A Mini-invasive Multi-function Biomedical Pressure Measurement System ASIC

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***Abstract*— A mini-invasive system ASIC for mulitple bladder pressure measurement function is presented. Not only can the period of measurement be adjusted, the flexibility is also enhanced by using a tunable IA (instrumentation amplifier). Because the pressure inside the body cavity (i.e., bladder) usually does not vary drastically, a long-term mode is required to save the battery power for a reliable observation. Besides, the pressure dynamics in a cavity also could be examined in the continuous mode. The IA amplifies the signal sensed by the pressure sensor, which is then fed into the following ADC (analog-to-digital converter). Owing to the intrinsic 1-atm pressure (one atmospheric pressure) existing inside the body cavity and the various resolution requirement for the different applications, the input range of the IA must be able to be adjusted to keep the required linearity. The pressure range of the proposed system is found out to be $10.4 \sim 27.7$ Psi with the maximum resolution of 8.42$\times 10^{-4}$ Psi, which is more than enough for most of pressure measurement applications.**

***Keywords*—pressure measurement, mini-invasive, bladder, IA, linearity**

I. Introduction

Pressure measurement of the body cavities, such as cranium, thoracic cavity, and bladder, is an important issue in physiological observation. Quality of patient's life could be improved by monitoring physiological signals, including the pressure reading of bladder [1]. One good example is that many hemiplegic or disabled patients are suffered from urocystitis and other bladder diseases, which might cause death by complication and infection therewith. However, almost all of these bladder diseases can be prevented or predicted by observing the abnormal syndromes of the bladder urine pressure variations. For instance, patients whose leak point pressure is greater than 40 cm-H_2O might have upper urinary tract deterioration because of voiding control by prevention of the normal neural pathway, [2], [3]. Therefore, periodic evaluation of these patients to discover their urodynamic situations and help these uro-ataxic to urinate normally have been recognized as one of the most important research topics in clinical medical investigations [4]. Sensing pressure in bladders is an important topic among many uro-researches. According to several prior reports, the pressure of the urine inside of the bladder is not exactly proportional to the volume. However, the urine pressure reveals the syndromes of a lot of urinary anomalisms, such as unusual LLP (leak point pressure), [5]. The involuntarily reflex contraction of a bladder with a small fluid volume may cause inconvenience of daily life. By contrast, the loss of continence given a high bladder pressure during bladder-urethral sphincter dyssynergia can result in long-term renal damages, frequent urinary tract infections, and infections of the kidneys, [6], [8]. Lots of ways to measure the urine pressure in a bladder have been reported, e.g., [7]. But, there are several disadvantage of the traditional ways whether *in vitro* or *in vivo* [10].

We propose a mini-invasive multi-function bladder urine pressure measurement system composed of a pressure sensor and an ASIC containing a high-linearity variable IA. Because of its tiny size and low power, the device can be implanted in the bladder to measure the pressure after proper packaging. Therefore, not only can we read the bladder pressure directly in real time *in vivo*, but also reduce side effects caused by the discomfort of the experimental target. The accuracy of the pressure measurement will be ensured. Notably, the long-term mode make the device very power efficient, which can monitor the urine pressure over an interval at least two weeks.

II. System Overview of the Urine Pressure Measurement System

Due to the demand of size miniaturization of mini-invasive devices and low power consumption for a long-term measurement, the proposed system has to adopt a wireless transmission such that the biomedical pressure information can be collected outside of the body using an external data reader. Referring to Fig. 1, the system overview of the entire mini-invasive multi-function biomedical pressure measurement system is composed of three major components : a pressure sensor, a control ASIC, and an RF module. Notably, "Timer and Control" in Fig. 1 is in charge of the switching between

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the working duration and sleeping interval where the sleeping interval is activated by shutting down the power of each block powered by "Power Buffer". The clock of these blocks is also disabled at the same time when the sleeping interval is chosen. The pressure sensor is an absolute pressure sensor, which means its differential output voltage is proportional to the absolute pressure. The differential output voltage will be amplified by the variable IA (instrument amplifier) in the ASIC and then quantized by the ADC after canceling intrinsic 1 atm pressure in the bladder. "PtoS" (parallel to serial circuit) is responsible for serializing the ADC output samples and framing with sync bits. Then, the data frames are delivered to the RF (radio-frequency) module for wireless communication with an external data reader (not shown).

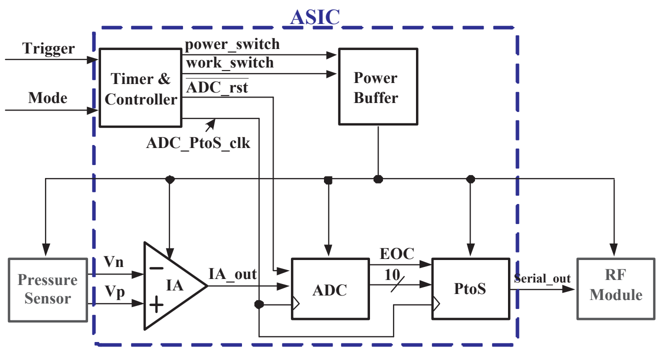

Fig. 1. Architecture of the mini-invasive system.

A. Control Sequence

Usually, the pressure in the body cavity isn't varied frequently or drastically. Hence, the proposed system can be set in a "long-term mode" which turn on the system for 10 seconds into the working duration every 5 minutes to save the battery power for long-term observation. By contrast, we shut down the unnecessary function blocks by cutting off their supply power in other time span, i.e., the sleeping interval. However, sometimes we want to observe the pressure variation of physiology dynamic behavior such as the pressure during urinating process or the pressure in the unhealthy bladder which have a tempestuous pressure variation. The proposed system is, then, set in "continuous mode" to keep turning on the system in working duration to measure the pressure in real-time. In a trigger mode, the proposed system will read one sample at a trigger pulse. Therefore, the pressure reading can be acquired whenever needed.

In the working mode, the data processing sequence is shown in Fig. 2. When $\overline{\mathrm{AD\_rst}}$ is pulled high, ADC begins to sample and quantize. It takes a total of 10 AD_PtoS_clk periods before the EOC (end of conversion) signal is asserted. The PtoS, then, frames the code with the sync bits and start bits to deliver them serially to the RF module. The period of the start bits and data bits is equal to the period of the AD_PtoS_clk, and is twice the period of the sync bits. The reason of the particular design is for the RF receiver to decode the data more precisely.

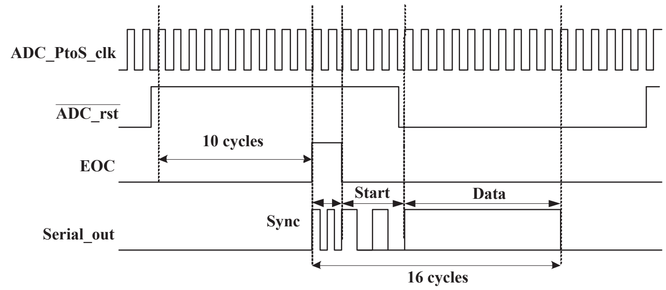

Fig. 2. Control sequence in the working mode.

B. Pressure Sensor

The pressure sensor chosen in the proposed system is composed of bridging resistors. The stable power supply is applied to the pressure sensor, and the differential output voltage will be proportional to the pressure. Thus, we can estimate the pressure based upon the measured voltage. A product of Asia Pacific Microsystem, namely ATP015, is adopted in the proposed system. It is an absolute pressure sensor with a output voltage of 85 mV at 1-atm, when the power supply voltage is 3 V. The ratio of the pressure versus voltage is 0.1724 Psi/mV. Notably, 1 Psi = 68 cm-H_2O, and then 1 mV = 11.723 cm-H_2O. Therefore, the IA can be adjusted according the ratio and the range to be observed.

C. IA with variable input range

The schematic of the proposed IA is shown in Fig. 4, which possesses three critical characteristics. The first one is the 1-atm canceling function. As mentioned in the above text, there is an output voltage overhead in the absolute pressure sensor at 1-atm. For example, the ATP015 has an output voltage of 85 mV at 1-atm given a 3.0 V power supply voltage. If the output voltage of the pressure sensor is amplified directly without canceling the overhead, the resolution may be too poor to attain a meaningful result [9]. Therefore, we can adjust the lower bound of IA's input range to 85 mV. Then, the output voltage of the IA will be 0 V at 1-atm. Meanwhile, the system output data will be 0000_0000. Similarly, if a different pressure sensor is adopted in the proposed system, the lower bound of IA's input range can be reset by tuning Vref to cancel the output voltage overhead at 1-atm.

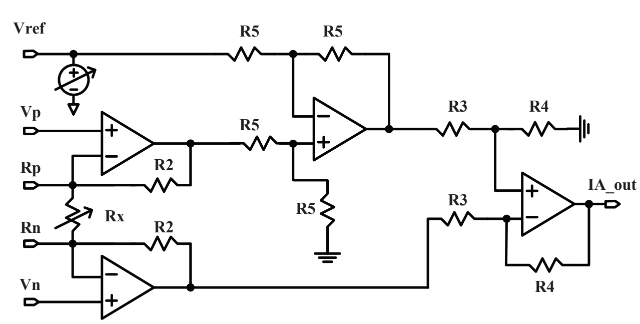

Fig. 3. Schematic of the tunable IA.

The second feature is that no matter what input range is, the output range is always 0∼VDD to meet the input range of ADC. The input range of the IA could be adjusted by setting Vref and Rx to change the resolution of the proposed system for different applications [10]. The finest input range of the IA is 5 mV such that the maximum resolution of the proposed system is 8.42×10^{-4} Psi. Moreover, other types of pressure sensors could be adopted to be used in different scenarios, such that flexibility will be ensured.

Last but not least, the IA has great linearity to ensure the linearity of the entire proposed system as well as the resolution. Therefore, the proposed system can provide reliable pressure readings.

D. 10-bit ADC

A charge-redistribution successive approximation ADC (SA ADC) is employed in this work, as shown in Fig. 4. A binary search through all possible quantization levels is performed to attain the final digital reading. When the $\overline{\text{AD\_rst}}$ is pulled high, the voltage of Vin is sampled. The Control block will generate D_out bit by bit at each AD_PtoS_clk cycle to the input of the DAC. The DAC, thus, generates an analog voltage according to the digits of the D_out. EOC will be asserted after 10 AD_PtoS_clk cycles to indicate that the D_out is the final code.

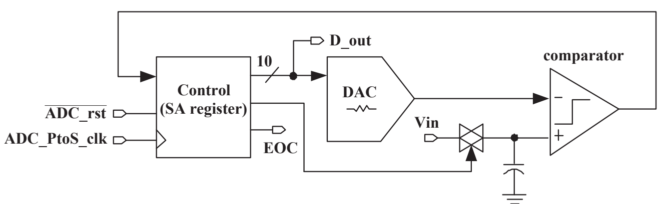

Fig. 4. Architecture of the SA ADC.

E. RF module considerations

Because the proposed system will be implanted in a bladder floating over the urine and surrounded by live tissues, the frequency of the carrier generated by the RF module should be low enough to transmit through the body to reduce the absorption rate. In addition, the data amount to be transmitted is not really heavy, which implies that the low ISM bands, either 2.0 MHz or 13.5 MHz, are better selections. Many off-shelf miniature RF products which meet the mentioned RF bands are available to be integrated into proposed system.

III. Simulation and Measurement

TSMC (Taiwan Semiconductor Manufacturing Company) 0.35μm 2P4M CMOS process is adopted to carry out the proposed mini-invasive chip design. Referring to the die photo shown in Fig. 5, the chip area is 2126 μm × 1834 μm (1245 μm × 1034 μm without pads). The simulation result of the control sequence in the working duration is totally correct in all of the PVT (process, supply voltage, and temperature) corners. Fig. 6 is a snapshot of functional measurement. Notably, Fig. 7 shows the output wave of the IA vs. a sine wave input, which indicates the I/O range of the IA. The linearity of the IA is revealed in Fig. 8. Besides, we can also see the several different input ranges of the IA from the same figure, while the output range is always kept the same. The INL and DNL of the ADC is found to be both less then 0.8 LSB. All of the characteristics of the proposed system is summarized in Table I. The Photo of the system prototype is shown in Fig. 9. The comparison of the proposed system with several previous designs is shown in Table II. The sensing range and the flexibility of the proposed system are much better. However, the average power consumption is only a little more than that of [9] due to a higher ADC resolution.

Max. sensing range	10.4 ∼ 27.7 Psi
ADC resolution	6 bits
ADC INL	< 0.8 LSB
ADC DNL	< 0.8 LSB
Max. resolution	8.42×10^{-4} Psi
supply voltage	3V
working power consumption	5.51 mW
in long-term mode	
average power consumption	0.98 mW
sleeping interval	5 minutes
working duration	10 seconds

TABLE I
Characteristics of the proposed system.

	[9]	[10]	proposed system
Max. sensing range	14.7 ∼ 19.7 Psi	10.4 ∼ 27.7 Psi	10.4 ∼ 27.7 Psi
ADC resolution	6 bits	8 bits	10 bits
Max. resolution	7.80×10^{-2} Psi	6.75×10^{-3} Psi	8.42×10^{-4} Psi
pressure sensing range	fixed	variable	variable
Timing modes	only 1 mode	2 modes	3 modes
supply voltage	3V	3V	3V
average power	0.97 mW	0.98 mW	0.98 mW

TABLE II
Comparison of the pressure measurement systems.

IV. Conclusion

We have proposed a mini-invasive multi-function biomedical pressure measure system. Besides utilizing the pressure sensor and the RF module to shorten the design time and cost, the ASIC in charge of commanding all of the components ensures the reliability on top of miniaturization. In order to carry out long-term observation, the sleeping interval and working duration are alternatively activated in long-term mode to extend the battery life. The system is able to precisely sense the pressure in the range of 10.4∼27.7 Psi, which has been deemed as more than enough for most of biomedical applications.

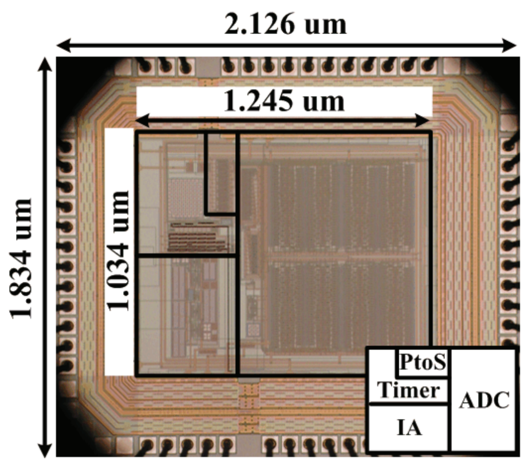

Fig. 5. The die photo of the control ASIC in the proposed system.

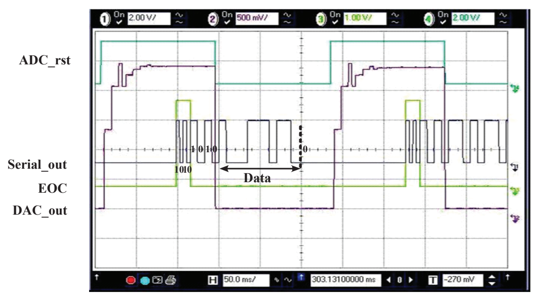

Fig. 6. measurement results in the working mode.

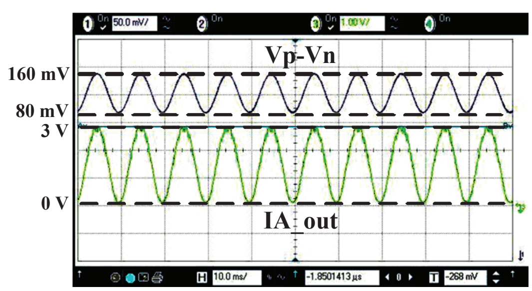

Fig. 7. Input v.s. output waveform of IA.

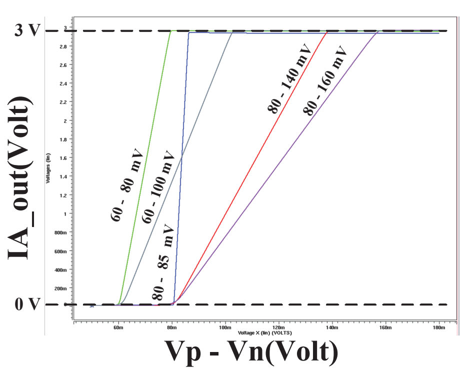

Fig. 8. DC transfer function of IA with different input ranges.

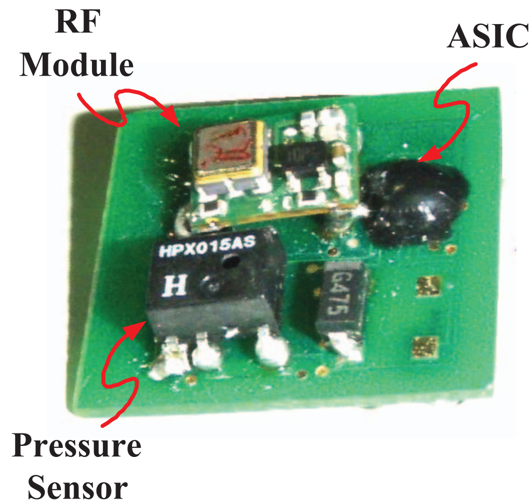

Fig. 9. Prototype of proposed system.

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