A Fast FPW Allergy Analyzer Prototype for Point of Care (POC)

Chia-Hao Hsu, *Student Member, IEEE*, Yue-Da Tsai, Yun-Chi Chen, Ming-Chih Lee, I-Yu Huang, and Chua-Chin Wang, *Senior Member, IEEE*

***Abstract* –An IgE antigen concentration analyzer system using a pair of two-port FPW (flexural plate-wave) sensors is proposed in this paper. The proposed system utilizes a frequency-shift readout method based on a peak detecting scheme to measure the resonant frequency shift. The frequency-shift readout circuit is integrated on silicon composed of a linear frequency generator, two peak detectors, two registers, and a subtractor. The frequency sweep range is from in 0.5 MHz to 11.6 MHz according to the characteristics of the FPW allergy biosensor. The sensitivity of the peak detector is 5 mV. The proposed frequency-shift readout circuit is verified by a prototype on PCB, where the maximal power consumption is 54 mW@5 kHz clock.**

Key word: IgE antigen measurement, frequency-shift readout circuit, FPW, resonant frequency, point of care (POC).

I. INTRODUCTION

In human serum, concentration of immunoglobulin E (IgE) is an important indicator to show the allergic level therein [1]. Many commercial allergy measurement instruments are available to measure IgE concentration, e.g., enzymelinked immunosorbent assay (ELISA) [2] , and surface plasmon resonance (SPR) [3], etc. Unfortunately, these commercial allergy measurement devices require multifarious testing samples, long operation time for sampling analysis procedures, expensive analysis instruments, and lot of analysts. They are provided mainly in large hospitals. By contrast, a low cost, high speed, and high precision for allergic level estimation is very much needed for those who are in small clinics or home [4], i.e., POC (point of care) .

A two-port allergy biosensor based on an ultrasonic flexural plate-wave (FPW) technique was proposed in [5]. The FPW allergy biosensor adopts the Cr/Au interdigital transducers (IDTs) to be a transmitter and a receiver. The sensitivity of the FPW allergy biosensor is $-8.5\times10^{7}cm^{2}g^{-1}$. Notably, the resonant frequency of the FPW allergy biosensor is variable, which is roughly anti-proportional to the purified human IgE antigen concentration. In this investigation, a frequency-shift readout system for the two-port FPW allergy biosensor is presented to reduce the operation time and overall cost. According to the resonant basics, the output signal amplitude of the FPW allergy biosensor will be maximum when the input frequency is equal to the central resonant frequency. Therefore, a high sensitive peak detector is needed to detect the maximum peak voltage and generate an enable signal to trigger a register to snapshot the frequency value. By calculating the difference between resonant frequencies of sensor1 (with antigen) and sensor2 (without antigen), the frequency-shift value is attained such that the IgE antigen concentration can be estimated.

This investigation is partially supported by National Science Council under grant NSC 99-2221-E-110-081-MY3 and EZ-10-09-44-98. It is also partially supported by Ministry of Economic Affairs, Taiwan, under grant 99-EC-17-A-01-S1-104, and 99-EC-17-A-19-S1-133. The authors would like to express their deepest gratefulness to Chip Implementation Center of National Applied Research Laboratories, Taiwan, for their thoughtful chip fabrication service.
C.-H. Hsu, Y.-C. Chen, Y.-D. Tsai, and C.-C. Wang are with Department of Electrical Engineering, National Sun Yat-Sen University, 80424, Taiwan. (email: ccwang@ee.nsysu.edu.tw)

II. FREQUENCY-SHIFT READOUT CIRCUIT

The FPW allergy biosensor propagates an acoustic wave via a mechanical thin plate [5]. Therefore, we use FPW sensor1 to be the experimental group and FPW sensor2 is the control group. Fig. 1 shows the design concept of the proposed system. Human blood drop will be placed at the hole of the serum separation micro-fluidic channel to drive the serum flowing into the cavity of sensor1, while sensor2 remains empty to serve as the base of antigen measurement.

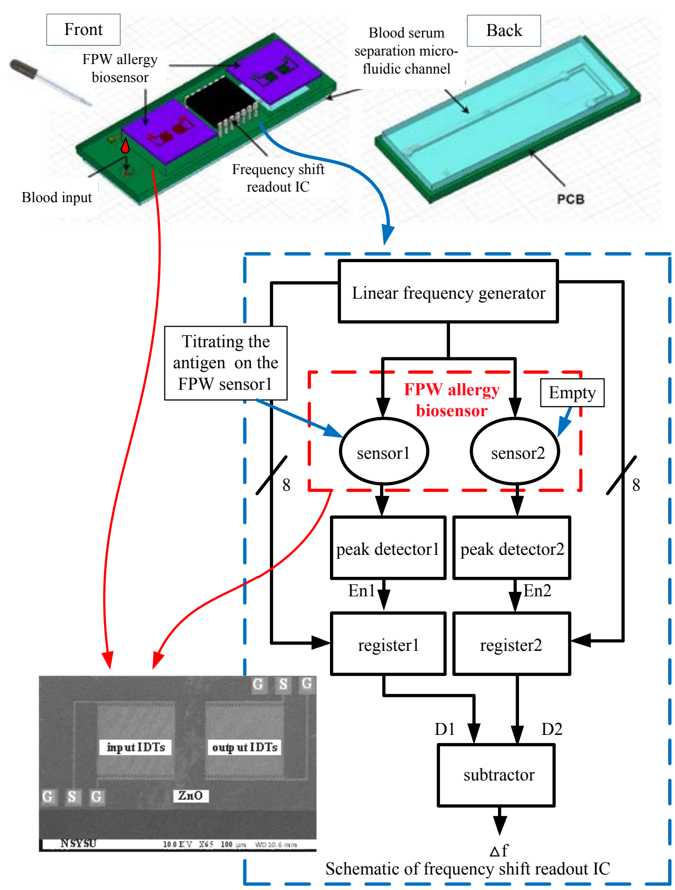

Fig. 1 Design concept of the proposed FPW allergy analyzer

Therefore, we need a frequency-shift readout circuit (IC) to estimate the amount of the frequency shift according to the characteristics of the FPW allergy biosensor.

The readout IC in Fig. 1 is composed of a linear frequency generator, a pair of peak detectors, two registers, and a subtractor. The linear frequency generator is composed of an 8-bit digital counter, an 8-bit DAC (digital-to-analog converter), and a voltage-to-frequency converter (VFC). The counter generates 0 to 256 up counting signal to the DAC. The DAC utilizes a typical current-steering structure to generate an appropriate potential to provide the VFC a proper voltage bias. The frequency tuning range of the VFC is swept from 0.5 MHz to 11.6 MHz, covering the frequency variation range of the FPW allergy biosensor (3 MHz – 9 MHz). The generated frequency fed into the FPW allergy biosensors, i.e., sensor1 and sensor2.

The output signal of the FPW allergy biosensor will reach its peak value when the input frequency equals to the resonant frequency. A peak detector is, then, used to detect the maximum peak from the FPW allergy biosensors' outputs and generate the enable signals, En1 or En2, given to the register1 and regisister2 to store the output value of the 8-bit digital up-counter. Finally, the difference between the storage values of register1 and regisister2 can be calculated by the subtractor. Therefore, we can obtain Δf by table looking the difference value.

III. Implementation

Fig. 2 shows the proposed FPW allergy analyzer prototype system. Notably, the proposed frequency-shift readout circuit for FPW allergy biosensor is realized on silicon by standard 0.18 μm CMOS technology, and Fig. 3 shows the die photo. The comparison with a similar prior work is tabulated in Table I. The resonant frequency of the FPW biosensors is around at 9 MHz, which is equal to 11001000_2 derived from the register2. Fig. 4 shows the measurement of the proposed system when the antigen is on the FPW sensor1. The storage value of register1 is 10110010_2. By calculation, the amount of the frequency shifting of the FPW sensor1 is around 22%.

Table I
Comparison with Prior Works

	proposed	[6]
technique	system on chip	on PCB discretes
Process	0.18 μm	N/A
Frequency resolution (MHz)	0.005	4.2
power(mW)	54	N/A
detecting method	peak detection	phase detection
Peak detection sensitivity(mV)	5	N/A
year	2011	2008

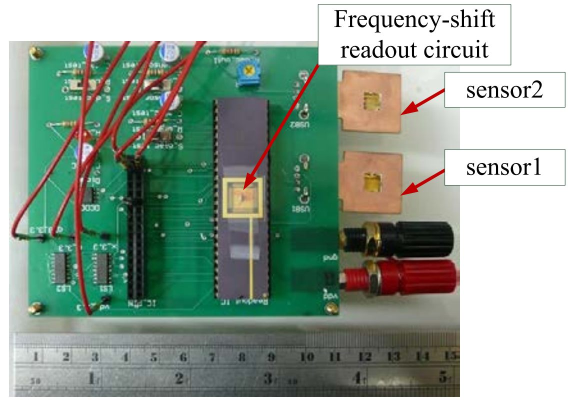

Fig.2 Physical FPW allergy analyzer prototype

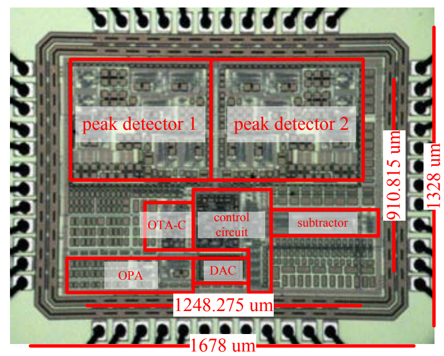

Fig. 3 Die photo of the proposed frequency-shift readout circuit

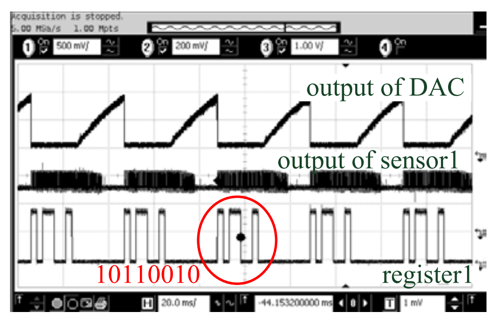

Fig. 4 Measurement of the proposed system

References

[1] H. J. Gould, B. J. Sutton, A. J. Beavil, R. L. Beavil, N. McCloskey, H. A. Coker, D. Fear, and L. Smurthwaite, "The biology of IGE and the basis of allergic disease," *Annual Review of Immunology*, vol. 21, pp. 579-628, Apr. 2003.

[2] R. M. Lequin, "Enzyme Immunoassay (EIA)/Enzyme-Linked Immunosorbent Assay (ELISA)," *Clinical Chemistry*, vol. 51, no. 12, pp. 2415-2418, Sep. 2005.

[3] X. Su and J. Zhang, "Comparison of surface plasmon resonance spectroscopy and quartz crystal microbalance for human IgE quantification," *Sensors and Actuators B: Chemical*, vol. 100, no. 3, pp. 309-314, Sep. 2004.

[4] H. Y. Tung, K. F. Tsang, K. L. Lam, and H. C. Tung, "A zero configured HomeCare gateway using ZigBee," *2011 IEEE International Conference on Consumer Electronics (ICCE)*, pp. 613-614, Jan. 2011.

[5] I-Y. Huang and M.-C. Lee, "Development of a FPW allergy biosensor for human IgE detection by MEMS and cystamine-based SAM technologies," *Sensors and Actuators B: Chemical*, vol. 132, no. 1, pp. 340-348, May 2008.

[6] W.-Y. Chang, P.-H. Sung, C.-H. Chu, C.-J. Shih, and Y.-C. Lin, "Phase Detection of the Two-Port FPW Sensor for Biosensing ," *IEEE Sensors Journal*, vol. 8, no. 5, pp. 501-507, May 2008.