An Implantable Long-term Bladder Urine Pressure Measurement System with a 1-atm Canceling Instrumentation Amplifier

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***Abstract*— An implantable system for long-term bladder urine pressure measurement system is presented. Not only is the design cost reduced, but also the reliability is enhanced by using a 1-atm canceling sensing IA (instrumentation amplifier). Because the urine pressure inside the bladder does not vary drastically, both the sleeping and working modes are required in order to save the battery power for long-term observation. 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 bladder, the IA must be able to cancel such a pressure from the signal picked up by the pressure sensor to keep the required linearity and the resolution for pressure measurement of the bladder urine. The pressure range of the proposed system is found out to be 14.7∼19.7 Psi, which covers the range of all of the known unusual bladder syndromes or complications.**

***Keywords*—urine pressure, implantable, bladder, IA, linearity**

I. INTRODUCTION

Many hemiplegic or disabled patients are suffering 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], [7].

Lots of ways to measure the urine pressure in a bladder have been reported, e.g, [1]. In vitro, we place a bladder or its model in a controllable experimental site, and observe the response of every charging influence, [8]. However, the result of such an experiment on a dead organ or a model is hardly to prove being the same as the that in vivo. By contrast, we can insert a pressure sensor, in vivo, by catheterization through urethra or other incision [9] and get the readings of the pressure inside the bladder under different conditions. Besides possible infection, it will make experimental target uncomfortable, which then cause the differences between in experiment and in reality. Cystometrogram (CMG) has been known to be a better way to plot the pressure-volume curve of bladder pressure. However, CMG is not a proper long-term recording platform because it is very time-consuming and costly [10].

We propose an implantable long-term bladder urine pressure measurement system composed of a pressure sensor and a control chip containing a high-linearity IA. Because of its tiny size and low power, we can implant the device in the bladder to measure the pressure after proper packaging the proposed system. Therefore, we can not only read the bladder pressure directly in real time in vivo, but also reduce the effects cause by the discomfort of experimental target. The accuracy of the pressure measurement will be ensured. Notably, the sleeping mode make the device very power efficient, which can monitor the urine pressure over an

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interval of about two weeks.

II. Architecture of the Urine Pressure Measurement System

Due to the demand of size miniaturization of implantable devices and low power consumption for a long-term measurement, the proposed system has to adopt a wireless transmission such that the urine pressure information can be collected outside of the body using an external data reader. Referring to Fig. 1, the infrastructure of the entire implantable long-term bladder urine 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 mode selection where the sleeping mode is activated by shutting down the power of each block which is powered by "Power Buffer". The clock to these block is also disabled at the same time when the sleeping mode 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 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).

A. Control Sequence

The pressure in bladder isn't varied frequently or drastically. Hence, the proposed system is turned on for 10 second into the working mode every 5 minutes to save the battery power for long-term observation. By contrast, we shut down the unnecessary function blocks by cut off their supply power in other time span, i.e., the sleeping mode.

In the working mode, the data processing sequence is shown in Fig. 2. When $\overline{\text{AD\_}rst}$ is pulled high, ADC begins to sample and quantize. It takes a total of 6 AD_clk periods before the EOC (end of conversion) signal is asserted. The PtoS, then, frames the code with the sync bits (1010) to deliver them serially to the RF module.

B. Pressure Sensor

The pressure sensor of the proposed system is ATP015, which is a product of Asia Pacific Microsystem, Inc., as shown in Fig. 3. It is basically composed of bridging resistors. A stable power supply is applied between S_VDD and S_GND. The differential output voltage on SO+ and SO- will be changed with the pressure applied on the surface of the sensor. According to the specifications, the output voltage is 87 mV when the applied pressure is 15 Psi given a 3.0 V supply voltage. The ratio of the pressure against voltage drop is 0.1724 Psi/mV. Notably, 1 Psi = 68 cm-H_2O, and then 1 mV = 11.723 cm-H_2O. Thus, we can estimate the pressure based upon the measured voltage.

C. IA with 1-atm canceling

The schematic of the proposed IA is shown in Fig. 4. Besides providing the required amplification of the sensed signal, the most important function thereof is to remove the intrinsic 1-atm ($\approx$ 85 mV) pressure of the pressure sensor output voltage. The absolute pressure sensor provides a differential output voltage 85 $\sim$ 114 mV in the range of 1 atm $\sim$ 19.7 Psi. (In other words, 5 Psi above 1 atm) However, the required resolution of proposed ADC is 6 bits. If we set the largest sensor output voltage, 114 mV, to be the upper bound and 0 mV be the lower bound, 1 LSB will be presented as 114 mV / 64 = 1.781 mV = 20.88 cm-H_2O. There is no way to identify the normal pressure of a bladder (about 10 cm-H_2O) in such a scenario. By contrast, if we set the input range proportional to the possible output voltage range of the pressure sensor (85 $\sim$ 114 mV), 1 LSB will be presented as (114-85) mV / 64 = 0.453 mV = 5.31 cm-H_2O. The resolution of entire system as well as the linearity is ensured.

D. 6-bit ADC

A charge-redistribution successive approximation ADC (SA ADC) is employed in this work, as shown in Fig. 5. A binary search through all possible quantization levels is performed to attain the final digital value. When the $\overline{\text{AD\_}rst}$ is pulled high, the voltage of V_in is sampled. the Control block will generate D_out bit by bit at each AD_clk cycle to the input of the DAC. The DAC, thus, generates an analog voltage according to the digits of the D_out which is to be compared with V_in. EOC will be asserted after 6 AD_{clk} cycles to indicate that the D_out is the final code.

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 quite low to transmit through the body. 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 implantable chip design. Referring to the layout shown in Fig. 6, the chip area is 1650 μm $\times$ 1480 μm (850 μm $\times$ 630 μm without pads). The simulation result of the control sequence in the working mode is totally correct in all of the PVT (process, supply voltage, and temperature) corners. Fig. 7 is a snapshot of the simulations. Notably, Fig. 8 shows the bandwidth of the IA, which is far more than the sampling rate of entire system. The linearity of the IA is revealed in Fig. 9. Besides, we can also see the 1-atm canceling of the IA from the same figure. The INL and DNL of the ADC is found to be both less then 0.5 LSB. All of the characteristics of the proposed system is summarized in Table I.

IV. Conclusion

We have proposed an implantable long-term bladder urine 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 and working mode are alternatively activated to extend the battery life. The system is able to precisely sense the pressure in the range of 14.7∼19.7 Psi, which has been deemed as a quite large range for the research of bladder malfunctions.

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sensing range	14.7 ∼ 19.7 Psi
ADC resolution	6 bits
ADC INL	0.232 LSB
ADC DNL	0.230 LSB
sleeping mode interval	5 minutes
working mode duration	10 seconds
supply voltage	3V
average power consumption	0.97 mW

TABLE I

Characteristics of the proposed system.

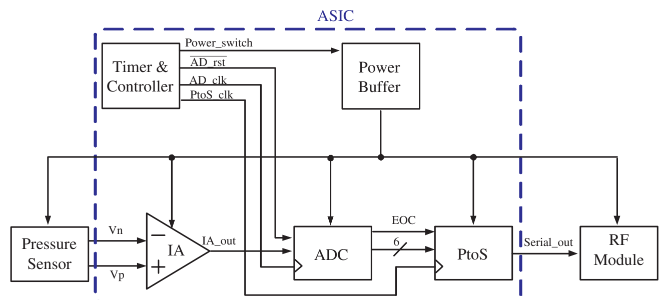

Fig. 1. Architecture of the implantable system.

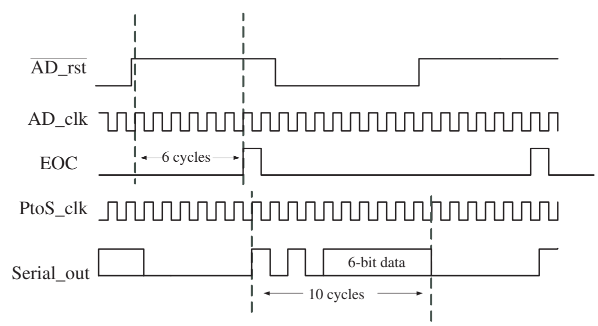

Fig. 2. Control sequence in the working mode.

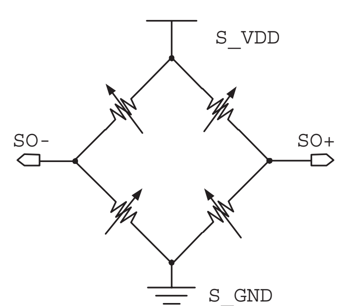

Fig. 3. Equivalent circuit of the pressure sensor

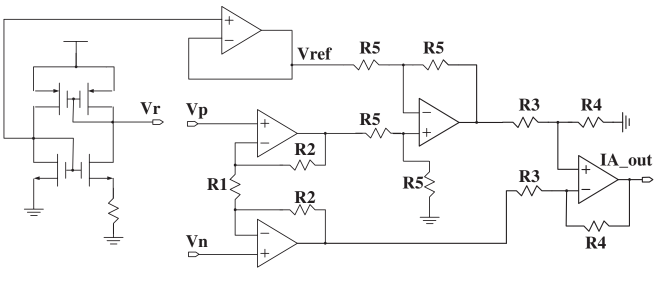

Fig. 4. Schematic of the IA.

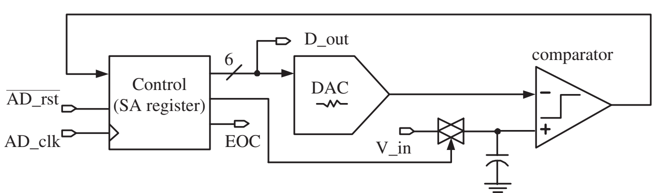

Fig. 5. SA ADC.

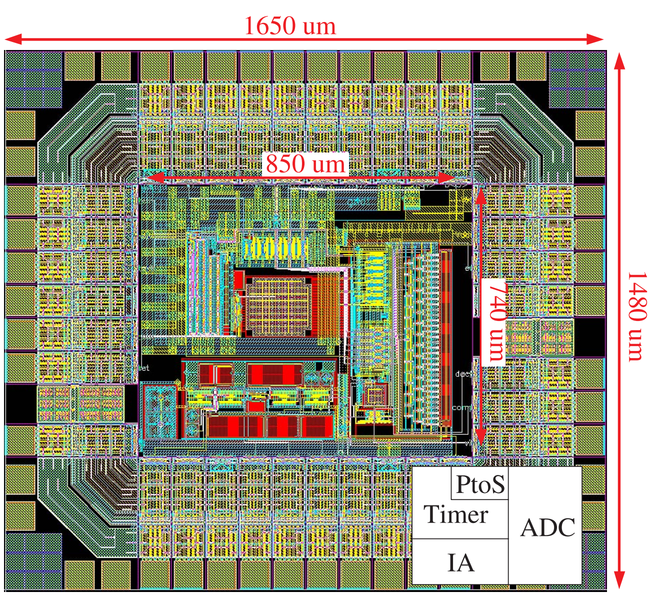

Fig. 6. The layout of the control ASIC in the proposed system.

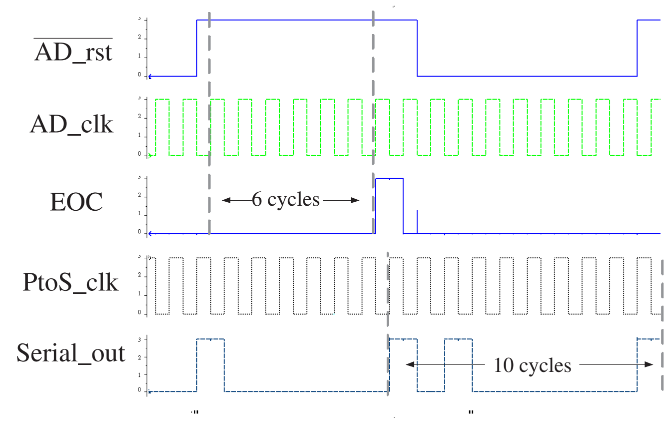

Fig. 7. Simulation results in the working mode.

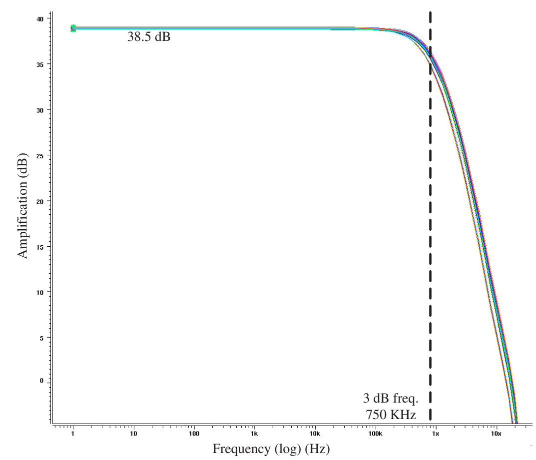

Fig. 8. Frequency response of the IA.

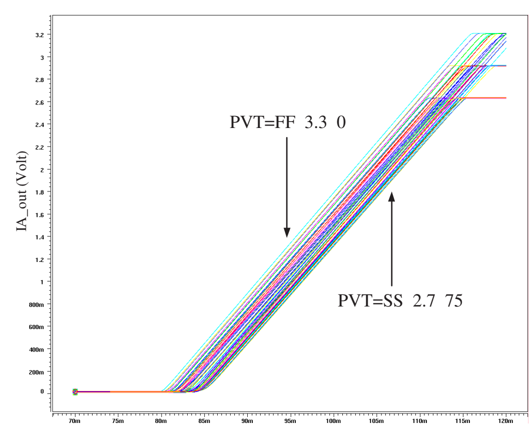

Fig. 9. DC transfer function of IA with 1-atm canceling.