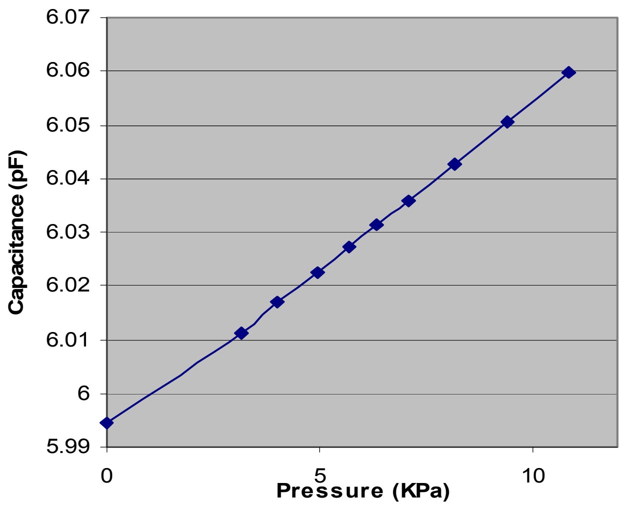


Figure 7. Change in capacitinace with pressure in the range 0-10kPa

The maximum difference between loading and unloading cycles was measured and expressed as a percentage of the full-scale deviation in order to calculate the hysteresis. Values ranging from 5 – 6 % have previously been calculated for polymer thick film devices [9]. In this work, the hysteresis was calculated to be between 0.17% and 0.83% as shown in Figure 8. This corresponds very well with the quoted above.

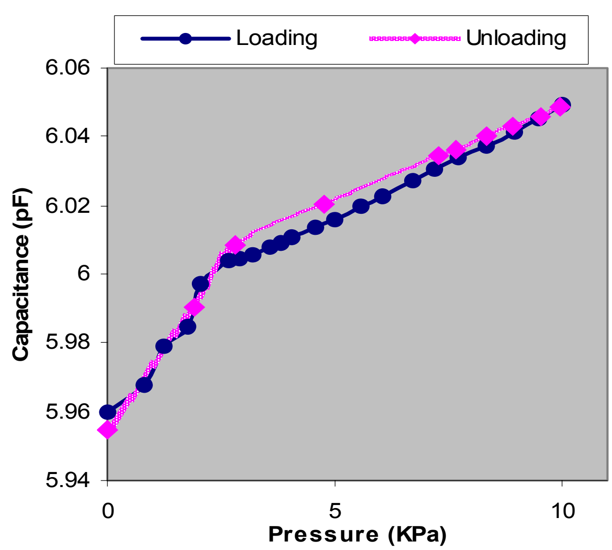


Figure 8. Hysteresis of SiGeB pressure sensors in GI tract pressure range

V. CONCLUSIONS

This work describes the development of a novel wireless sensor prototype suitable to measure the contractions pressure inside the GI tract. The pressure sensors are fabricated based on the heavily doped compensated SiGeB. The sensors designed to be used in the medical pressure range (0-300mmHg) with a good sensitivity to small pressure changes.

Operation and experimental study proved that the prototype worked as designed. Increasing battery lifetime was the main design requirement. Based on this, a number of techniques have been developed to achieve this goal and reduce overall power consumption. The RF antenna part with the impedance matching circuit has been designed with great attention. Obviously the RF circuit showed a superior level of power reflected back (<-22dB). The SiGeB pressure sensors were evaluated using the wireless prototype in a special developed test bench. It was seen that sensors displayed a high sensitivity to the desired pressure changes in the range 0 - 10 kPa. The hysteresis of the sensors was measured as well and found to be very low in comparison with other developed sensors.

ACKNOWLEDGMENT

This work was supported by the Enterprise Ireland Commercialization Fund 2003 as part of the MIAPS project, reference no. CFTD/03/425.

VI. REFERENCES

[1] A. Leung,W. H.Ko, T.M. Spear, and J. A. Bettice, "Intracranial pressure telemetry system using semicustom integrated circuits," IEEE Trans.Biomed. Eng., vol. 33, pp. 386–395, Apr. 1986.

[2] G. Iddan, G. Meron, A. Glukhovsky, and P. Swain, "Wireless capsule endoscopy," Nature, vol.405, p.417, 2000.

[3] M. Skidmore, "Mini transmitter saves babies," NASA Aerosp. Technol.Innov, vol. 7, No.1, pp.7–8,1999.

[4] H. J. Park, I. Y. Park, J. W. Lee, B. S. Song, C. H. Won, and J. H. Cho, "Design of miniaturized telemetry module for bi-directional wireless endoscopes," IEICE Trans. Fund. Electron, Commun., Comput. Sci.,Vol.E86-A, No.6, pp. 1487–1491, 2003.

[5] L. Wang, E. Johannessen, T. B. Tong, A. Astaras, S. P. Beaumont, A. F. Murray, J. M. Cooper, and D. R. S. Cumming, "An integrated sensor microsystem for industrial and biomedical applications," Proc. 19th IEEE-IMTC, Anchorage, AK, pp. 1717–1720, May 2002.

[6] S.Chatzandroulis, S.Koliopoulou, D.Goustouridis, D.Tsoukalas, "Capacitive Pressure Sensors and Switches Fabricated Using Strain Compensated SiGeB", Microelectronic Engineering, Vol.83, pp. 1209-1211, 2006.

[7] Nordic VLSI nRF905 Multiband Radio Transceiver data sheet, nRF905rev1_3, http://www.nvlsi.com.

[8] AD7746 24-bits Capacitance to Digital Converter data sheet, Analog Devices, http://www.analog.com.

[9] K. Arshak, D. Morris, A. Arshak, O. Korostynska, and E. Jafer, E, " Development of a Wireless Pressure Measurement System Using Interdigitated Capacitors" Sensors Journal, IEEE, Vol. 7, No.1, pp. 122 – 129, Jan. 2007.