## Development of a Smart Biosensor IC by Using a Differential Current-to-Time Interval Converter in BiCMOS Process

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A smart biosensor IC is developed by using a differential current-to-time interval converter in BiCMOS process. This biosensor IC provides a digital output directly connectable to a microprocessor.

Figure 1 shows a cross-sectional diagram of an ISFET using 0.35 standard CMOS process [1]. It has a floating gate structure which is passivated by a pH sensitive membrane. Figure 2 shows a smart biosensor circuit based on a differential current-to-time interval converter. This circuit gives a digital output for a differential ISFET, which consists of an ISFET and a reference FET (REFET) with the same ISFET characteristics but insensitive to pH variation, both incorporate in the same device structure. The differential ISFET measurement configuration was applied to reduce effectively any additional common-mode disturbances such as temperature dependency as well as common-mode noise [2]. Figure 3 shows the circuit diagram of the smart biosensor circuit implemented with BiCMOS operational transconductance amplifiers (OTAs) in figure 4 and CMOS comparators in figure 5 [3]. It consists of a differential ISFET, a ramp integrator, two current-tunable Schmitt triggers, and two logic gates. The upper Schmitt trigger is composed of a voltage comparator, an OTA, bias current  $I_1$ , and a resistor  $R_1$ . The bias current  $I_1$  represents the current of the ISFET to be detected. The lower Schmitt trigger is identical to the upper Schmitt trigger, except that  $I_2$  is used instead of the  $I_1$ . The  $I_2$  is the current of the REFET to be compared with that of the ISFET. Figure 4 shows circuit diagram of a high efficiency OTA used for the converter shown in figure 3. It consists of a bias circuit, a differential input stage, an output buffer, and compensating circuitry to improve frequency stability. Figure 5 shows the circuit diagram of comparator used for the converter shown in figure 3.

To see how the RD-to-TI converter operates, refer to Figure 6, which shows the signal waveforms at the various nodes of the converter, and assume that both of the Schmitt triggers are at their positive saturation level  $V_{CC}$  and that  $I_1$  is greater than  $I_2$ . Prior to the start of the conversion cycle, switch S is closed, thus discharging capacitor C and setting the input voltages of Schmitt triggers  $v_{INT}$  to 0 V. The conversion cycle begins by opening switch S. Since the reference current  $I_R$  flows through the capacitor,  $v_{INT}$  linearly rises with a slope of  $I_R / C$ . When  $v_{INT}$  reaches the threshold voltage of the lower Schmitt trigger  $V_{\text{TH2}}(=I_2R_1)$ , The output of the lower Schmitt trigger  $v_{\text{SMT2}}$  falls to zero, and the output of the XOR gate  $v_{OUT}$  becomes high. Denoting  $t_2$  the time duration for which  $v_{SMT2}$  keeps  $V_{CC}$ , it can be written  $t_2 = CR_1 I_2 I_R$ . The conversion process continues until  $v_{\rm INT}$  reaches the threshold voltage of the upper Schmitt trigger  $V_{\text{TH}1}$  (= $I_1R_1$ ). At this instant, the output of the upper Schmitt trigger  $v_{\text{SMT}1}$  falls to zero; therefore,  $v_{OUT}$  becomes low, and the output of the NOR gate  $v_{SW}$  becomes high. Switch S is now closed, thus clamping the voltage v<sub>INT</sub> to ground. This, in turn, makes the outputs of the Schmitt triggers rise  $V_{\rm CC}$  to and  $v_{\rm SW}$  go to low. Switch S is now opened, and new conversion process is started. Denoting  $t_1$  the time duration for which  $v_{\text{SMT1}}$  keeps  $V_{\text{CC}}$ , it can be written  $t_1 = CR_1 I_1 / I_R$ . The time width of  $v_{\text{OUT}}$ pulse is given by  $\Delta t = t_1 - t_2 = CR_l/I_R(I_1 - I_2)$ . The digital equivalent output can be obtained by counting the pulse width with an external clock.

## References

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[2] Y. H. Ghallab and W. Badawy, "A new differential PH sensor current mode read-out circuit using two operational floating current conveyor," 2004 IEEE International Workshop on Biomedical circuit and systems, pp. S1/5,13-16, Dec. 2004.

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Figure 1 A cross-sectional diagram of an ISFET using 0.35 standard CMOS process.



Figure 2 Smart biosensor circuit based on a differential current-to-time interval converter.



Figure 3 Circuit diagram of the smart biosensor circuit.



Figure 4 Circuit diagram of the OTA used for the converter shown in Figure 3.



Figure 5 Circuit diagram of the comparator used for the- converter shown in Figure 3.



Figure 6 Voltage waveforms at the various nodes of the converter shown in Figure 3, where  $\Delta T = K(I_1 - I_2).$