A 32x32 ISFET array with in-pixel digitisation and column-wise TDC for ultra-fast chemical sensing

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Summary

• Ion-sensitive field effect transistor (ISFET) enable large-scale integration for chemical sensing.
• pH-to-Time inverter structures enables offset compensation and noise power optimisation.
• Asynchronized coarse-fine TDC for fast data conversion, simplified structure for edge capture and integration.
• A 32x32 sensor array with column-wise TDC, fully digital-like implementation.
• Enables fast low-power chemical imaging for μm and μs

Features

• 10ns switching power for pixel readout
• ± 7V offset compensation
• Mostly digital implementation
• Total power consumption <7mA @1kHz
• Wide-band(2-500) Noise 0.07pH
• Sensitivity 31mV/pH, min 0.013pH
• 15b TDC with asynchronous conversion

Introduction

Large-scale arrays consisting of miniature sensors or electrodes can be integrated together with low noise analogue front-ends with direct conversion and subsequent processing. CMOS ISFETs enable large-scale integration into a mm-size silicon chip, with full on-chip interfacing and processing circuitry, inciting to the decreasing feature size of CMOS technology. High density integration of ISFET arrays in CMOS greatly reduces the cost, but also introduces design challenges for scalability of the sensor interface[1].

The ISFET readout plays an essential role in minimizing the sensor size and keep linearity with a fast sampling rate. Simplified circuits with low power consumption and noise are required to retrieve chemical signal among large sensor offset.

Sensor pixel

• The ISFET can be viewed as an AC-coupled amplifier or comparator, which is chemical sensitive.
• pH-To-Time conversion[2] based on inverter/comparator switching.
• Triangle wavefront trigger the switching and PWM is generated.
• Offset compensation and signal gain is provided by:

\[ V_{TDC} = \frac{C_{G} + C_{pH} + C_{pd}V_{int}}{V_{FF}} \]

\[ T_{out} = T_{in} \times \frac{1}{(V_{T} + k) + C_{G} + C_{pH} + C_{pd}V_{int}} \]

• Greatly reduce the power and supply voltage requirement.
• Linearity is preserved due to capacitive division and gain.
• Noise is increased but can be well controlled under chemical

Asynchronous TDC

• 15bit TDC for PWM output direct from the inverter output.
• 10bit coarse converter based on async counter and 5 bit fine based on the delay line.
• Asynchronous trigger to detect both edge of PWM, interval between edge and clock are captured and summed.
• Mostly digital design, with the delay of fine converter tuned globally via current source.

Implementation

• A 32x32 sensor array was implemented in a typical 0.18μm CMOS technology.
• Column-wise TDC with full digital interface to the top level FSM
• TDC and pixel are height aligned, with potential to scale up the system dimension.
• Most design can be synthesised to optimize power and area.
• Total area of 0.9m2 excluding the FSM.

Results

• Simulation of the complete system was performed using an estimated chemical change and capacitance model.
• Measured results using implemented chips and various chemical testing.
• Offset compensation of ±7V, and pH sensitivity of 31mV/pH was achieved.
• Integrated noise referred to pH is 0.07 with minimum resolution of 0.013pH.
• Fast chemical imaging (1k measured, 5k simulated) was performed, milliseconds time resolution was achieved.

Table 1: Comparison of ISFETs sensing system performance.

<table>
<thead>
<tr>
<th>specifications</th>
<th>This work</th>
<th>[1]</th>
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<th>[3]</th>
<th>[4]</th>
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<tbody>
<tr>
<td>Process (µm)</td>
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<td>Supply (V)</td>
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<tr>
<td>Offset compensation</td>
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<td>±0.065</td>
<td>±0.065</td>
<td>±0.065 /0.007</td>
<td>±0.019</td>
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<td>Offset (mV)</td>
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<td>Power (µW)</td>
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<td>Total power (mW)</td>
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<td>Simulated average power consumption per 1 sample @5kHz</td>
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References: