A 0.026 mm$^2$ Capacitance-to-Digital Converter for Biotelemetry Applications Using a Charge Redistribution Technique

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Outline

• Motivation
  – Capacitive sensor interface circuits

• Concept
  – Sensor problem and solution

• Proposed circuit
  – Operation

• Measurement results

• Conclusion
Motivation

Increasing demand for wireless healthcare systems

Ex1) A patch to monitor [1]
- Blood pressure
- Heart rate
- Other vital signs

Ex2) Swallowable capsule endoscope for monitoring stomach and intestine. [2]

Motivation

Some wireless healthcare systems require pressure measurement. (e.g., blood pressure, sound pressure)

A capacitive pressure sensor interface circuit
Target Application

Sensor interface for **Bladder monitoring**

3 days pressure measurement

Bladder monitoring system

- Low power: 100µA order battery
- Small size: 8mm x 5mm
Capacitive sensor interface

Conventional circuits

• C/Volt converter & ADC [3]
  😞 large area and high power consumption

• C/Digit converter (ΔΣ type) [4,5] < 4.25 mW
  😞 Opamp: high power consumption

SAR type C/D Converter is proposed.

=100μA

order

SAR C/D converter

SAR (Successive Approximation Register) + capacitive sensor

😊 Low power (no opamp)
😊 Small area
😊 Robustness to supply voltage fluctuations
Problem of capacitive sensors

Dynamic range does not match

![Diagram showing capacitance and pressure relationship with offset capacitance and sensor range indicated.]
Proposed solution (1 of 2)

1. Sensor capacitance scaling
   ⇒ Any large sensor capacitance can be measured.
2. Offset canceling
Converter range is shifted to the scaled sensor range.
Full range conversion

- Sensor capacitance scaling
- Offset canceling

Full range conversion can be achieved
Proposed circuit

- Sensor capacitance scaling
  \( k \) : Scaling factor

- Offset canceling
Offset canceling operation

The Sensor shows offset capacitance
 Offset canceling (1 of 5)

Store charge to the sensor
Offset canceling (2 of 5)

Charge conservation
Offset canceling (3 of 5)

Charge redistribution
Offset canceling (4 of 5)

Capacitance comparison

\[ 2^N C_R > k C_{x\_offset} \]

MSB Capacitance > Sensor Capacitance
Offset canceling (5 of 5)

Charge redistribution and comparison sequence proceeds
Comparison sequence

Offset max

Cap

Larger?

Smaller?

Larger?

Smaller?

Larger?

Smaller?

Larger?

Smaller?

Larger?

Smaller?

kC_{x_{offset}}

Binary Search

Obtain sensor offset

Time
Converting the varying part of the sensor’s capacitance
Operation (1 of 3)

Store charge to the sensor
Operation (2 of 3)

Charge conservation
3. MSB conversion

\[ \frac{V_{DD}}{C_{total}} (\sum C_R + C_{MSB} - kC_x) > 0 ? \]
Conversion features

\[ \frac{V_{DD}}{C_{\text{total}}} \left( \sum C_R + C_{\text{MSB}} - kC_x \right) > 0 ? \]

1. \( V_{DD} \) does not affect conversion result
   \( V_{DD} \): Supply voltage

2. Offset canceling
   \( C_R \): Offset canceling capacitor

3. Sensor capacitance scaling
   \( k \): Scaling factor
Chip photo

Area : 0.026 mm²
Total capacitance : 6 pF
MEMS sensor experiment

![Graph showing the output code in response to pressure in mmHg. The graph plots a linear relationship between pressure and output code, increasing from 200 to 255 as pressure increases from 0 to 60 mmHg.]
# Measurement results (1)

<table>
<thead>
<tr>
<th>Specification</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Resolution</td>
<td>8 bit</td>
</tr>
<tr>
<td>Supply Voltage</td>
<td>1.0-1.8 V</td>
</tr>
<tr>
<td>Sampling Rate</td>
<td>262 kHz</td>
</tr>
<tr>
<td>SNR</td>
<td>43.22 dB</td>
</tr>
<tr>
<td>ENOB</td>
<td>6.83 bit</td>
</tr>
<tr>
<td>Current Consumption</td>
<td>169 $\mu$A @ $V_{DD} = 1.4$ V</td>
</tr>
<tr>
<td>DNL</td>
<td>-0.97 to 0.79 LSB</td>
</tr>
<tr>
<td>INL</td>
<td>-1.27 to 0.99 LSB</td>
</tr>
<tr>
<td>Area</td>
<td>0.026 mm$^2$</td>
</tr>
<tr>
<td>Total Capacitance</td>
<td>6 pF, including 3.6 pF offset canceling cap</td>
</tr>
</tbody>
</table>
Measurement results (2)

The same SNR for a supply voltage of 1.0 V to 1.8 V

<table>
<thead>
<tr>
<th>Supply Voltage</th>
<th>1.0 V</th>
<th>1.4 V</th>
<th>1.8 V</th>
</tr>
</thead>
<tbody>
<tr>
<td>SNR</td>
<td>43.4 dB</td>
<td>43.2 dB</td>
<td>43.2 dB</td>
</tr>
<tr>
<td>ENOB</td>
<td>6.88 bit</td>
<td>6.83 bit</td>
<td>6.84 bit</td>
</tr>
</tbody>
</table>

*Bias voltage is changed in proportion to supply voltage.*
Conclusion

A capacitive pressure sensor interface circuit is proposed.

It is suited for wireless healthcare systems.

😊 Features

• Low power consumption: 236 $\mu$ W
• Small area: 0.026 mm$^2$
• Robustness: tolerance for $V_{DD}$ fluctuation
• Full dynamic range conversion
Thank you for your interest!

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