Frequency-domain CMOS Capacitance Interface

Tuneable Sensitivity and Adjustable Dynamic Range

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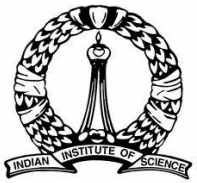
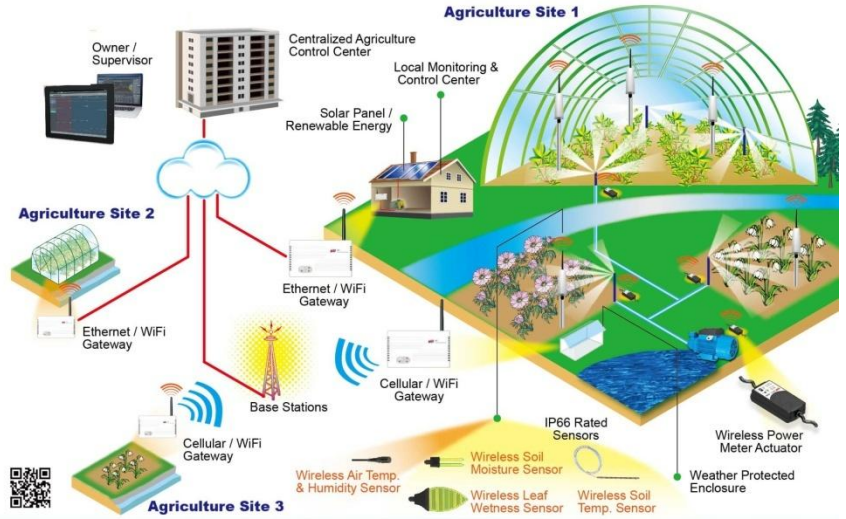


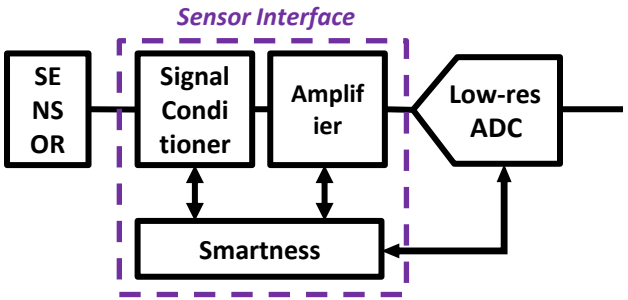
Problem Statement

- **Measure small values of measurand.**
  - Capacitance change
  - Time duration
- **Avoid high resolution ADCs**
  - Use **ONLY 8-10 bit** ADCs
- **Low Cost** – Design & Manpower (NRE) & fabrication
- **Multi-sensor compatible**



Desired Features

- **Integrated sensor interface**
- **Minimum Area;** just enough **Performance**
- **Reconfigurable Sensitivity**
- Identify **tuning knobs.**

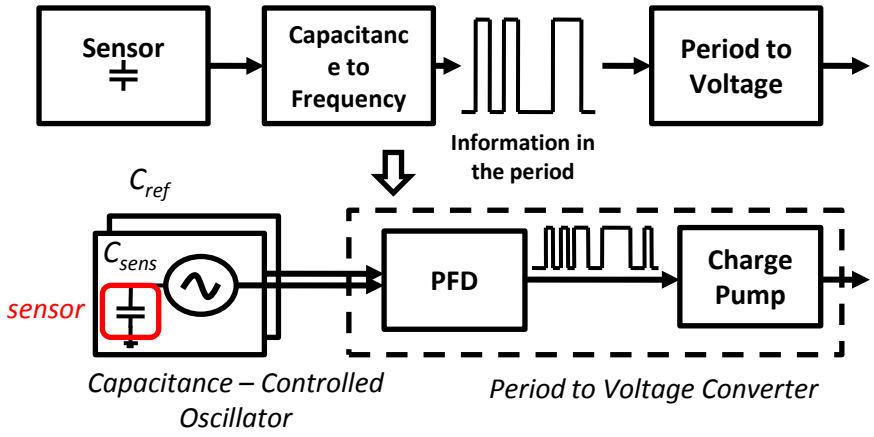


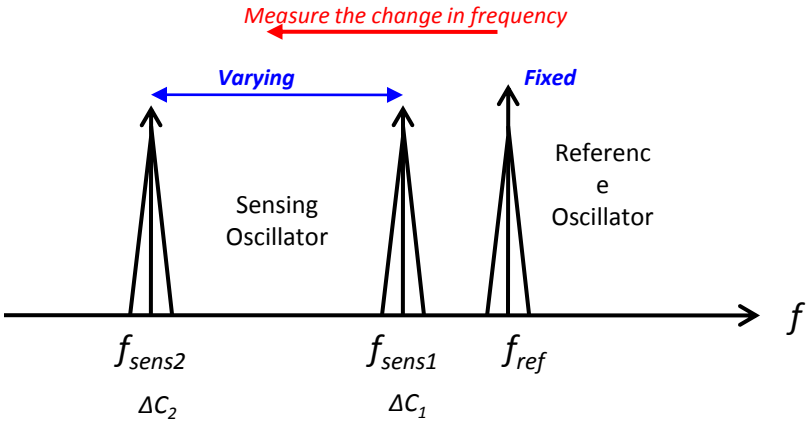
Applications

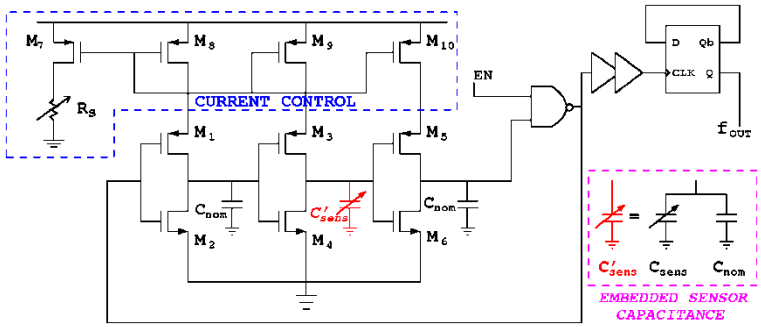
Remote Health Monitoring Systems, Wearable Electronics, **IoT,** Industrial Health Monitoring, **Biomedical Diagnostics**, Home automation, etc

Proposed Solution

Integrated Sensor Interface Design







Oscillation frequency

$$\frac{1}{[f_{ref}, f_{sens}]} = \frac{2\,DM\,V_{osc}[C_{ref}, C_{sens}]}{I_{ctrl}}$$

Tuning knobs

Osc. freq. and Cap. relation

$f_{ref} > f_{sens}$; $C_{ref} < C_{sens}$

$C_{ref} = C_{nom}$

$C_{sens} = C_{nom} + \Delta C_{sens}$

The Sensor Interface has four main blocks

* C to F
* F to V
* Control and Synchronization
* Sensor

Pradeep Dixena, M.E Thesis "Frequency Domain Capacitance to Digital Conversion", ARSL Alumnus

Measurement Results - I

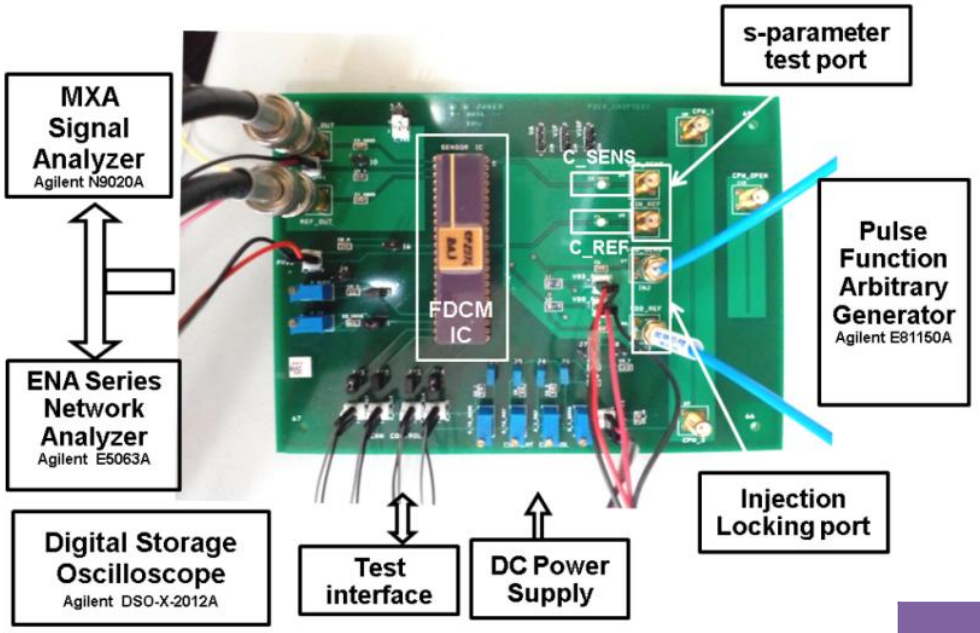


Fig: Measurement Setup

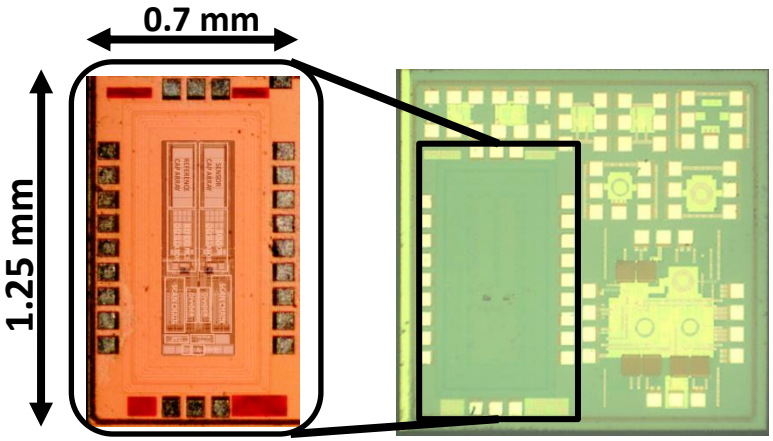


Fig: Die Micrograph of chip (UMC 130nm process) designed by Pradeep Dixena.

System Summary

Process	0.13µm CMOS 1P8M
Area	0.17 mm^2
Die Size	0.7mm x 1.25mm
Freq. Range	9 MHz – 24 MHz
Power	3.8 mW
Voltage Supply	1.2 V

Measurement Results – II

Tunable Sensitivity and Adjustable Dynamic Range

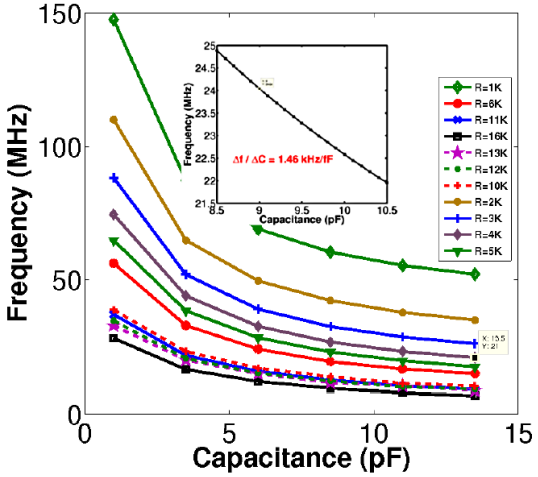


Fig: Sensitivity Tuning - I

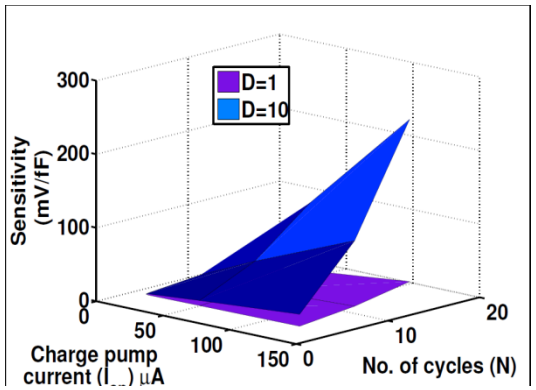


Fig: Sensitivity Tuning - II

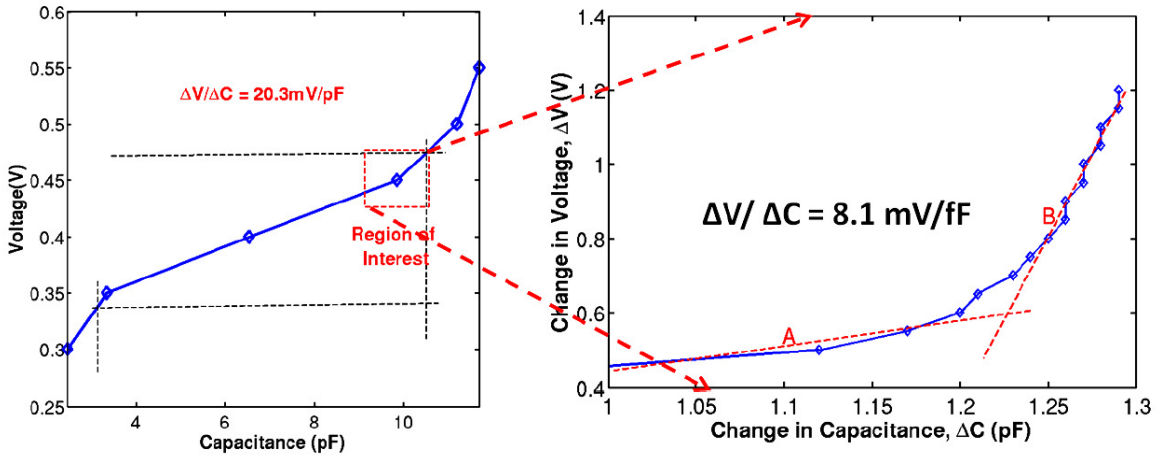


Fig: Adjustable Dynamic Range

Measurement Results - III

Parameter	This Work [1]	[2]	[3]	[4]	[5]	[6]
Sensitivity (mV/fF)	**8.1**	0.3	0.83	0.09	4	5
Technology (um)	**0.13**	0.35	0.35	0.35	0.5	0.7
Voltage Supply (V)	**1.2**	3.3	3.3	5	3.3	5
Power (mW)	**3.2**	7.9	1.44	50	0.001	7
Area (mm^2)	**0.17**	0.47	0.048	6.25	0.0078	2.66

[1] Javed G.S., ISCAS 2016 [2] F. Aezinia, TCAS-II 2013 [3] D. Y. Shin, TCAS-II 2011
[4] Zhen Ye, Sensors 2013 [5] S. Y. Peng ,TCAS – I 2008 [6] A. Heidary ,JSSC 2008

Sensitivity is enhanced by 2x – 10x in a fraction of the area

Summary and Conclusion

✓ The optimization of this system for operation around a nominal capacitance of 10 pF, with a variation of 1 pF, and a resolution of hundreds of atto Farads, and sensitivity enhancement enables its use in precision navigational systems.

✓ The use of digital ring oscillators in this architecture, substantially reduces the footprint of the system, paving the way for its integration as a "pixel" in capacitance measurement arrays.

✓ The choice of a set of system variables, such as the charge pump current, integration time, and division ratio, can optimize performance for different applications, some of which require a trade off between precision and measurement time.

Sensitivity enhancement, reduced footprint, adjustable dynamic range, optimized performance