A 0.35μm 1.25V Piezo-Resistance Digital ROIC for Liquid Dispensing MEMS

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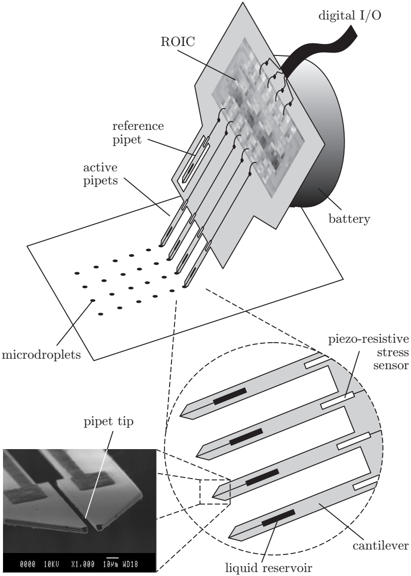
Bioplume Scenario

- Liquid dispensing **MEMS** for μdroplet patterning
- Integrated **piezo-resistive** stress sensor to control **positioning**
- Dummy-based **differential reading** to cancel T/M/E disturbing signals

- Multi channel digital **ROIC**
- **Low-power** to prevent drying
- **Low-voltage** for single cell battery operation

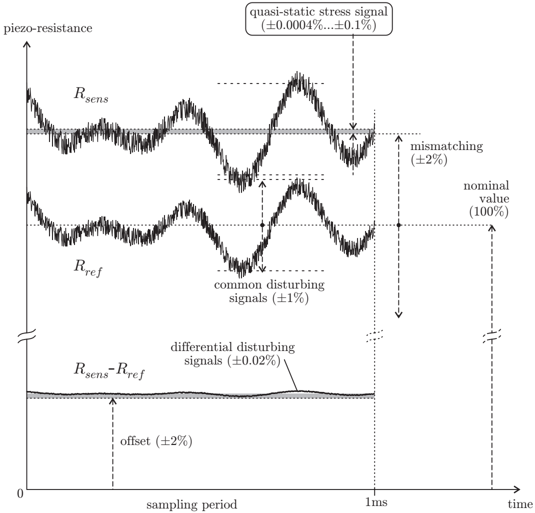


Integrated piezo-resistance

- Nominal value: 5KΩ to 10KΩ 100% (±20%)
- Quasi-static **stress signal** (9bit): ±0.0004%. . . ±0.1%
- Technology mismatching: ±2%
- Dynamic disturbing signals: ±1%

⇓

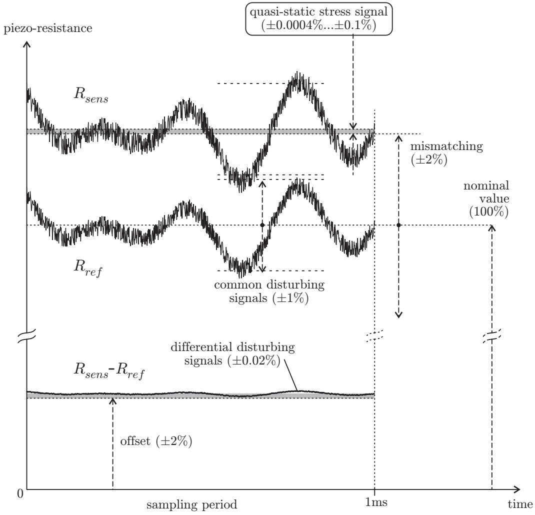
±0.02% (50LSB) dynamic residual!



Gain Balancing Strategy

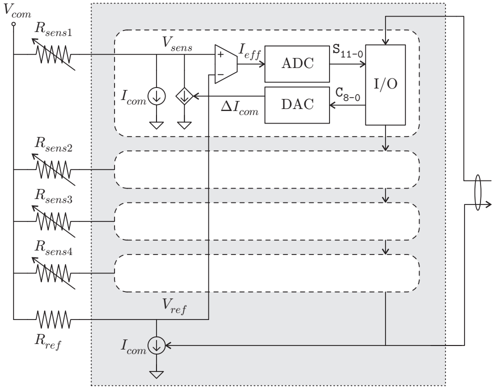
- Maximum gain compensation: ±2%
- Gain accuracy: ±0.0002%/2%=±0.01%
- Gain **dynamic range**: 2%/0.01%=(8+1)bit

- Residual dynamic disturbing: ±0.25LSB
- Residual DC: ±25LSB compensated by digital post-processing



ROIC Architecture

- **Parallel** processing to reduce noise bandwidth
- Overall **programmable** sensitivity (I_{com})
- Differential gain **balancing** through sensor bias (ΔI_{com})
- **OTA** pre-amplification
- **Integrating** A/D conversion
- **Digital only** read-out/program-in
- **Independent** references to avoid crosstalk

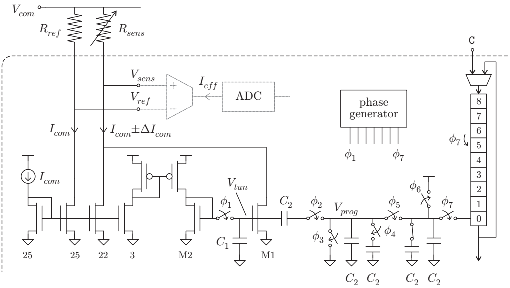


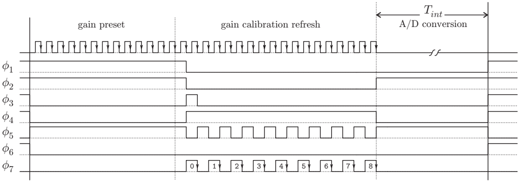
Input Gain Balancing

- Calibration through **DAC**: $\Delta I_{com}(\mathtt{C}_{8\text{-}0})$
- Gate tuning:

$$\Delta V_{tun} = \frac{C_2}{C_1+C_2}\left(V_{prog} - \frac{V_{DD}}{2}\right)$$

- Compensation of **piezo mismatch** + **OTA unbalance**
- Repeated before every acquisition
- Design parameters: C_1=9pF, C_2=0.5pF





$$V_{sens} - V_{ref} = I_{com}\left[R_{sens}\left(1 \pm \frac{\Delta I_{com}}{I_{com}}\right) - R_{ref}\right]$$

OTA Preamplifier

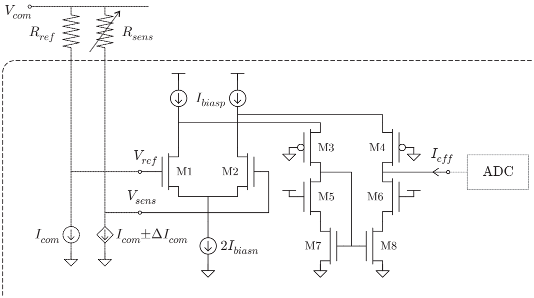
- Differential V to **single ended** I

$$I_{eff} = G_m\,(V_{sens} - V_{ref})$$

- Equivalent input **low-noise**
- Large **diff.** gain (in subthreshold):

$$G_m = \frac{I_{biasn}}{nU_t}$$

- High **common** rejection ratio
- Design parameters: $I_{biasp,n} = 56\mu\text{A}, 44\mu\text{A}$



$$DR(V_{sens}) \sim 1\text{mV}/4\mu\text{V}$$

$$(R_{sens} \sim 5\text{k}\Omega \text{ and } I_{com} \sim 200\mu\text{A})$$

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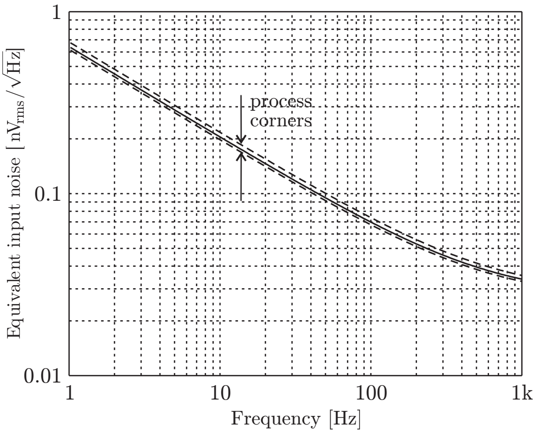

$$V_{neq} \simeq 2\mu\text{V}_{\text{rms}} \text{ up to 1kHz}$$

$$(V_{nres} \sim 0.4\mu\text{V}_{\text{rms}} \text{ for } R_{sens} = 10\text{k}\Omega)$$

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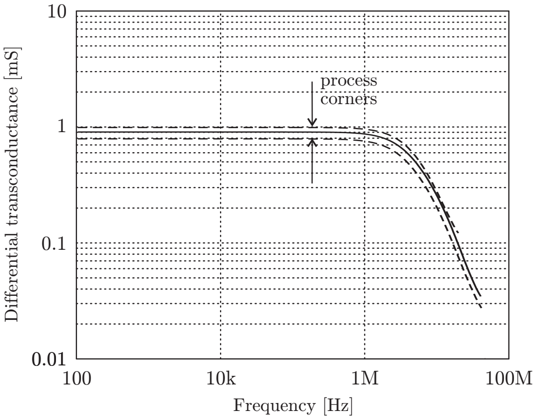

$$G_m \geq 0.8\text{mS}$$

$$DR(I_{eff}) \sim 1\mu\text{A}/4\text{nA}$$

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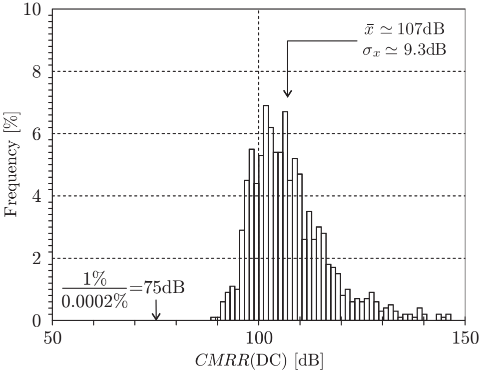
$$\frac{1}{CMRR} = \frac{\Delta G_m}{G_m} \left(1 - \frac{1}{1 + \frac{1}{2nG_m R_{tail}}} \right)$$

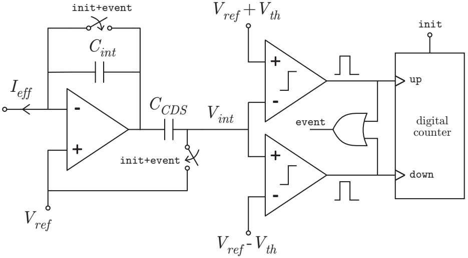
$CMRR \rightarrow \infty$ for $\Delta G_m \rightarrow 0$ or $R_{tail} \rightarrow \infty$

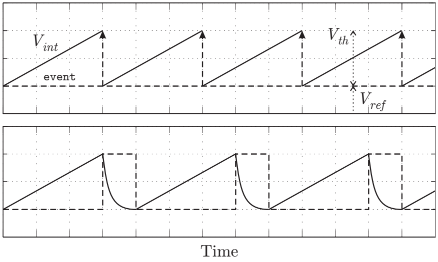
MOSFET mismatching + I_{biasn} finite impedance



A/D Conversion

- Spike counting: **PDM+digital filter**
- **CDS** for low-frequency noise suppression
- **Low-voltage** switching ⇒ large **reset times**
- Design parameters: $C_{int} = 4\text{pF}$, $V_{th} = 312\text{mV}$
- X Classic PDM: reset-time **non-linearity**





Upper range **saturation** of the A/D curve!

A/D Conversion

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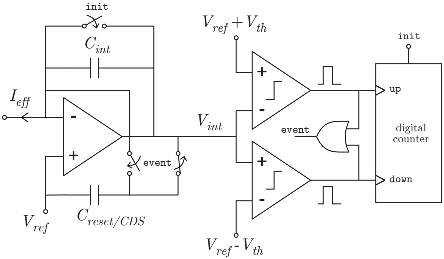
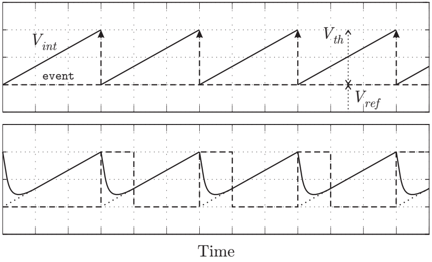
✓ New **insensitive** PDM

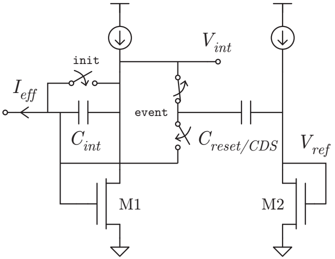




$$S_{11\text{-}0} = \pm\frac{I_{eff}\,T_{int}}{C_{int}\,V_{th}} = \pm\frac{G_m\,T_{int}}{C_{int}\,V_{th}} I_{com}\left[R_{sens}\left(1 \pm \frac{\Delta I_{com}}{I_{com}}\right) - R_{ref}\right]$$

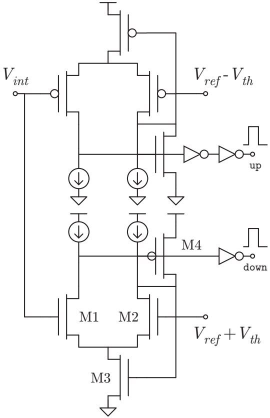
Low-Voltage CMOS Blocks

- Compact **CTIA** with **CDS**



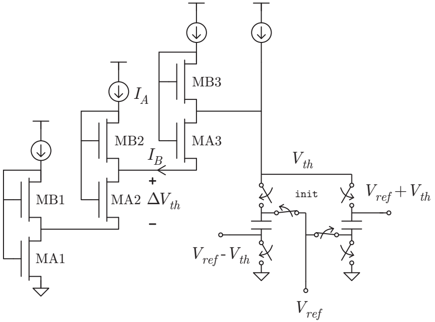
Low-Voltage CMOS Blocks

- Compact **CTIA** with **CDS**
- Class-AB window **comparator**



Low-Voltage CMOS Blocks

- Compact **CTIA** with **CDS**
- Class-AB window **comparator**
- Modular and floating threshold **generator**



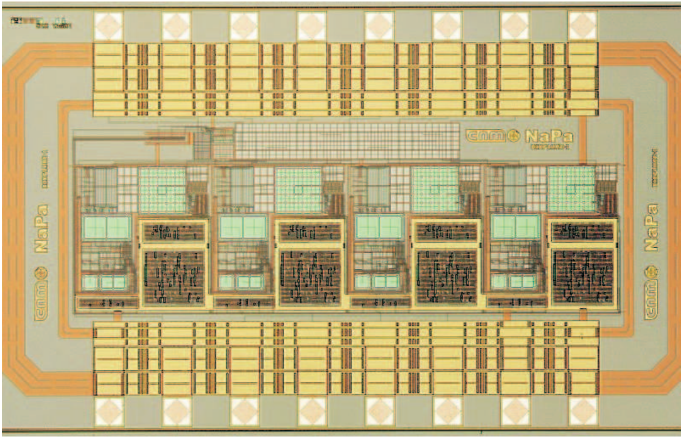
$$\Delta V_{th} = U_t \ln \left[\frac{(W/L)_B}{(W/L)_A} \left(1 + \frac{I_B}{I_A}\right) + 1 \right]$$

MA : weak inversion conduction

MB : weak inversion saturation

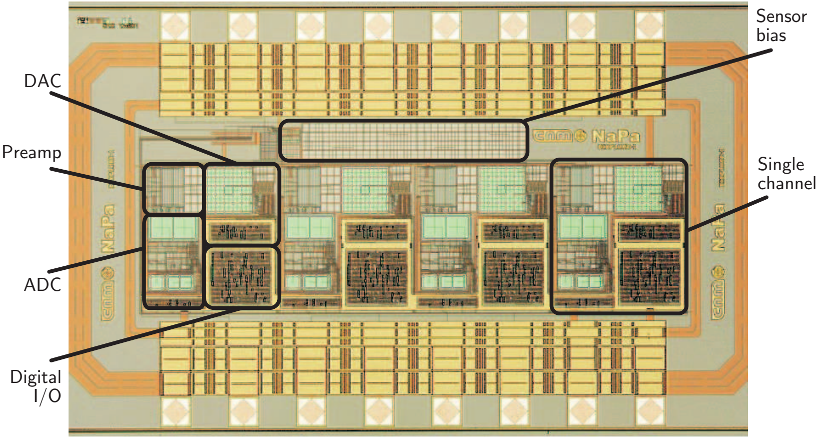
ROIC Integration

- 0.35μm 2P 4M CMOS technology $2.4\text{mm} \times 1.3\text{mm} = 3.1\text{mm}^2$



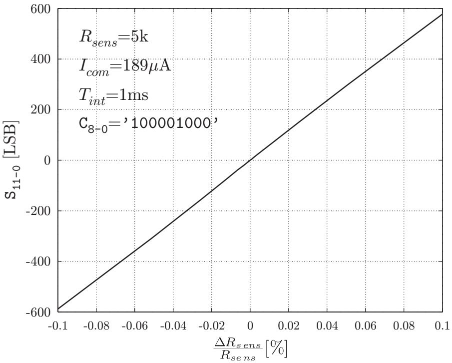
ROIC Integration

- $0.35\mu m$ 2P 4M CMOS technology $2.4mm \times 1.3mm = 3.1mm^2$



Results

- **MEMS** + **ROIC** integration not completed yet...
- Meanwhile, results from **post-layout** simulation



- 4 channel power supply: **1.5mW** at **1.25V**
- Ideally:

$$\left|\frac{S_{11\text{-}0}}{\Delta R_{sens}/R_{sens}}\right| = \frac{G_m T_{int}}{C_{int} V_{th}} I_{com} R_{sens} \equiv \frac{0.8\text{mS} \times 1\text{ms}}{4\text{pF} \times 312\text{mV}} \times 189\mu\text{A} \times 5k\Omega \simeq 6\text{kLSB}/\%$$

V_{th} PTAT and G_m 1/PTAT. If $I_{com,bias}$ **PTAT** $\Rightarrow$ $S_{11\text{-}0} \neq f(T)$

Conclusions

- **Quad-channel** ROIC for integrated **piezo-resistive** sensors.
- Sensor balancing by **digital gain tuning**.
- Robust built-in **A/D conversion**.
- **Low-voltage** and **low-power** CMOS circuit realization.
- Integration in **0.35μm 2-poly 4-metal** technology.
- **Post-layout** electrical simulation results.