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Low power analog frontend for ISFET sensor readout

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Abstract:

A low power analog frontend (AFE) for Ion-Sensitive Field effect Transistor sensor readout is presented. The AFE is demonstrated with off-the-shelf components. It includes a biasing circuit to bias an ISFET sensor, a noise rejecting current readout circuit, and a sigma-delta analog to digital converter. The digital output can be interpreted by a simple counter to acquire the ion-concentration in a drop of liquid on top of the calibrated ISFET sensor. A PH sensing experiment is performed to validate the AFE. Total power consumption is less than 40 µW with 1.8 V supply.

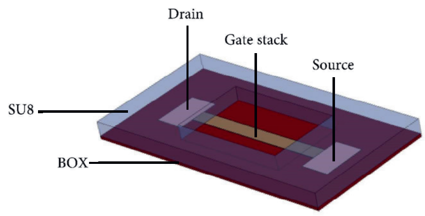
Key words: Analog frontend; Current mode sensor; Phase sensitive detection; Current rectifier; Current multiplier.

Introduction

ISFET (Ion-Sensitive Field Effect Transistor) sensor is a type of sensors that exploits the ion-concentration influence on its *I-V* curve. An ISFET works like a MOSFET whose gate metal is removed (Fig. 1*a*). The gate oxide is covered by a sensitive layer and immersed in the liquid-under-test for trapping certain targets (ions, biomarkers, etc.). As shown in Fig. 1*b*, when the reference electrode (immersed in the liquid-under-test) is biased properly, the surface potential Ψ_S of the ISFET's channel will be linearly related to V_{ref}. At the same time, Ψ_S can be modified by chemical events when the target is trapped on-site. The amount of modification depends on the concentration of the target. Thus, bio/chemical events can be translated into electrical signals by ISFET sensors.

This paper presents an analog frontend (AFE) sensor readout circuit (Fig.2) that biases the ISFET sensor and reads the corresponding sensor current into digital stream. Adopting phase sensitive detection (PSD) technique, [1] the readout circuit is able to move the low frequency noise (accompanied with the sensor current) to higher frequency band. A low pass filter followed by a 1st-order sigma-delta ADC is used to convert the low-noise signal into digital stream.

The readout circuit is demonstrated in PCB with off-the-shelf components, consumes less than 40 µW with 1.8 V supply.



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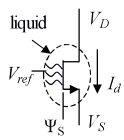

b

Fig.1 Ion-Sensitive Field Effect Transistor
a Layout representation of the proposed ISFET
b A sketch of the ISFET sensor. V_{ref}: reference electrode voltage, Ψ_S: surface potential, $V_{D/S}$: drain/source bias voltage, I_d: drain current. Ψ_S is linearly proportional to V_{ref} and monotonically varying with the amount of targets trapped on-site. I_d varies monotonically with Ψ_S.

Principle of operation and circuit implementation

The proposed AFE is shown in Fig. 2. V_{DS} is an AC signal of frequency f_o=77 *Hz* that excites the device under test (DUT), in order to modulate the sensor information into a sensor current I_{SENSE} of carrier frequency f_o. The DUT adopted here is an ISFET sensor, whose gate oxide is sensitive to H^+ concentration. Due to the non-linear I_d-V_{ref} behavior of ISFETs, the AFE needs to apply a square wave across V_{DS} when sensing. For ease of interpreting the circuit principle, V_{DS} is drawn here as a sinusoid. Since the DUT has symmetric drain and source connections, the sensor current I_{SENS} is also a square wave, symmetrical with respect to 0 ampere. The square wave current has two states. In state *S1*, when I_{SENS} is negative: V_r is high, I_{SENS} is conducted through M1, and mirrored by CM1 to I_O; in state *S2*, when I_{SENS} is positive: V_r is low, I_{SENS} is conducted through M2, and mirrored by CM2 to I_O. Adding the two states together, makes I_O the rectified version of the sensor current.

$$I_O = I_{SENS} \times V_r \qquad (1)$$

Thus, through the bidirectional negative feedback current conveyer formed by the opamp and transistors M1-M2, the input current I_{SENS} is mixed with V_r. Interestingly, V_r is a square wave voltage whose phase is locked with the excitation signal V_{DS} via the same feedback loop.

With Eq. (1), the sensor information carried in the square wave current is demodulated back to DC frequency, and the low frequency noise is shifted to a frequency band centering at f_o. Then I_O is passed through an LPF to remove the noise at high frequency, and obtain a DC current I_{OF} that varies monotonically with the amplitude of I_{SENS}. A sigma delta ADC is used to readout the filtered current. Since the input is a DC current, a simple counter can be used instead of a complicated decimation filter. The counter counts the number of rising edges at the output (D_{OUT}), which is proportional to the amplitude of the input current (I_{OF}).

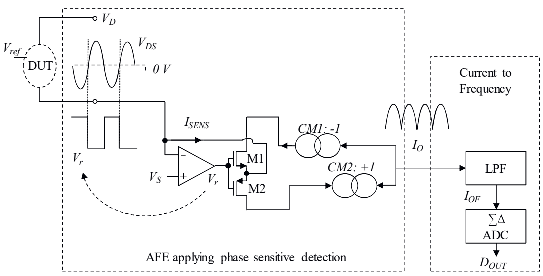

Fig. 2 Block diagram of the proposed AFE. V_r (phase locked to the excitation signal V_{DS}) is generated out of the biasing circuit. V_{DS} is drawn here as a sinusoid. The system actually applies square wave for easy implementation.

Measurement Results

An n-channel ISFET on ultra-thin SOI with HfO2 as its gate oxide has been applied for PH sensing. [2] The sensor was biased with voltage while sampling its drain current. Different PH buffers were changed consecutively from PH=3 to PH=9, and back from 9 to 3 during the measurement. The measurements were done both with the proposed AFE and a precision semiconductor analyzer (Agilent 4156A), in order to validate the performance of the readout AFE. (a) With Agilent 4156A, the ISFET was biased at V_{ref}=1.3 *V*, V_S=800 *mV*, V_D=1.1 *V*. (b) With the AFE, the ISFET was biased at V_{ref}=1.3 *V*, V_L=800 *mV*, V_H=1.1 *V (*V_L and V_H voltages applied on the Drain and source alternatively, forming a square wave V_{DS} at a frequency of 77 *Hz)*. The measurement results are shown in Fig.3. The digital output from the AFE was counted for the number of rising edges, and proves to be reasonably coherent with lab instrument measurements (Fig. 3).

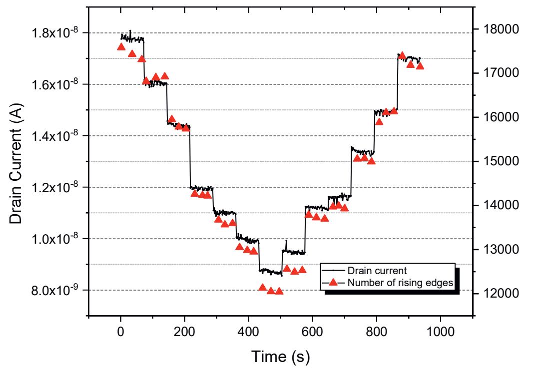

Fig. 3 *PH sensing performed to verify the performance of the readout AFE. Left axis: measurements performed by Agilent 4156A; Right axis: number of rising edges from the presented AFE*

Conclusions

An ISFET sensor readout AFE is demonstrated. It modulates the sensor information with a square wave signal by applying alternating bias to the sensor; adopts a novel current mode structure in the lock-in amplifier. A PH sensing experiment validates that the readout AFE is able to work with ISFET sensors by biasing them in amperometric mode, and provide good current readout results. The system operates at 1.8V supply, consumes less than 40μW, and the simple structure makes it suitable to be integrated in a single chip.

References

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