# Frequency Domain CMOS Capacitance Interface

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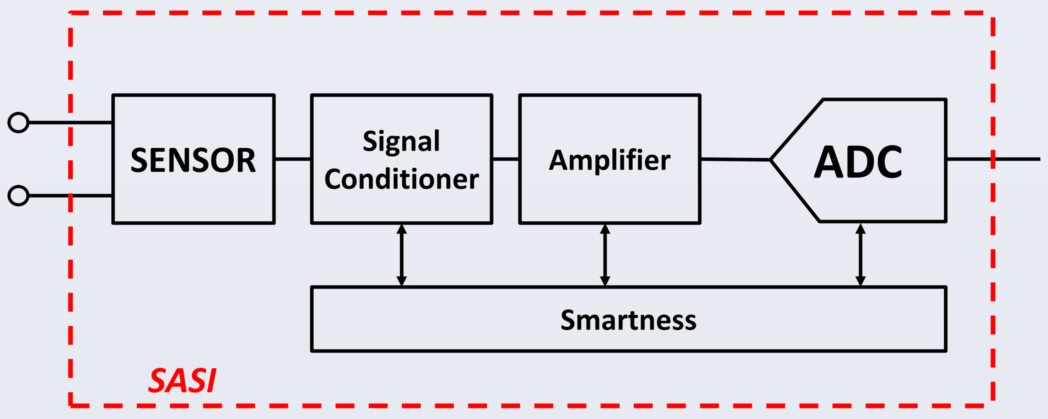
## MOTIVATION

- **Emerging applications in areas – Internet of Things, Biomedical implants and Wireless and Autonomous Sensors – demand systems having integrated, linear and multi-sensor interfaces.**
- **Low value capacitance measurement** helps in Industrial, Automotive, and Defence systems
- **Medical / Industrial diagnostic capabilities**
- **Compatibility** to standard CMOS process allows for scalable design process and higher capacitance stability
- **Sensitivity reconfigurability**
- **Our Work** aims to create and an **integrated sensor interface** that operate at the **highest** possible **sensitivity scalable to function reliably to measure capacitance.**

### Proposed Solution for Sensor Interface



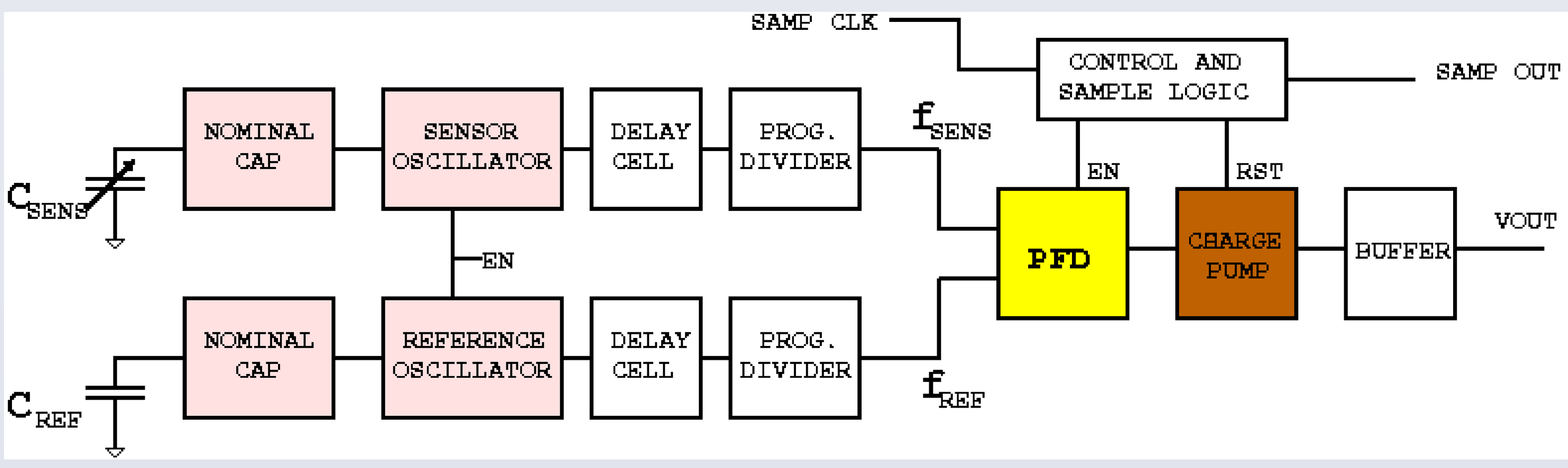

SASI: Smart Analog Sensor Interface

**Challenges in Integrated Sensor Interface**

- Reconfigurable
- High Sensitivity and Linearity
- Dynamic range matching of ADC input and sensor signal output
- Low interference
- Multi-sensor
- Low Cost / Area

## FREQUENCY DOMAIN CAPACITANCE MEASUREMENT CIRCUIT

### Proposed Architecture




## TUNABLE SENSITIVITY AND ADJUSTABLE DYNAMIC RANGE

**Capacitance Sensitivity**

$$\frac{\partial T_{diff}}{\partial C_{diff}} = \frac{2MV_{osc}}{I_{ctrl}}$$

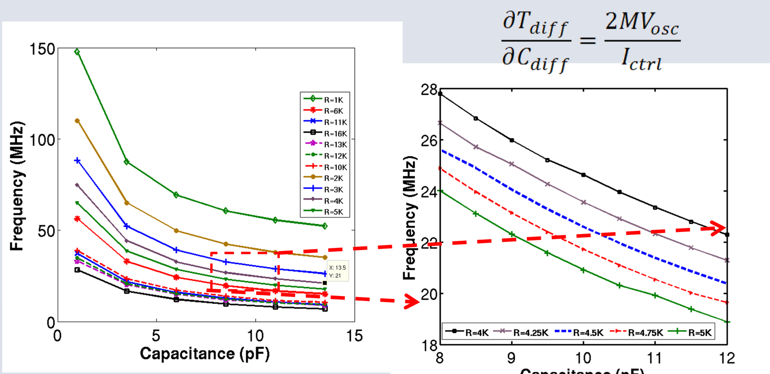



Figure: Oscillation Frequency and its sensitivity to capacitance

**Time Sensitivity**

$$\frac{\partial V_{cp}}{\partial C_{diff}} = D\frac{N(N+1)}{2}\frac{I_{cp}}{C_{cp}}$$

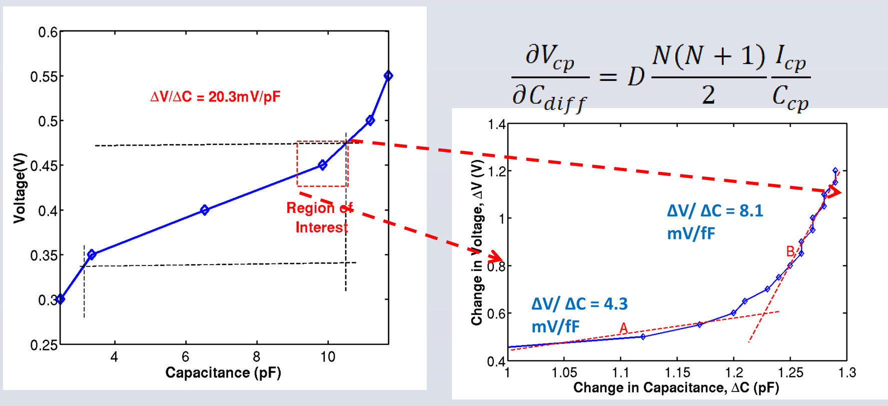



Figure: Charge Pump voltage sensitivity and effect of parameter selection

**Overall System Sensitivity**

$$\text{Total Sensitivity} \quad \frac{\partial V_{cp}}{\partial C_{diff}} = DN(N+1)\frac{I_{cp}}{C_{cp}}\frac{MV_{osc}}{I_{ctrl}}$$

Voltage | Frequency

**Sensitivity Reconfigurable Parameters**

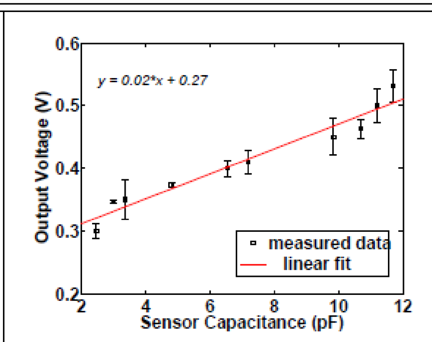
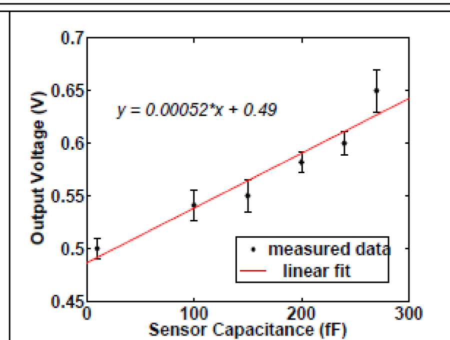
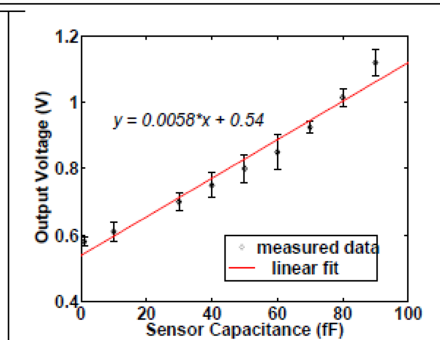
**$\mathcal{S}$ensitivity = [$I_{cp}$, N, D]**

**Performance of Reconfigurable Sensor Interface**

| $I_{CP}$ | 10 µA | | 50 µA | | 120 µA | |
|---|---|---|---|---|---|---|
| | D=1 | D=10 | D=1 | D=10 | D=1 | D=10 |
| N=4 | 0.15 | 1.5 | 0.77 | 7.65 | 1.8 | 18 |
| N=10 | 0.83 | 8.25 | 4.2 | 42 | 9.9 | 99 |
| N=16 | 2.04 | 20.4 | 10.2 | 102 | 24.48 | 244.8 |

- **Low Sensitivity;** Large Capacitance (pF) measurements
- **Moderate Sensitivity;** Tens of femto farads (fF) measurements
- **High Sensitivity;** Tens of atto farad (aF) measurement

### Measured CV Characteristics of the different dynamic ranges

| C-V Transfer Function |  |  |  |
|---|---|---|---|
| Sensitivity | Low | Moderate | High |
| Linearity Error (%) | 1.262% | 0.94% | 0.81% |
| Range | Wide | Moderate | Small |
| Capacitance Dynamic Range | 3.2 pF-12 pF | 10-300 fF | 1-100 fF |
| [$I_{cp}$,N,D]† | [10µA,4,1] | [50µA,4,1] | [75µA,10,1] |



† $I_{cp}$=Charge Pump Current, N=Measuring Interval and D=Frequency Division Ratio

## EXPERIMENTAL SETUP

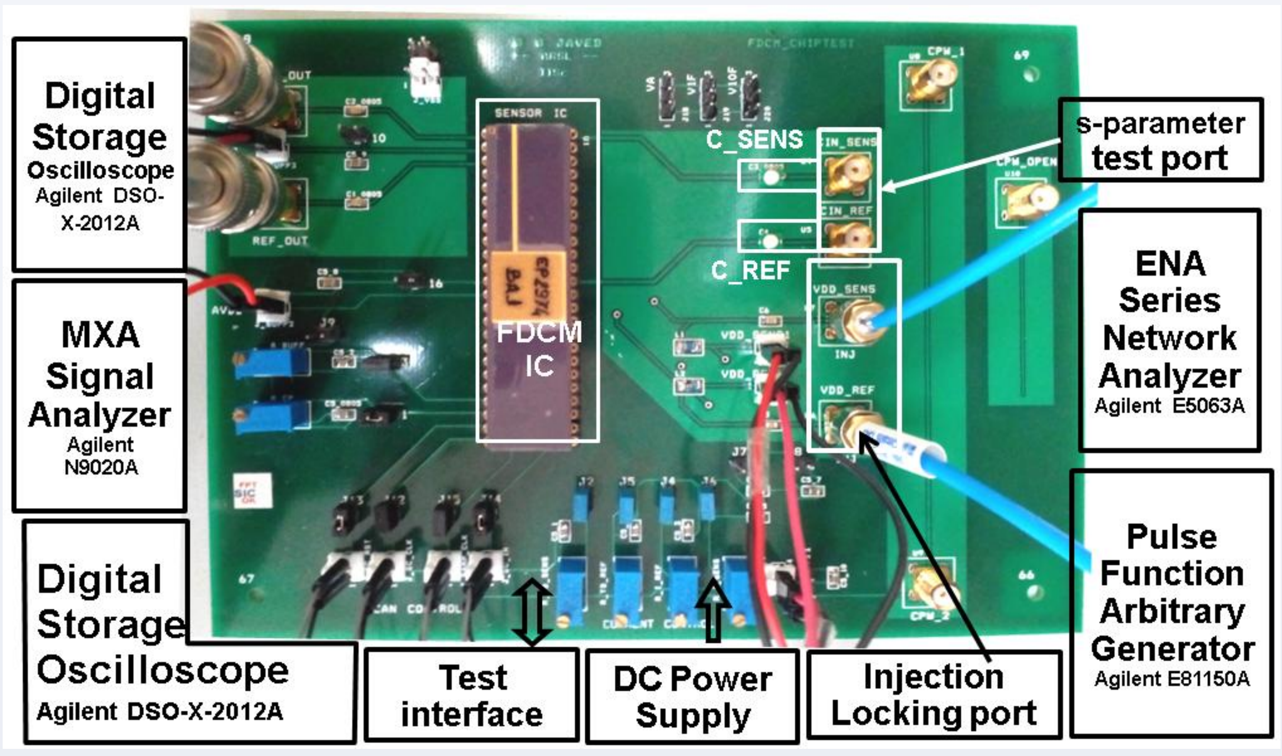



Figure: Measurement Setup

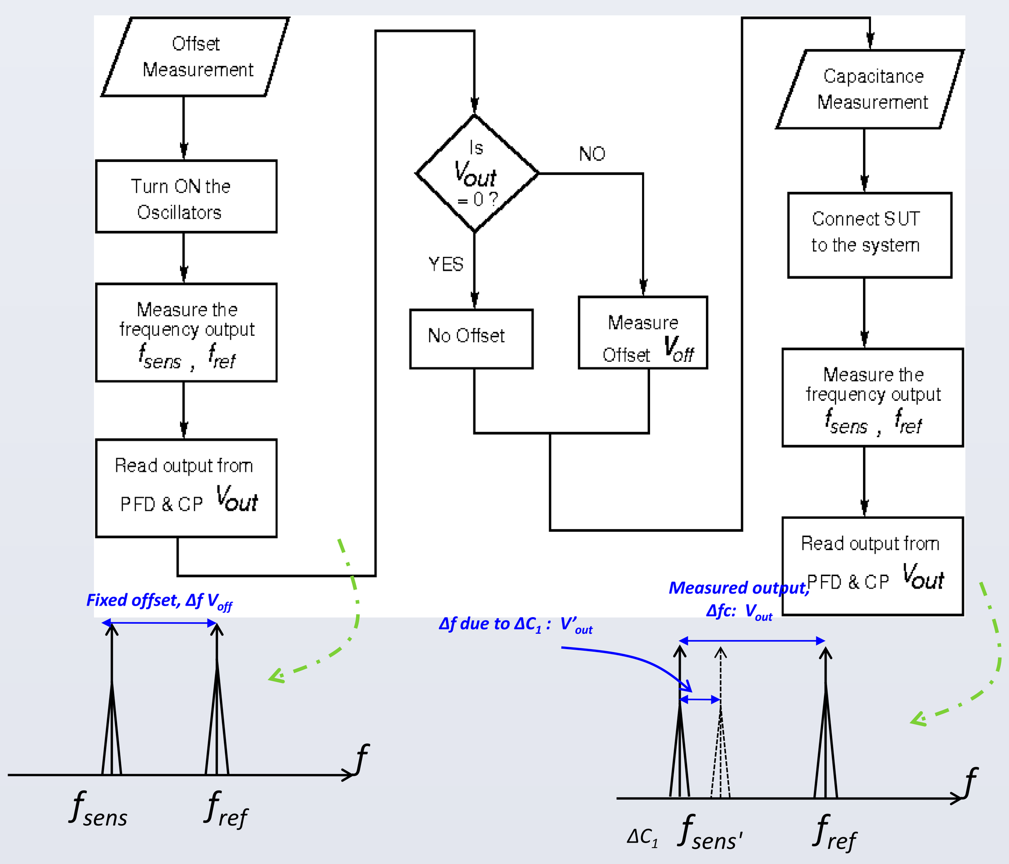



Figure: Measurement Flow

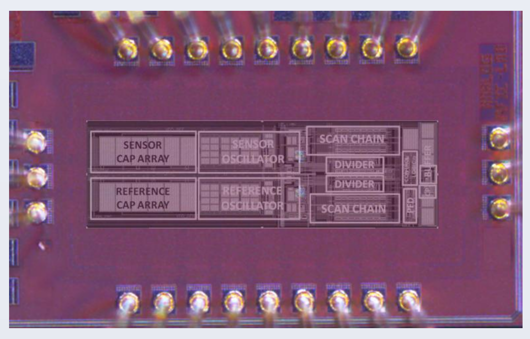
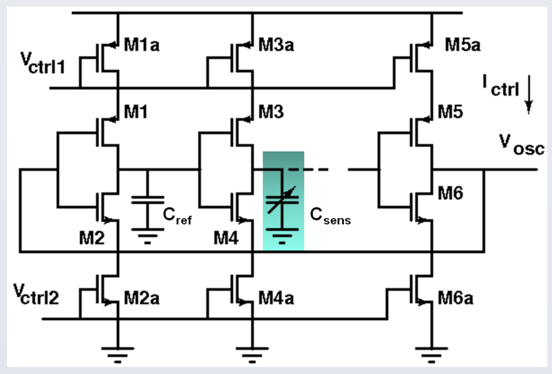


Figure: Die photomicrograph with key layout blocks highlighted



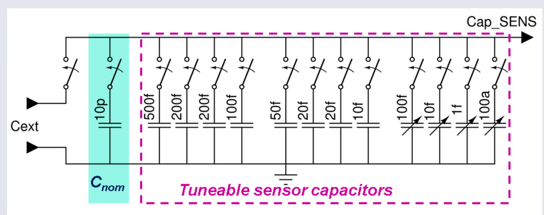




Figure: Sensor capacitance integrated Oscillator

## PERFORMANCE SUMMARY

**Voltage** = 1.2V **Capacitance Range** = 0 – 100fF **Low Power [2-6] 0.7mW**
**Lowest Area [2-6] 0.17mm² ! Highest Sensitivity [1-7] 244.8 mV/fF !!**

| | Target | Sensing Frequency | Technology | Area | Power Consumption | Sensitivity |
|---|---|---|---|---|---|---|
| [1] | Capacitive Sensing | 1 Hz - 1 GHz | 0.18 µm CMOS | 3.9 x 3.83 $mm^2$ | 30µW/channel | 164pA/aF ∮ |
| [2] | Capacitive measurements for DNA detection | DC | 0.5 µm CMOS | 6.4 x 4.5 $mm^2$ | NA | NA |
| [3] | Chemicals Permittivity detection | DC | 0.18 µm CMOS | NA | NA | 530 mV/fF |
| [4] | Impedance Spectroscopy and DNA detection | 10 Hz - 50 MHz | 0.35 µm CMOS | 2 x 2 $mm^2$ | 84.8 mW | 330 pA (BW = 10 Hz) |
| [5] | Humidity detection | DC | 0.6 µm CMOS | 4.8 $mm^2$ | 1.19 mW | 30 $fF/\%RH$ (BW = 1 kHz) |
| [6] | Capacitive Sensing | 0.5 - 500 kHz | 0.35 µm CMOS | 0.94 x 1.08 $mm^2$ | 6.4 mW | NA |
| [7] | Capacitive Sensing | DC - 1 kHz | 0.18 µm CMOS | 0.028 $mm^2$ | 165 µW/pixel | 200 mV/fF |
| **This work** | Capacitive Sensing | 9 MHz - 24 MHz | 0.13 µm CMOS | **0.7 x 1.25 $mm^2$** | **0.7 mW** | **244.8 mV/fF ‡ 4.2 mV/fF †** |

∮ derived
‡ With the tuning variables set at [$I_cp, N, D$] = [120µA,16,10]
† With the tuning variables set at [$I_cp, N, D$] = [50µA,10,1]

## REFERENCES

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## ACKNOWLEDGEMENTS

We thank the Department of Electronics and Information Technology (DeitY), Ministry of Communication and Information Technology (MCIT), Government of India for funding this research.

### Contact Information

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