

A Mini-invasive Multi-function Bladder Urine Pressure Measurement System

Chua-Chin Wang, *Senior Member, IEEE*, Chi-Chun Huang, Jun-Han Wu, I-Yu Huang[§],
Chih-Peng Li[†], Yun-Chin Lee[‡], and Wen-Jen Wu[‡]

Department of Electrical Engineering
National Sun Yat-Sen University
Kaohsiung, Taiwan 80424
email : ccwang@ee.nsysu.edu.tw

Abstract—A mini-invasive system for different purposes of the bladder urine pressure measurement is presented. Not only can the period of measurement be adjusted, the flexibility is also enhanced by using a variable IA (instrumentation amplifier). Because the urine pressure inside the 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 bladder 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 bladder 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 6.75×10^{-3} , which covers the range of all of the known unusual bladder syndromes or complications.

Keywords—urine pressure, mini-invasive, 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-H₂O 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 anomalies, 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 a mini-invasive multi-function bladder urine pressure measurement system composed of a pressure sensor and a control chip containing a high-linearity variable IA. Because of its tiny size and low power, we can implant the device 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 the 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

[§] Prof. I.-Y. Huang is an assistant professor with Dept. of Electrical Engineering, National Sun Yat-Sen University, Taiwan.

[†] Prof. C.-P. Li is an assistant professor with Institute of Communication Engineering, National Sun Yat-Sen University, Taiwan.

[‡] Dr. W.-J. Wu and Dr. Y.-C. Lee are with Dept. of Urology, Kaohsiung Medical University Chung-Ho Memorial Hospital, Taiwan.

transmission such that the urine 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 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 switching between 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 to 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).

A. Control Sequence

Usually, the pressure in the bladder 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 second 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 cut off their supply power in other time span, i.e., the sleeping interval. However, sometimes we want to observe the pressure of urinal 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 the working mode, the data processing sequence is shown in Fig. 2. When $\overline{AD_rst}$ is pulled high, ADC begins to sample and quantize. It takes a total of 8 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.

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-H₂O, and then 1 mV = 11.723 cm-H₂O. 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, and there are three advantages of the IA. 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 get a meaningful result [11]. 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 another pressure sensor is adopted in the proposed system, the lower bound of IA’s input range can be re-tuned by V_{ref} to cancel the output voltage overhead at 1-atm.

The second advantage is that no matter what input range is, the output range is always 0~3 V to meet the input range of ADC. Besides canceling the voltage overhead of different pressure sensors at 1-atm, adjusting the input voltage range by setting V_{ref} and R_x can change the resolution of the proposed system for different applications. In a normal scenario, the pressure changes slowly and slightly, and a system with high resolution is needed to observe the pressure. On the other hand, the pressure may change substantially in a critical scenario. Then, the input range will be adjusted to increase the range of measurement. Moreover, other type of pressure sensors could be adopted to be used in other different scenarios, Such a flexibility will be appreciated.

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 measure pressure precisely.

D. 8-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 $\overline{AD_rst}$ is pulled high, the voltage of V_{in} is sampled. The Control block will generate D_out bit by bit at each AD_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 8 AD_PtoS_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 low to transmit through the body such that the

absorption rate can be reduced. 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) 0.35 μm 2P4M CMOS process is adopted to carry out the proposed mini-invasive chip design. Referring to the layout shown in Fig. 5, the chip area is 1840 μm \times 1560 μm (1104 μm \times 844 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 the simulations. Notably, Fig. 7 shows the bandwidth of the IA in different amplification, which is far more than the sampling rate of entire system. 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 the same. The INL and DNL of the ADC is found to be both less than 0.5 LSB. All of the characteristics of the proposed system is summarized in Table I. The comparison of the proposed system with our previous design is shown in Table II. The sensing range and the flexibility of the proposed system are much better, but the average power consumption is only a little more than [11] because of the better ADC resolution.

IV. CONCLUSION

We have proposed a mini-invasive multi-function 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 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 a quite large range for the research of bladder malfunctions.

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Max. sensing range	10.4 ~ 27.7 Psi
ADC resolution	6 bits
ADC INL	0.362 LSB
ADC DNL	0.374 LSB
Max. resolution	6.75×10^{-3} Psi
supply voltage	3V
working power consumption	6.27 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.

	[11]	proposed system
Max. sensing range	14.7 ~ 19.7 Psi	10.4 ~ 27.7 Psi
ADC resolution	6 bits	8 bits
Max. resolution	7.80×10^{-2} Psi	6.75×10^{-3} Psi
pressure sensing range	fixed	variable
Timing modes	only long-term	long-term or continuous
supply voltage	3V	3V
in long-term mode		
average power consumption	0.97 mW	0.98 mW

TABLE II

COMPARISON OF THE PRESSURE MEASUREMENT SYSTEMS.

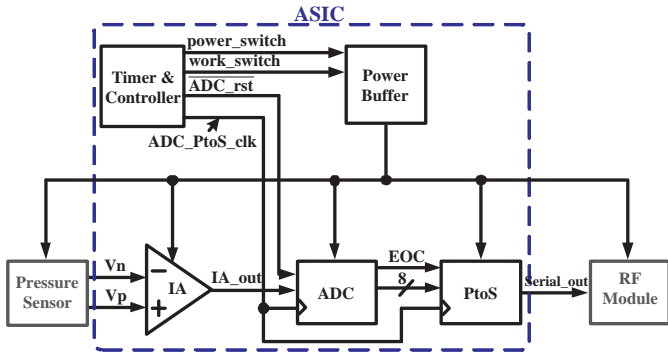


Fig. 1. Architecture of the mini-invasive system.

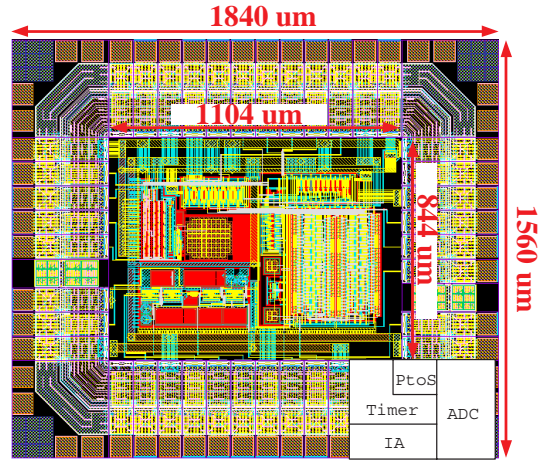


Fig. 5. The layout of the control ASIC in the proposed system.

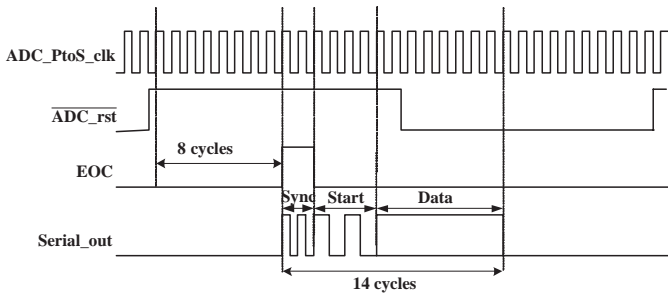


Fig. 2. Control sequence in the working duration.

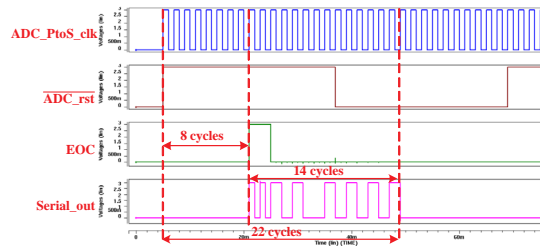


Fig. 6. Simulation results in the working duration.

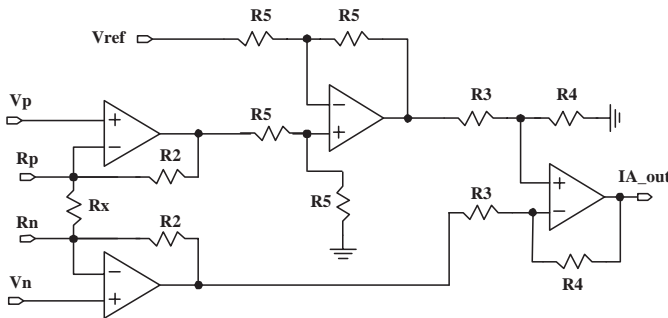


Fig. 3. Schematic of the IA.

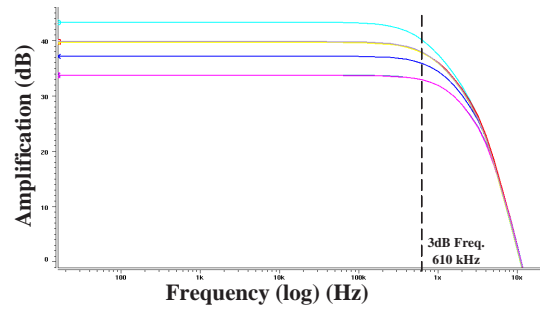


Fig. 7. Frequency response of the IA.

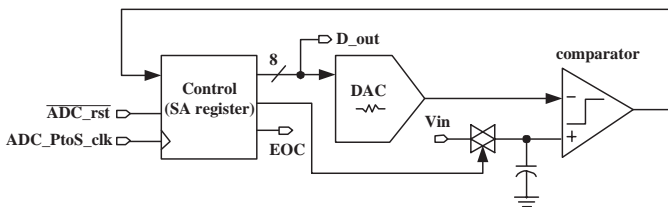


Fig. 4. Architecture of the SA ADC.

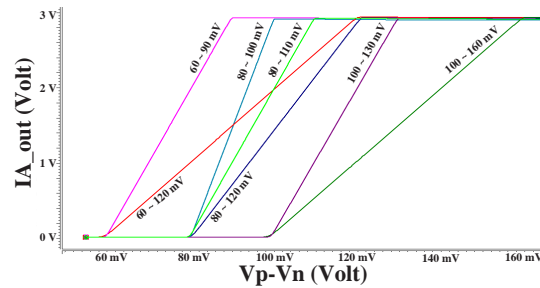


Fig. 8. DC transfer function of IA with different input range.