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 $V_{TH2}(= I_2R_1)$, The output of the lower Schmitt trigger v_{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 $t_2 = CR_1I_2/I_R$. The conversion process continues until v_{INT} reaches the threshold voltage of the upper Schmitt trigger V_{TH1} $(=I_1R_1)$. At this instant, the output of the upper Schmitt trigger v_{SMT1} 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_{INT} to ground. This, in turn, makes the outputs of the Schmitt triggers rise V_{CC} to and v_{SW} go to low. Switch S is now opened, and new conversion process is started. Denoting t_1 the time duration for which v_{SMT1} keeps V_{CC}, it can be written $t_1 = CR_1I_1/I_R$. The time width of v_{OUT} pulse is given by $\Delta t = t_1 - t_2 = CR_1/I_R(I_1 - I_2)$. 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.
[3] H. Kim, W. S. Chung, H. J. Kim, S. H. Son, "A Resistance Deviation-to-Pulse Width Converter for Resistance Sensors," *IEEE Trans. Instrumentation and Measurement*, vol. 58, no. 2, pp. 397-400, Feb. 2009.

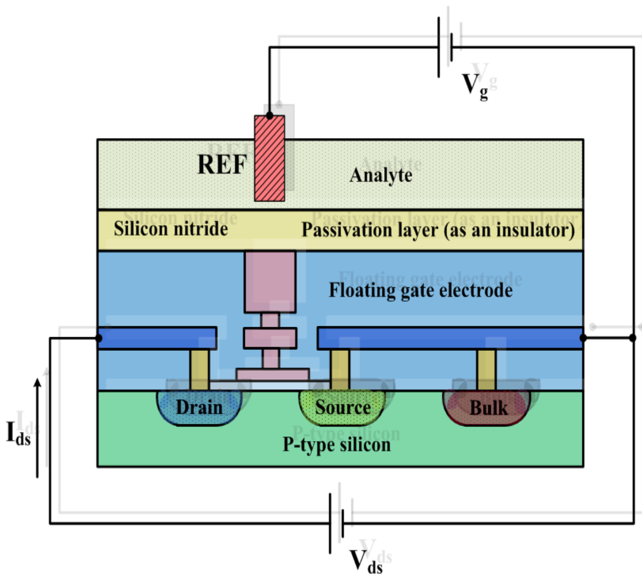

Figure 1 A cross-sectional diagram of an ISFET using 0.35 standard CMOS process.

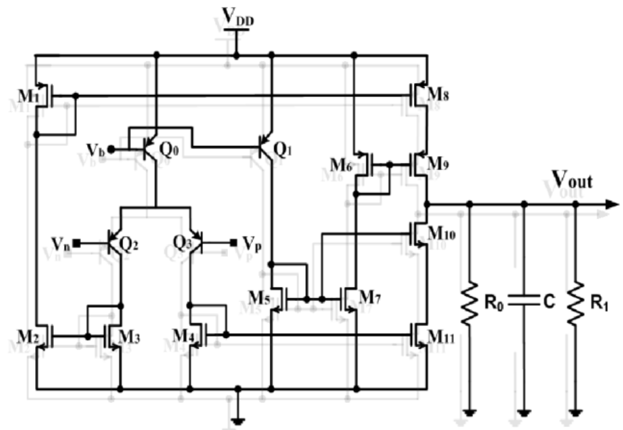

Figure 4 Circuit diagram of the OTA used for the converter shown in Figure 3.

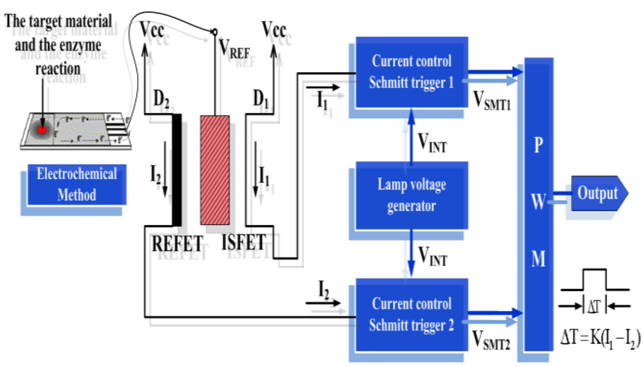

Figure 2 Smart biosensor circuit based on a differential current-to-time interval converter.

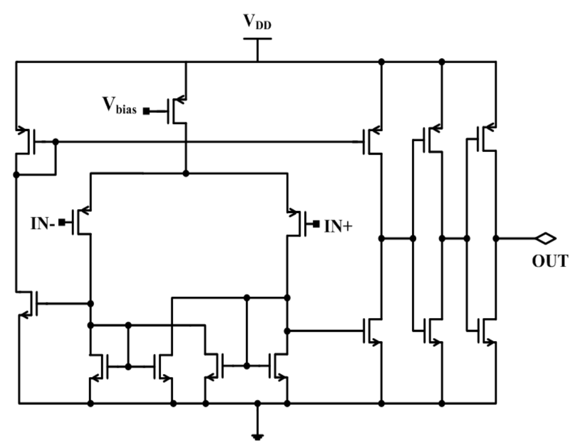

Figure 5 Circuit diagram of the comparator used for the- converter shown in Figure 3.

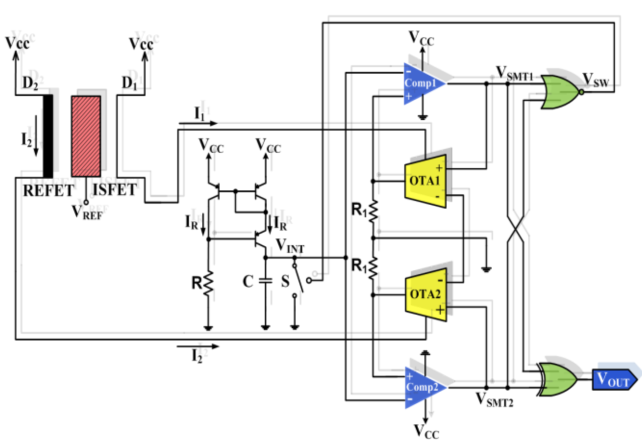

Figure 3 Circuit diagram of the smart biosensor circuit.

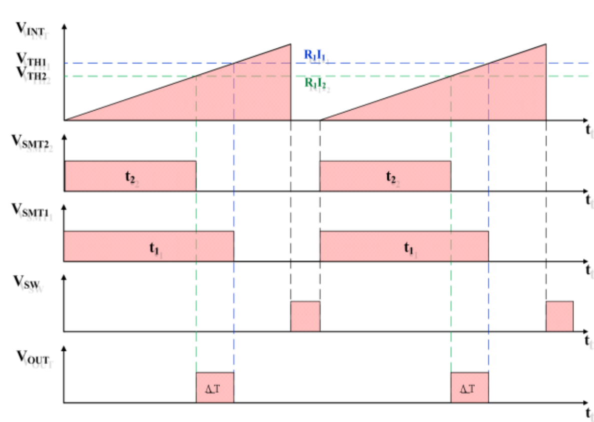

Figure 6 Voltage waveforms at the various nodes of the converter shown in Figure 3, where $\Delta T = K(I_1 - I_2)$.