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

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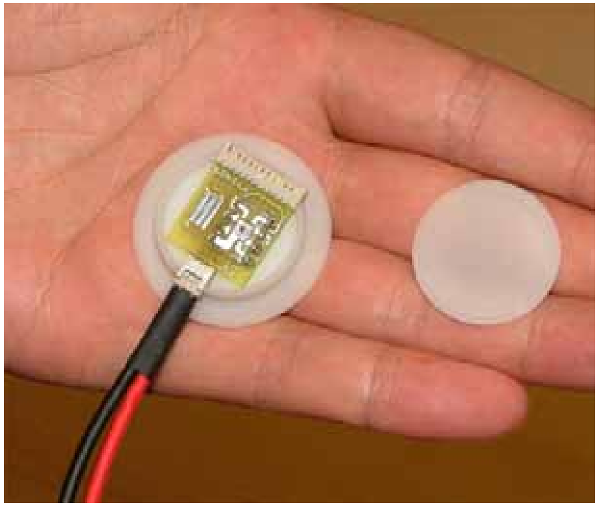
Outline

- 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**

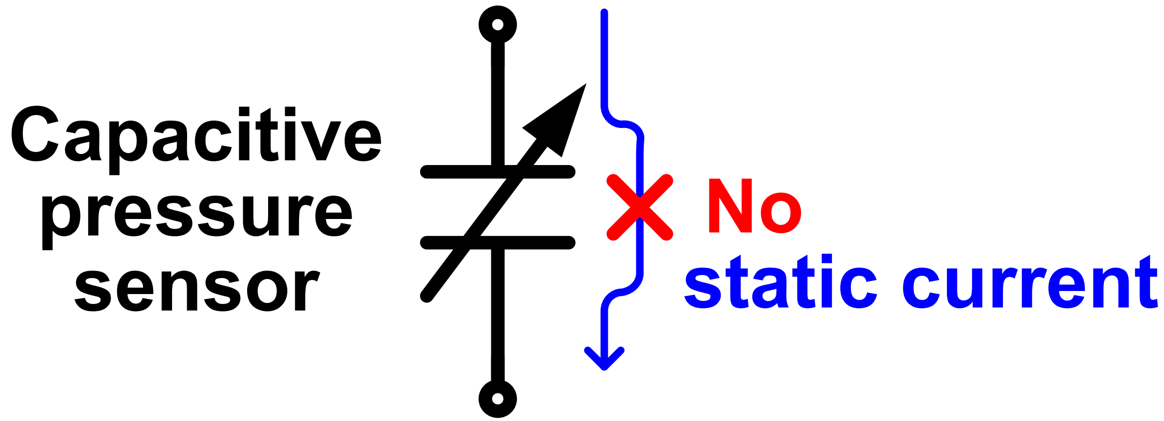
Ex2) Swallowable capsule endoscope for monitoring stomach and intestine. [2]

[1] [Online] http://news.com.com/The+next+thing+on+the+Net+Your+cardio+system/2100-11395_3-5865625.html
[2] [Online] http://www.rfsystemlab.com/sayaka/

Motivation

Some wireless healthcare systems require pressure measurement.

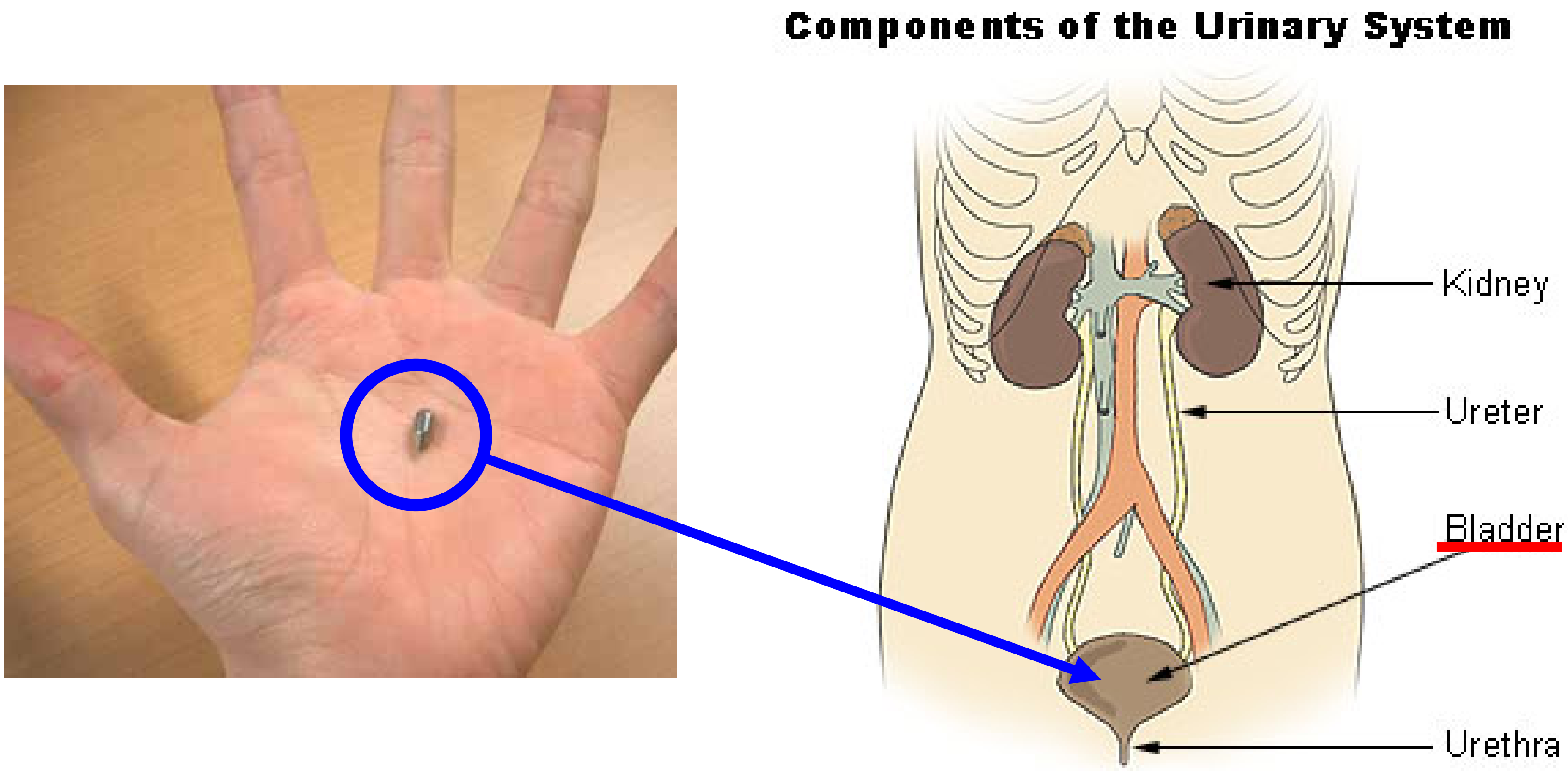
(e.g., blood pressure, sound pressure)



➡ **A capacitive pressure sensor interface circuit**

Target Application

Sensor interface for Bladder monitoring



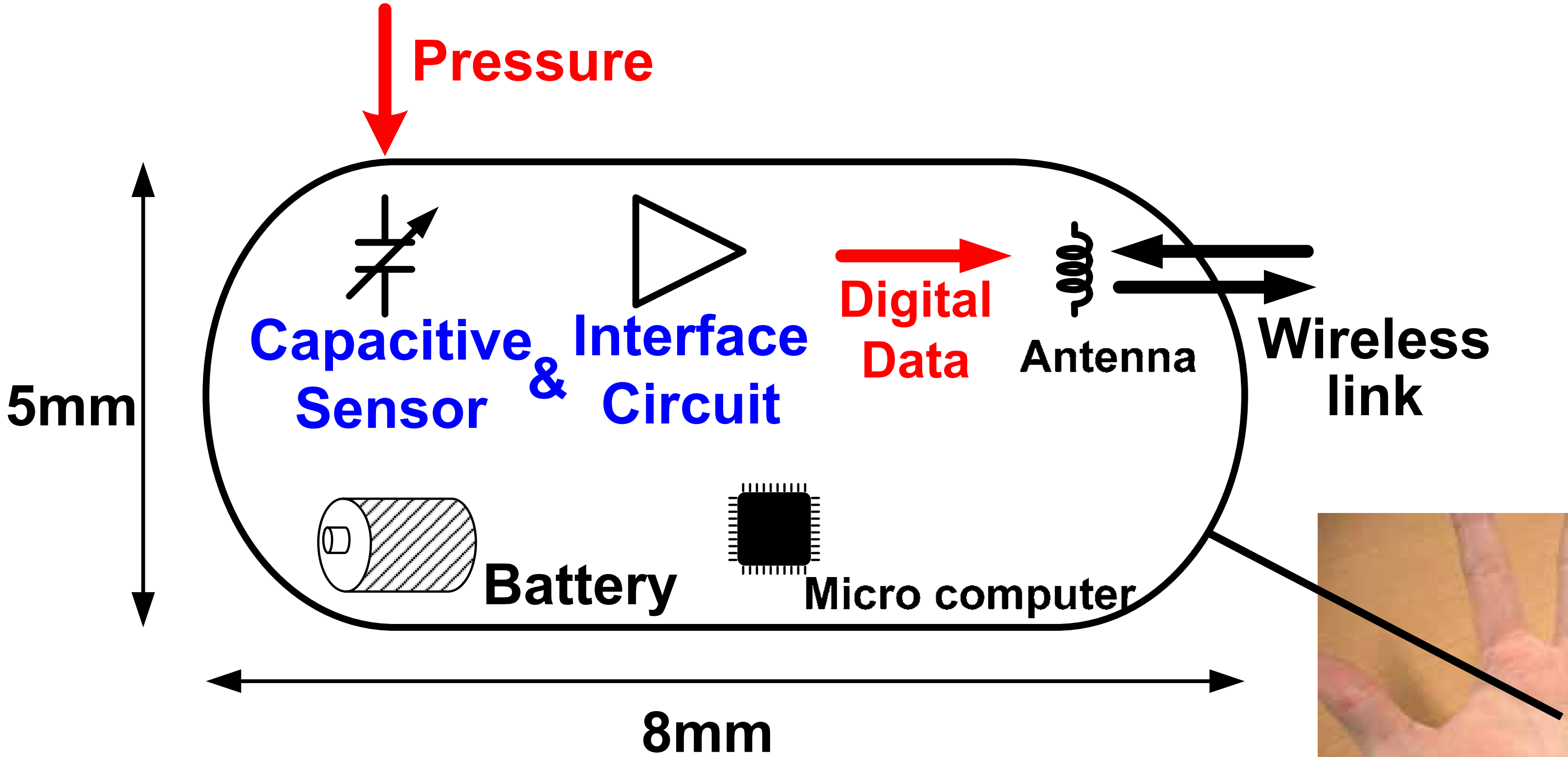
3 days pressure measurement

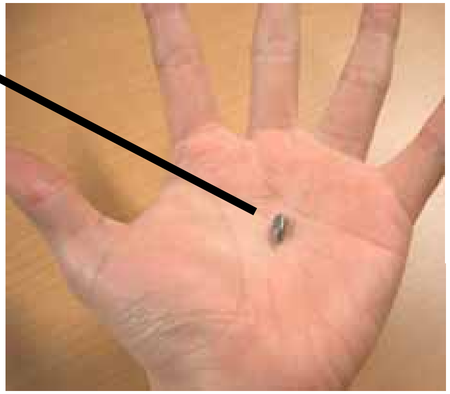
[Online] http://ja.wikipedia.org/wiki/%E8%86%80%E8%83%B1 ,Under GDFL licence
http://ja.wikipedia.org/wiki/Wikipedia:Text_of_GNU_Free_Documentation_License

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.

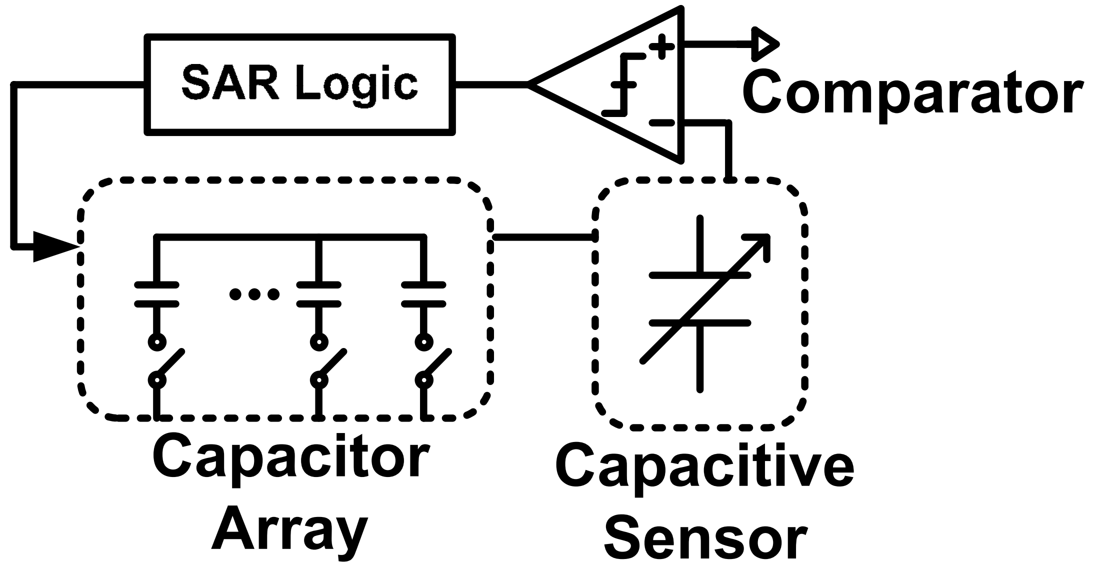
=100μA order

[3] J. C. Lotters et al. "A sensitive differential capacitance to voltage converter for sensor applications," 1999.
[4] M. Yamada and K. Watanabe, "A capacitive pressure sensor interface using oversampling Δ-Σ demodulation techniques," 1997.
[5] Analog Devices "AD7745" Available:http://www.analog.com/jp/prod/0,,760_1077_AD7745,00.html

SAR C/D converter

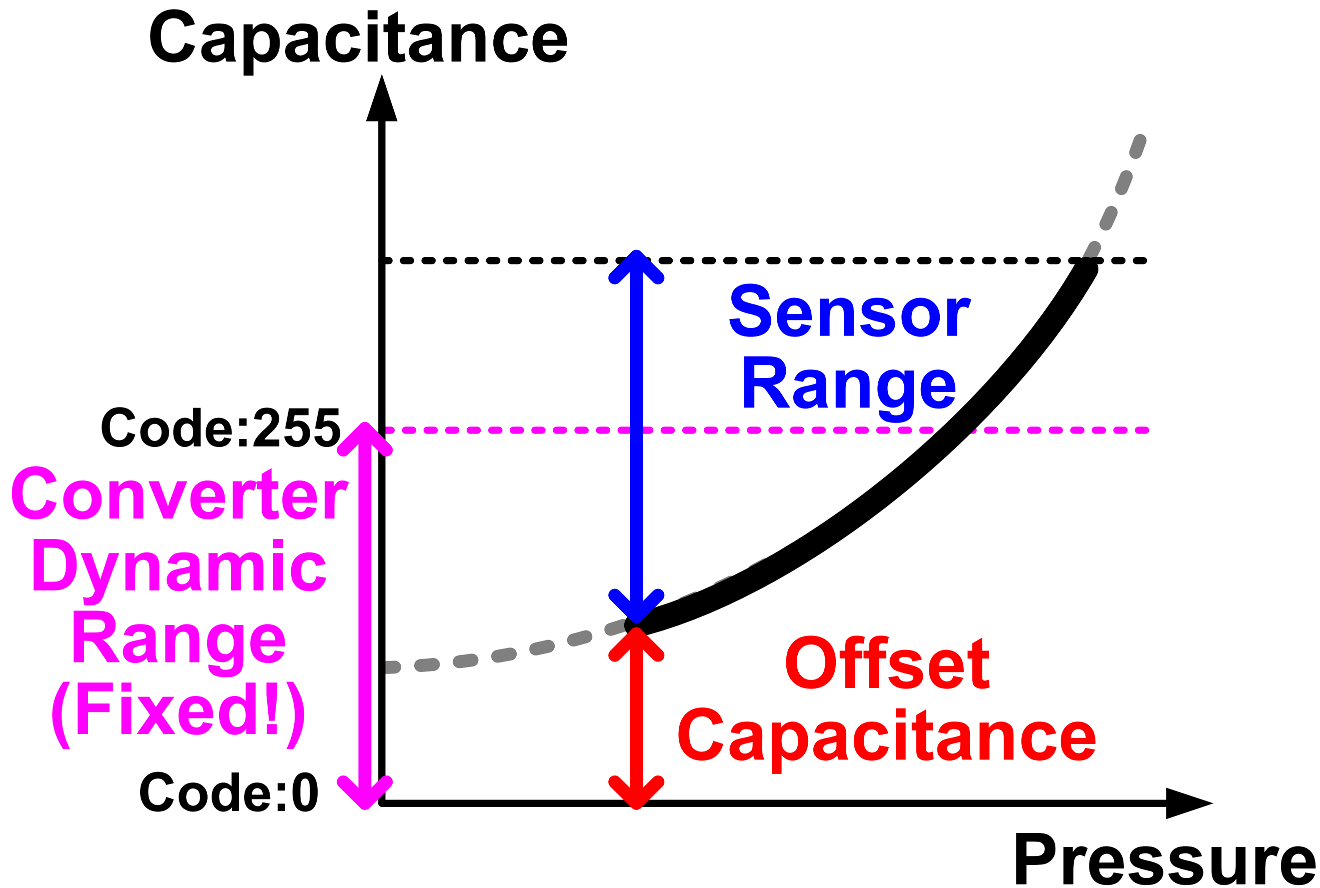
SAR (Successive Approximation Register)
+ capacitive sensor

- ☺ Low power (no opamp)
- ☺ Small area
- ☺ Robustness to supply voltage fluctuations



Problem of capacitive sensors

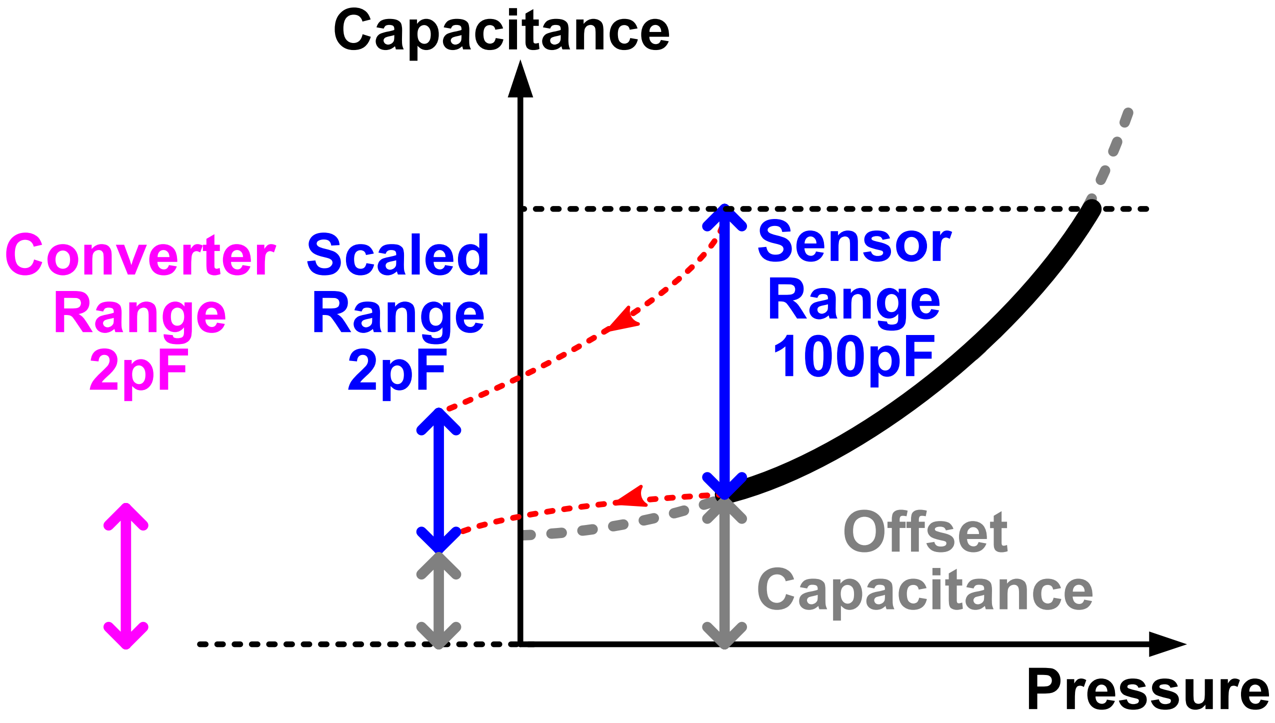
Dynamic range does not match



Proposed solution (1 of 2)

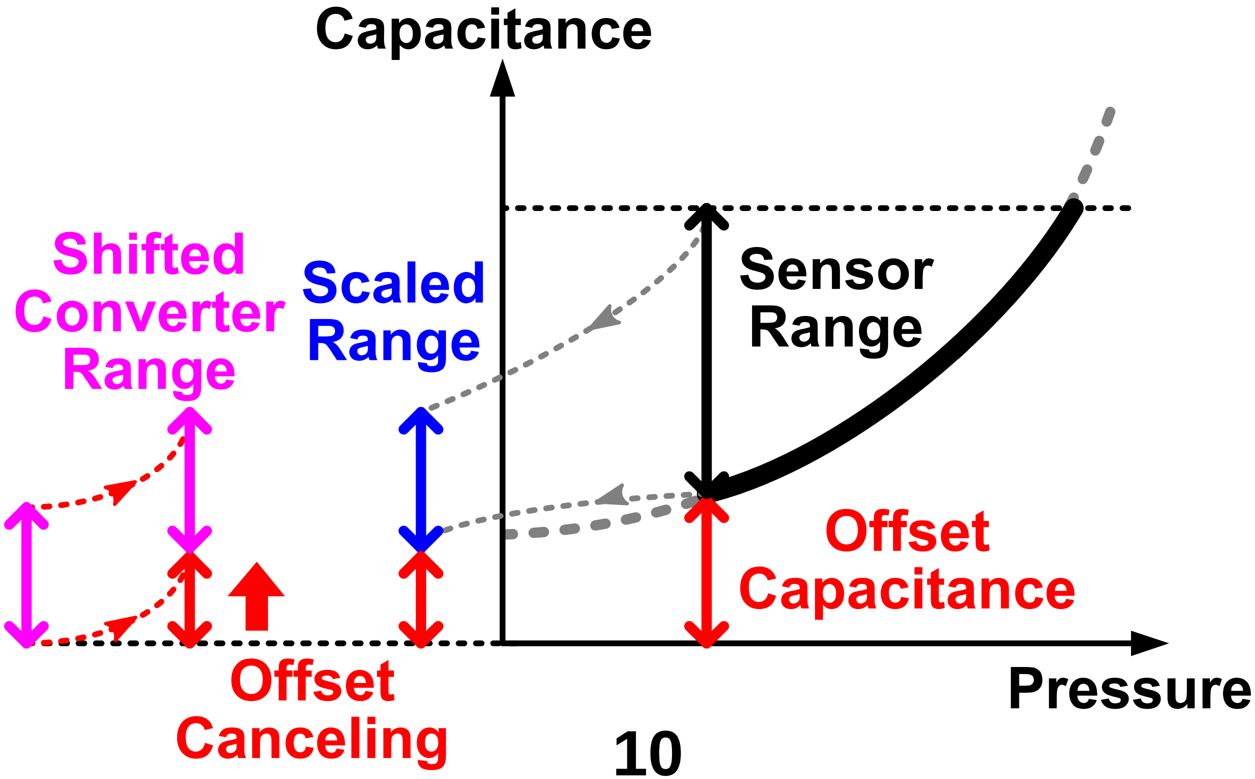
1. Sensor capacitance scaling

⇒ Any large sensor capacitance can be measured.



Proposed solution (2 of 2)

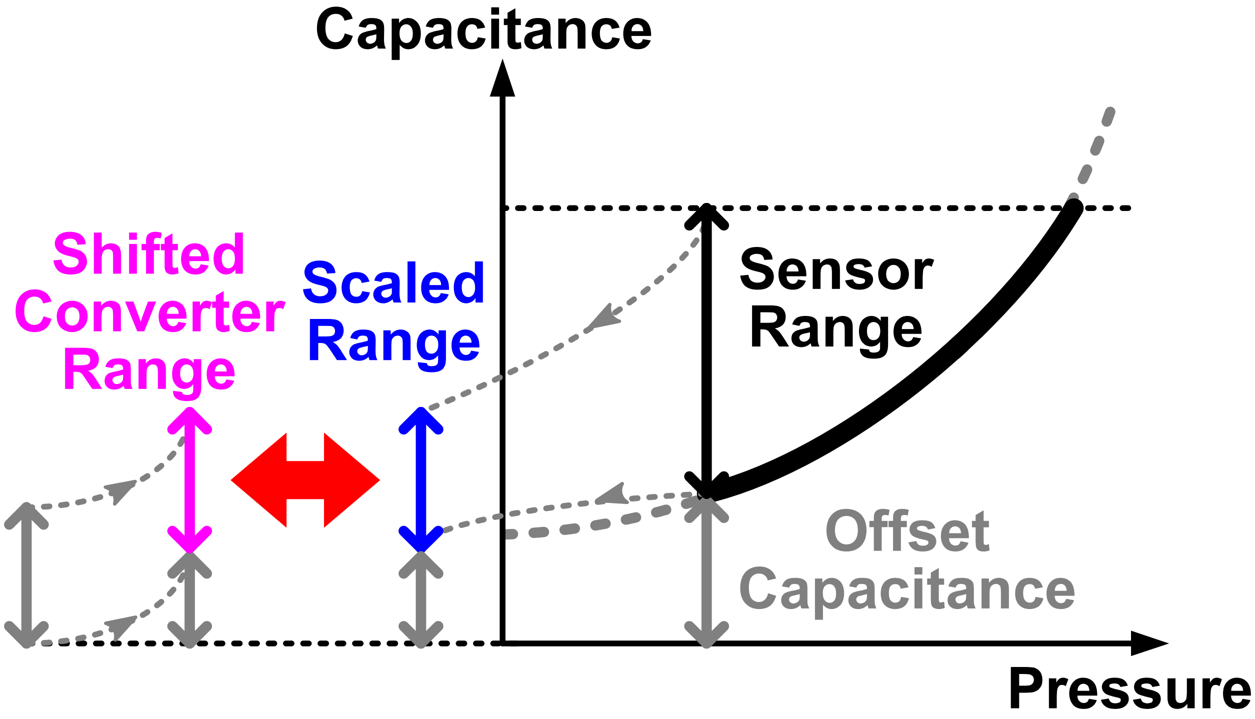
2.Offset canceling
Converter range is shifted to the scaled sensor range



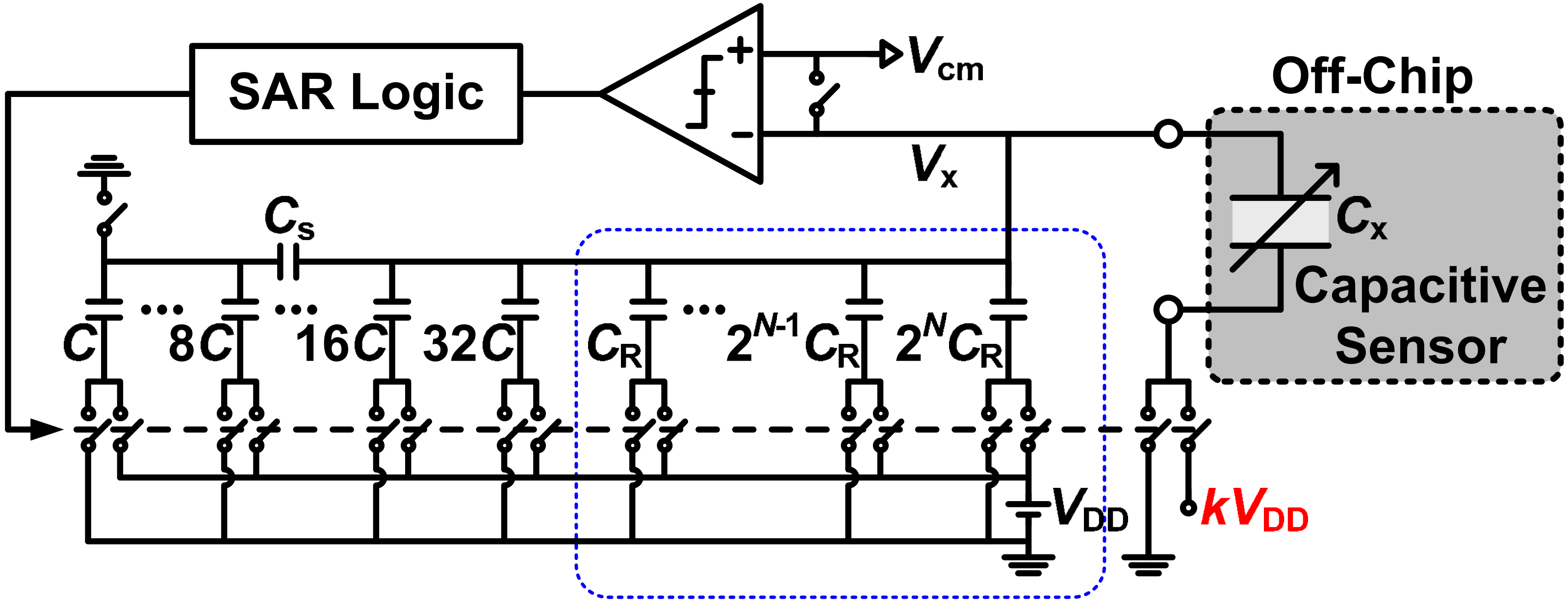
Full range conversion

- -Sensor capacitance scaling
- -Offset canceling

Full range conversion can be achieved



Proposed circuit



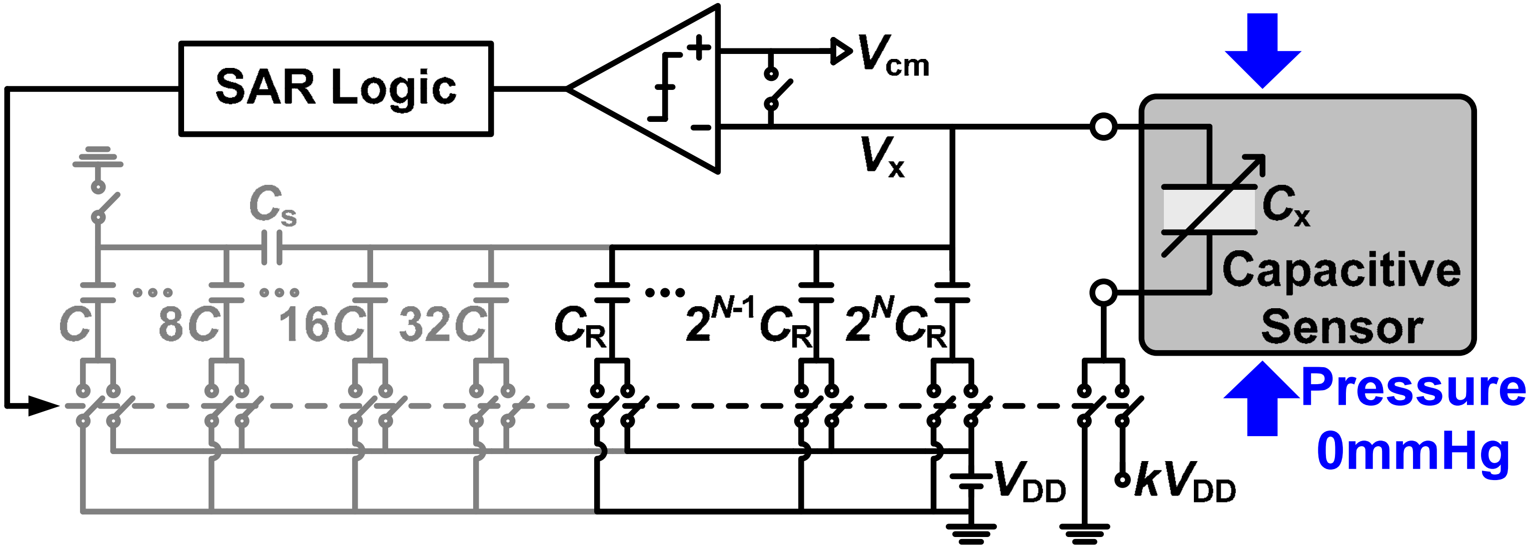
Offset canceling capacitor array

-Sensor capacitance scaling

k : Scaling factor

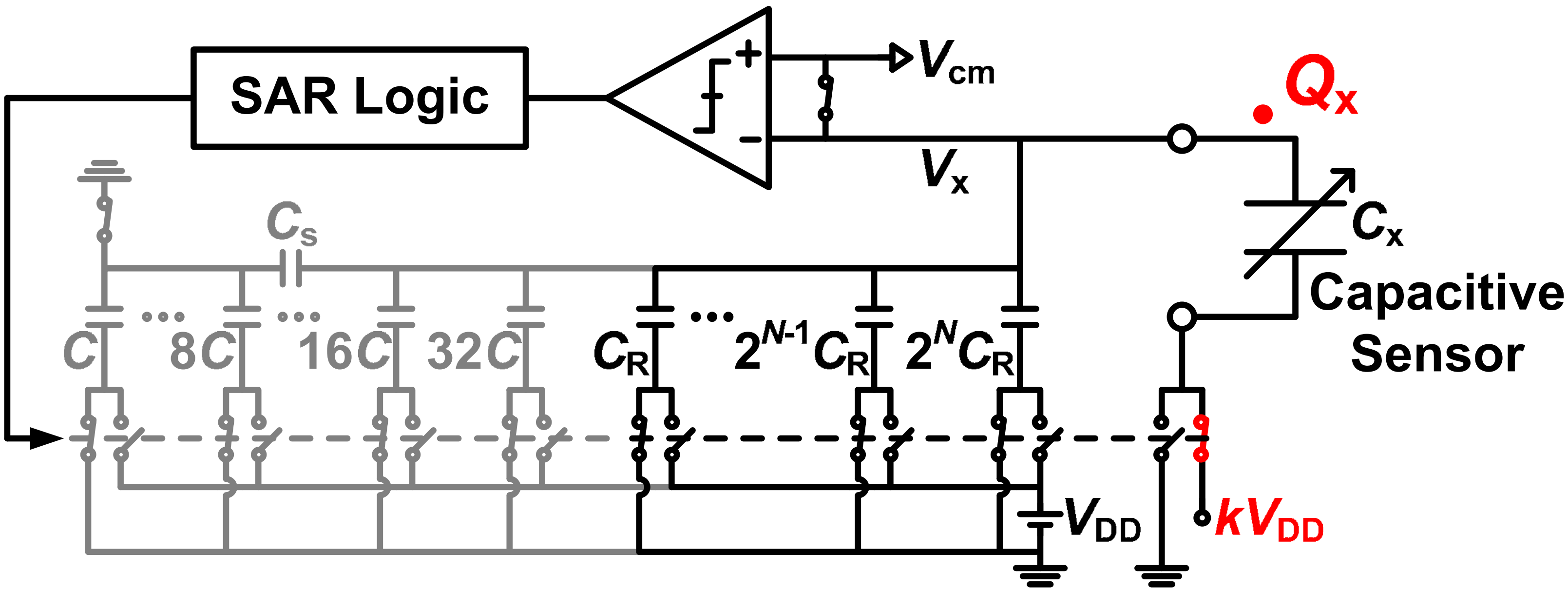
-Offset canceling

Offset canceling operation



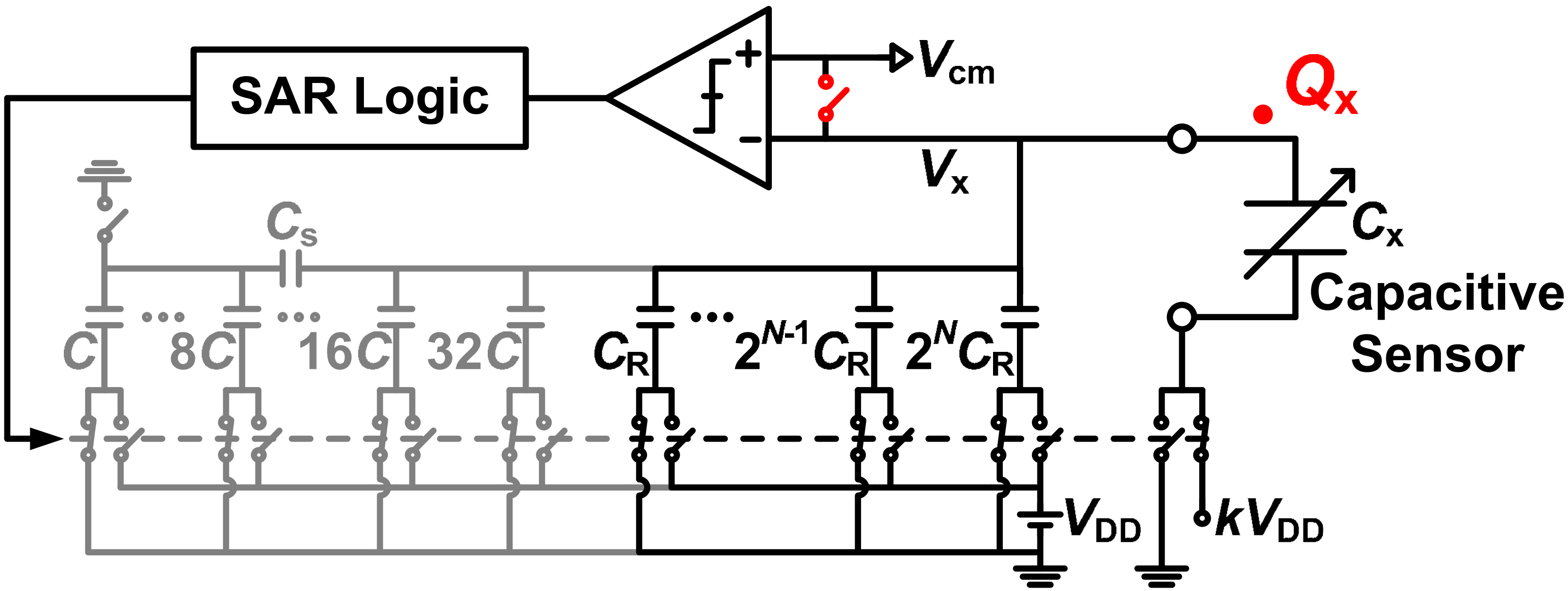
The Sensor shows offset capacitance

Offset canceling (1 of 5)



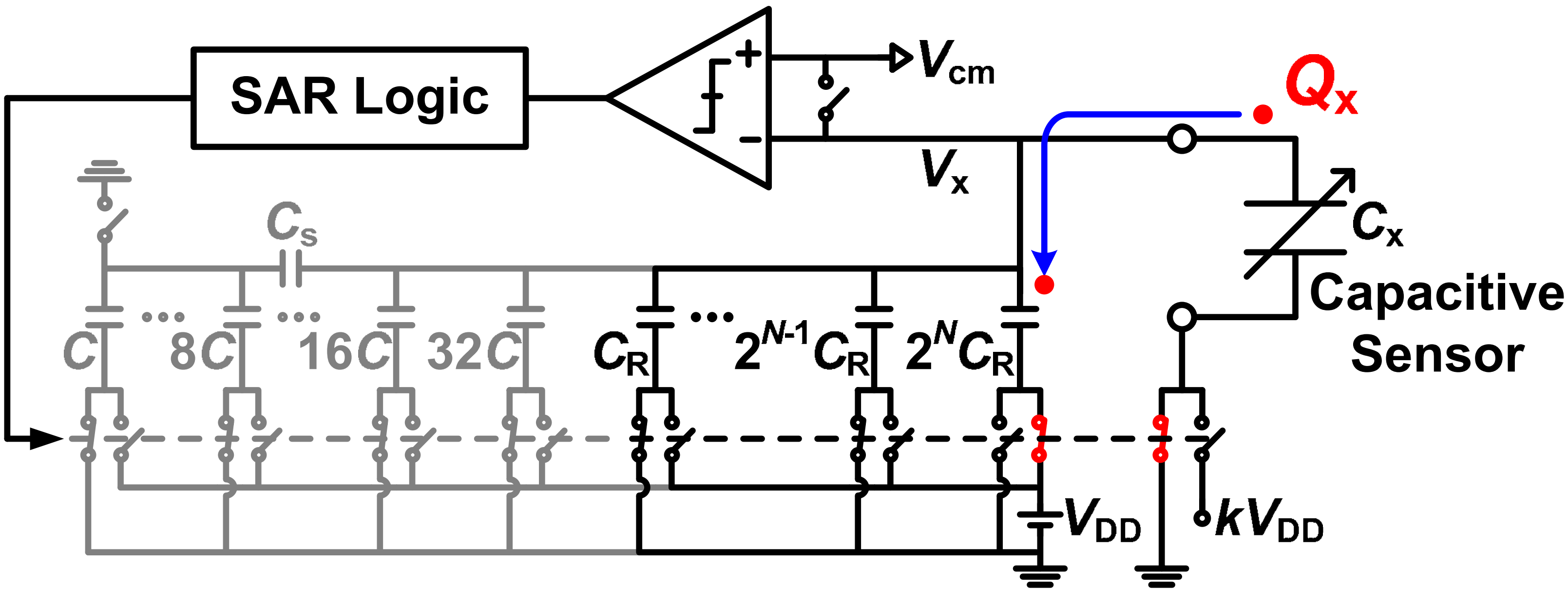
Store charge to the sensor

Offset canceling (2 of 5)



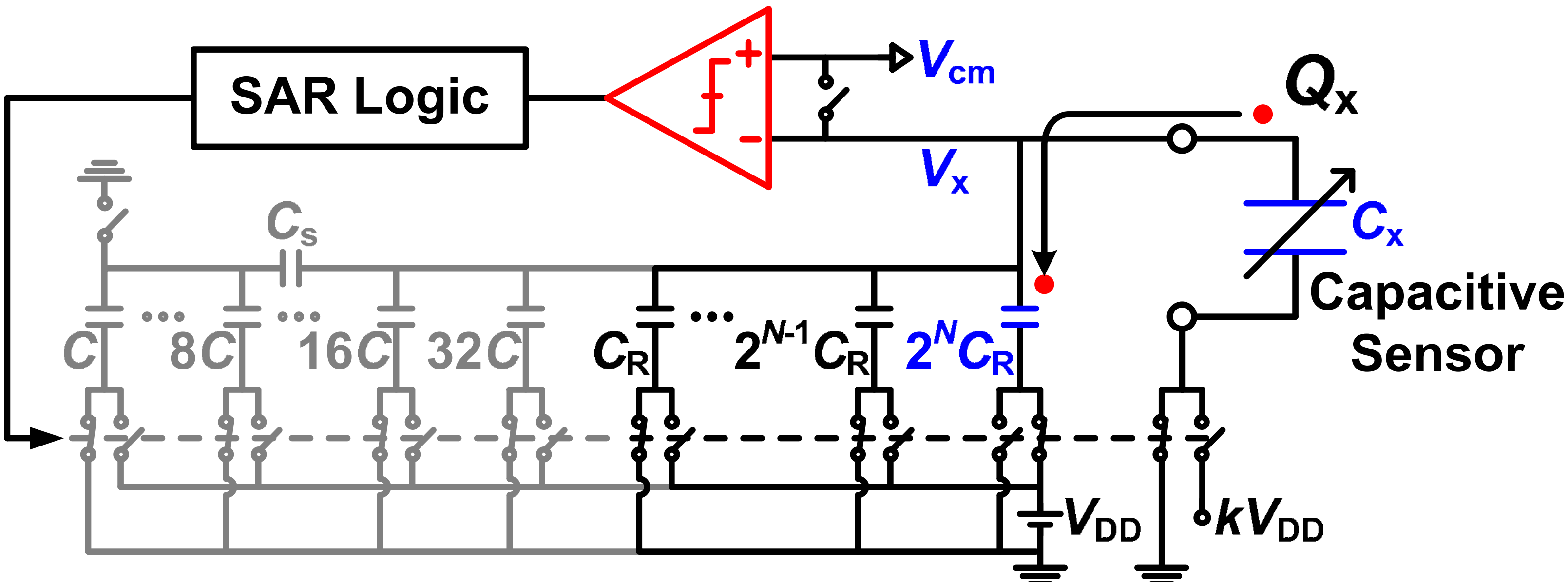
Charge conservation

Offset canceling (3 of 5)



Charge redistribution

Offset canceling (4 of 5)

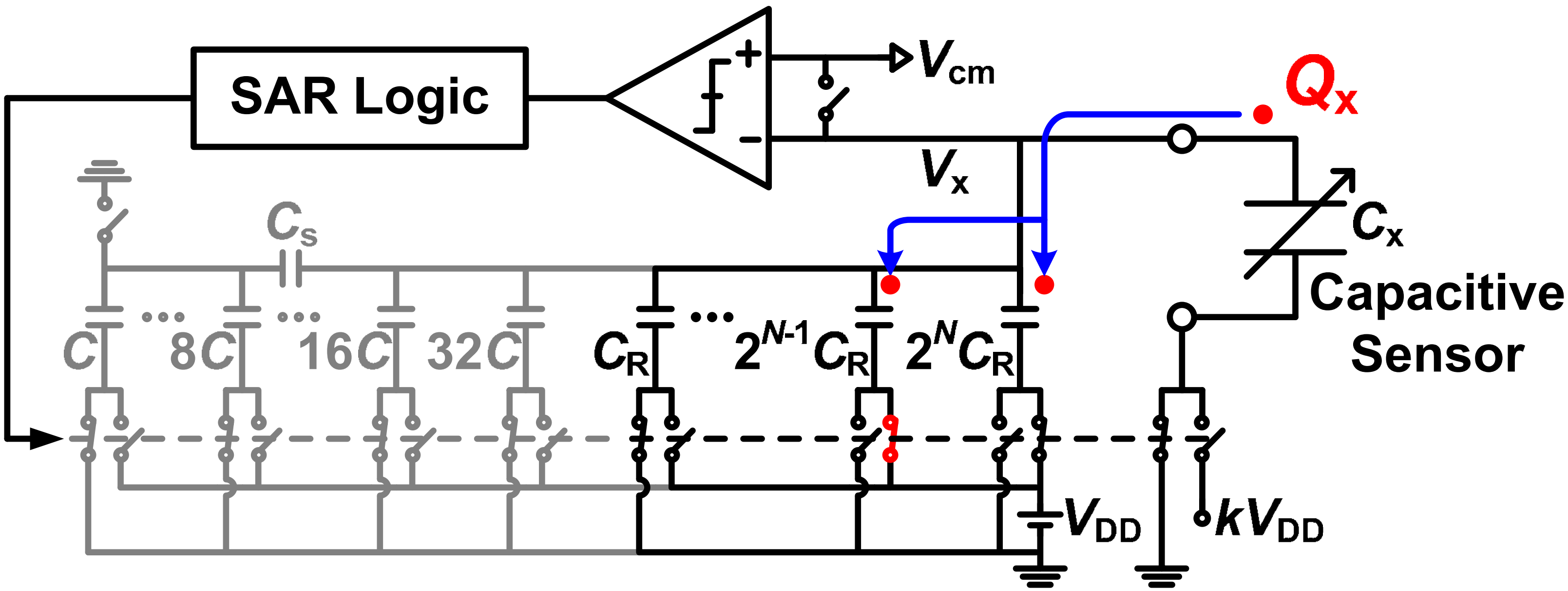


Capacitance comparison

$$\underbrace{2^N C_R}_{\text{MSB Capacitance}} > \underbrace{kC_{x\_offset}}_{\text{Sensor Capacitance}}\ ?$$

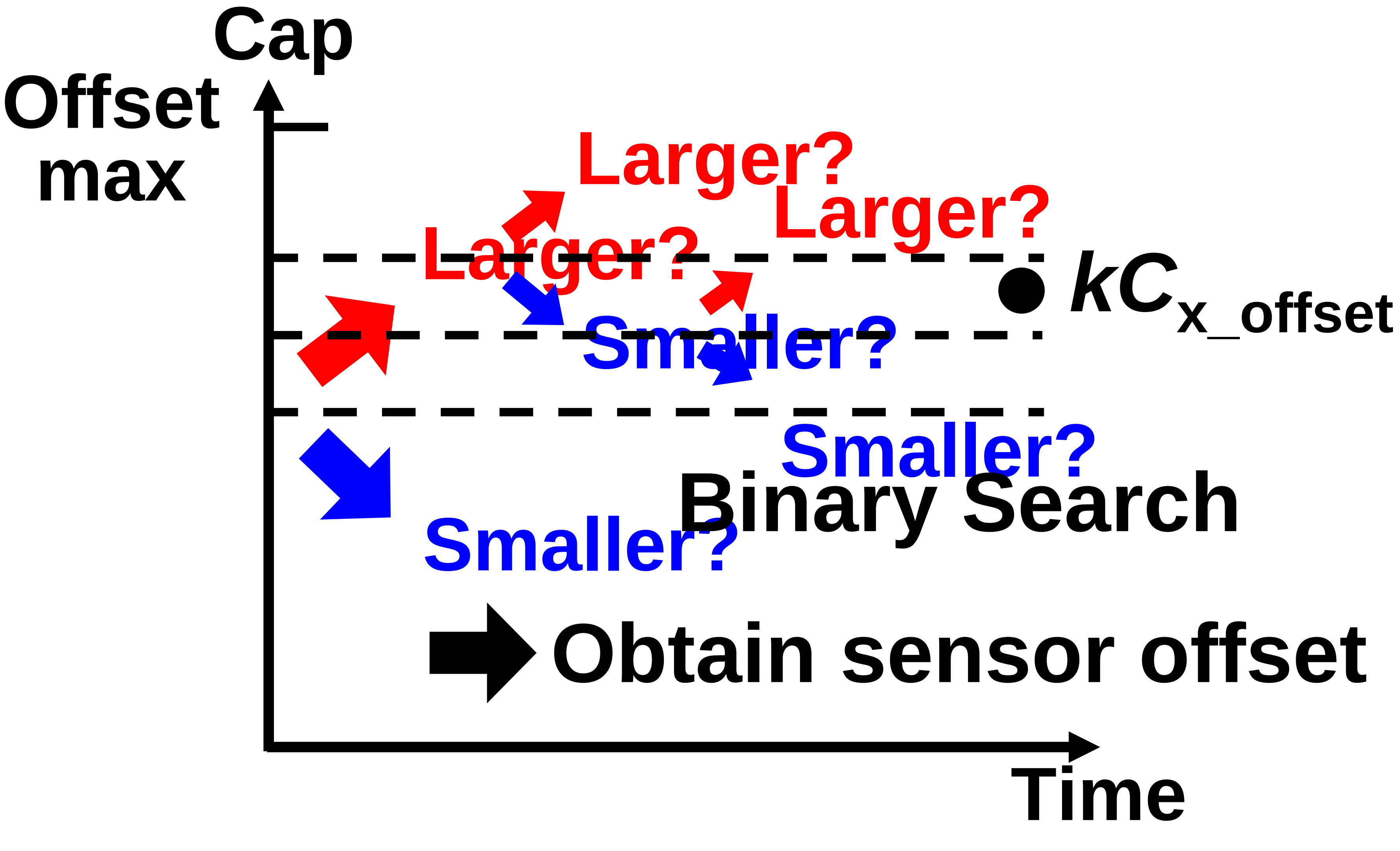
MSB Capacitance   Sensor Capacitance

Offset canceling (5 of 5)

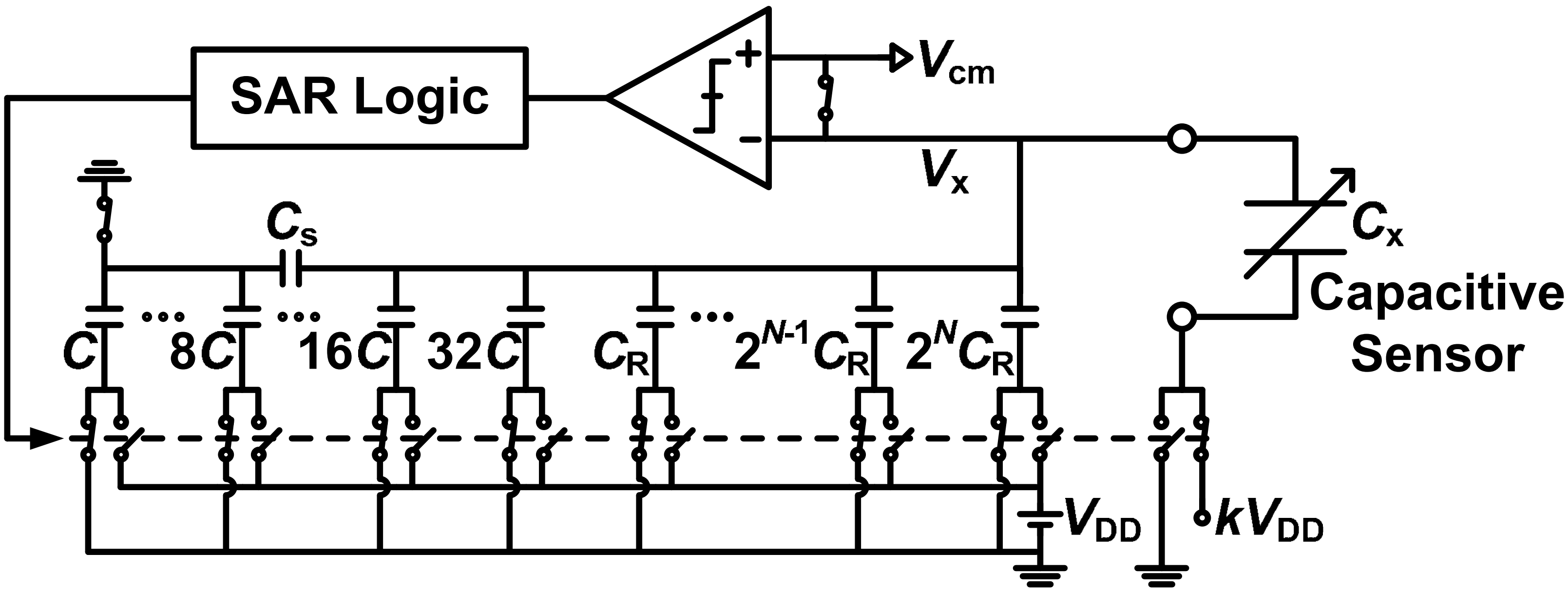


Charge redistribution and comparison sequence proceeds

Comparison sequence

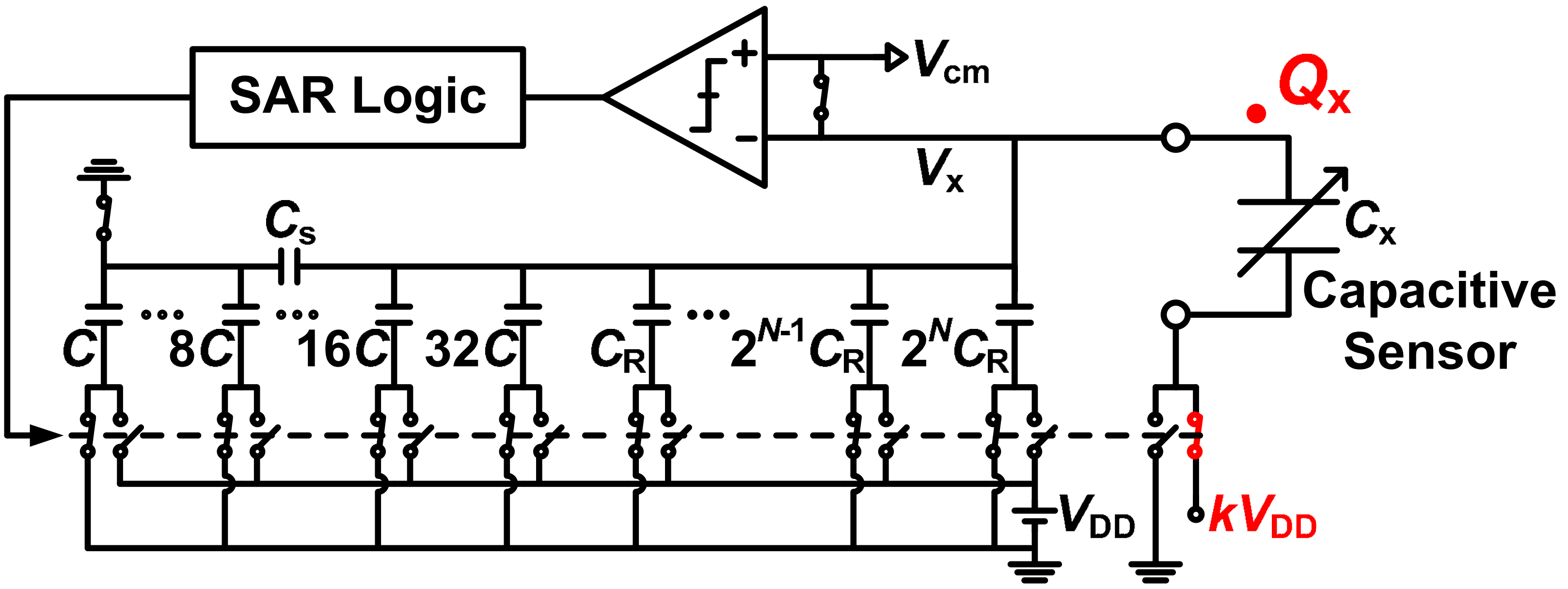


Operation



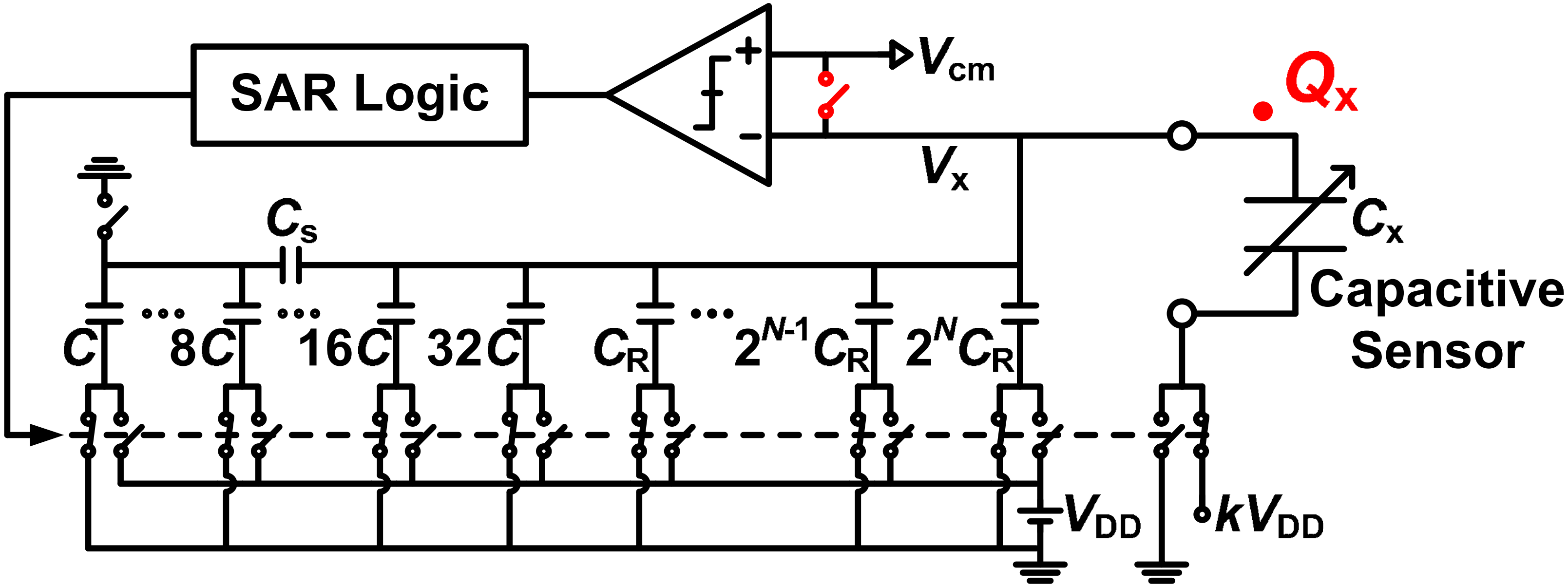
Converting the varying part of the sensor's capacitance

Operation (1 of 3)



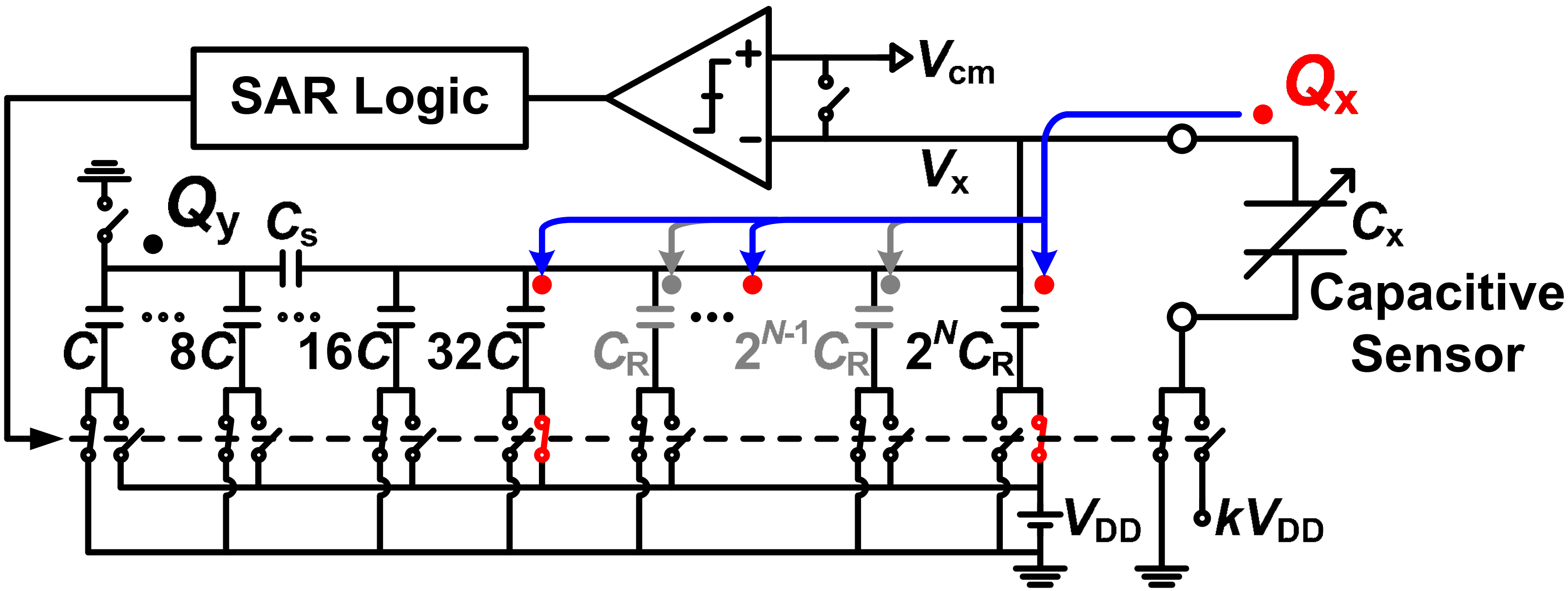
Store charge to the sensor

Operation (2 of 3)



Charge conservation

Operation (3 of 3)



3. MSB conversion

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

Conversion features

$$\frac{\underline{V}_{DD}}{C_{total}}\left(\sum C_{\underline{R}} + C_{MSB} - \underline{k}C_x\right) > 0\,?$$

1. V_{DD} does not affect conversion result

   $\underline{V_{DD}}$: Supply voltage

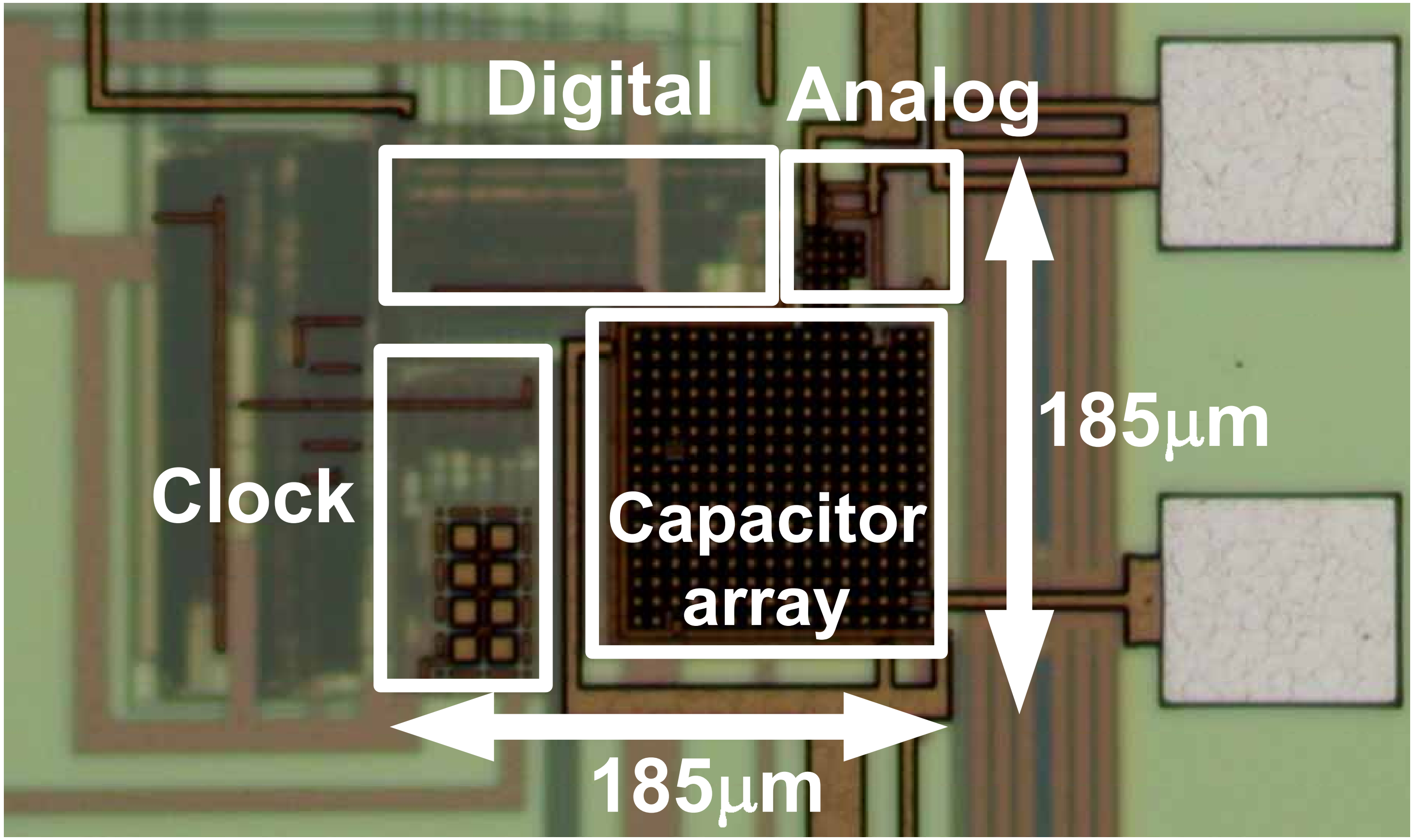
2. Offset canceling

   $\underline{C_R}$: Offset canceling capacitor

3. Sensor capacitance scaling

   $\underline{k}$: Scaling factor

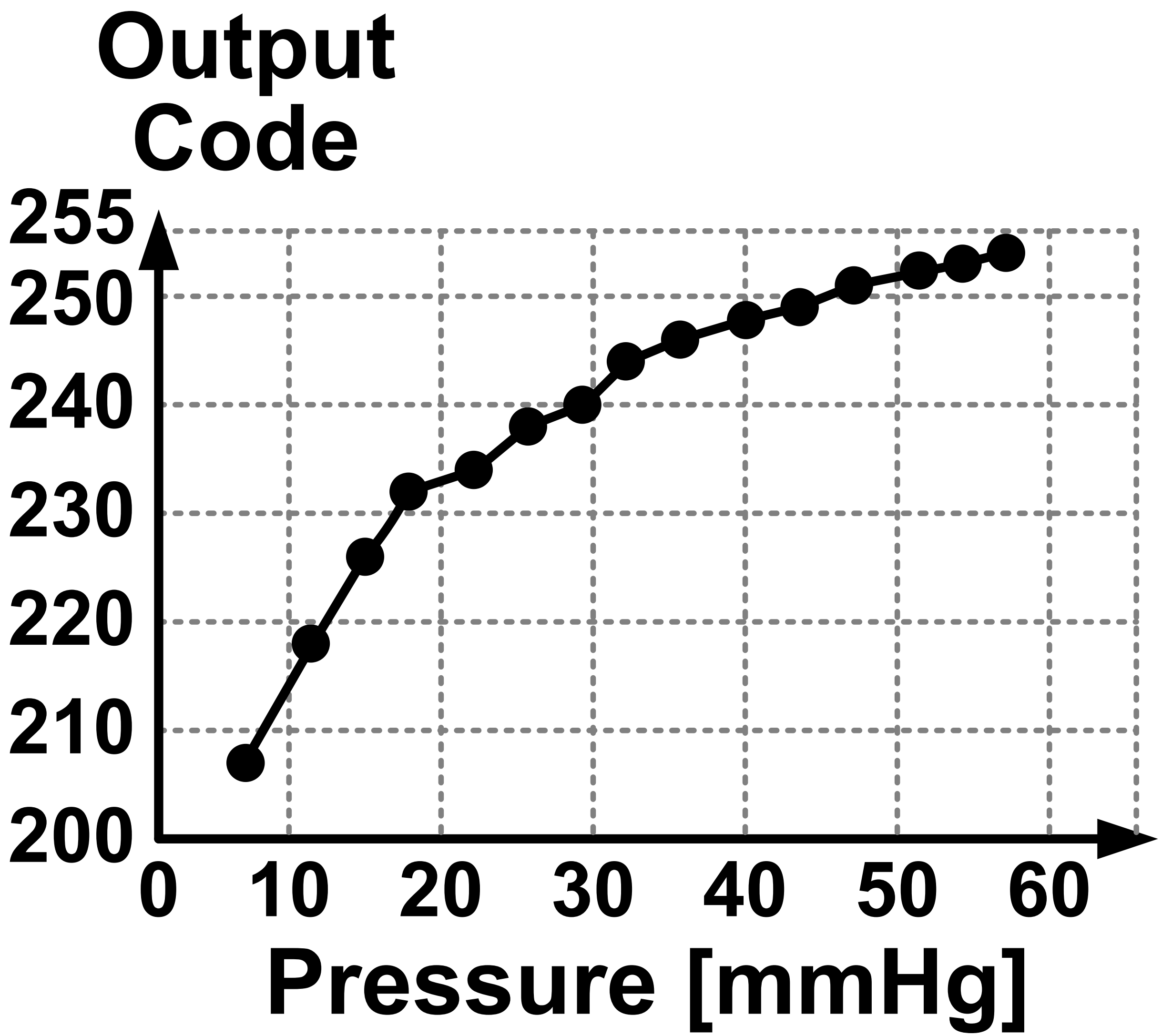
Chip photo



Area : 0.026 mm^2

Total capacitance : 6 pF

MEMS sensor experiment



Measurement results (1)

Resolution	8 bit
Supply Voltage	1.0-1.8 V
Sampling Rate	262 kHz
SNR	43.22 dB
ENOB	6.83 bit
Current Consumption	169 μA @V_{DD} = 1.4 V
DNL	-0.97 to 0.79 LSB
INL	-1.27 to 0.99 LSB
Area	0.026 mm^2
Total Capacitance	6 pF, including 3.6 pF offset canceling cap

Measurement results (2)

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

Supply Voltage	1.0 V	1.4 V	1.8 V
SNR	43.4 dB	43.2 dB	43.2 dB
ENOB	6.88 bit	6.83 bit	6.84 bit

***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 μW**
- **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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