A fA-Range Low-Power Multi-Channel Digital Read-Out Integrated Circuit for Differential Mobility Analyzers

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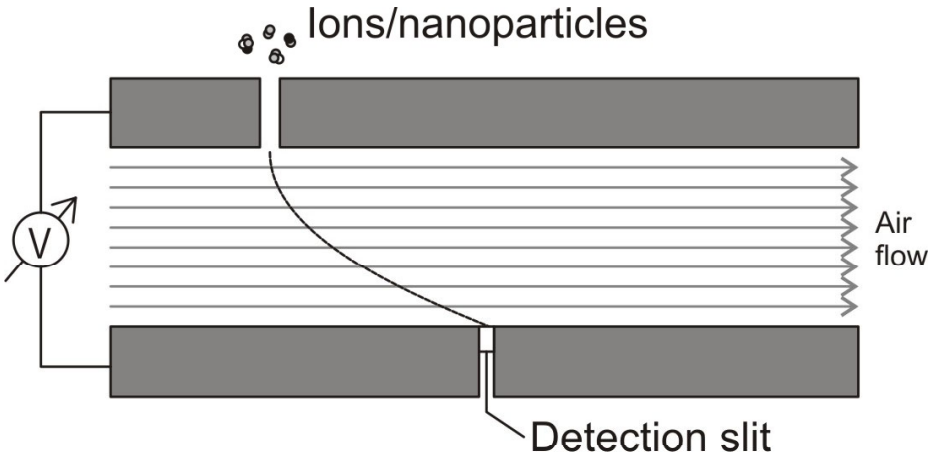
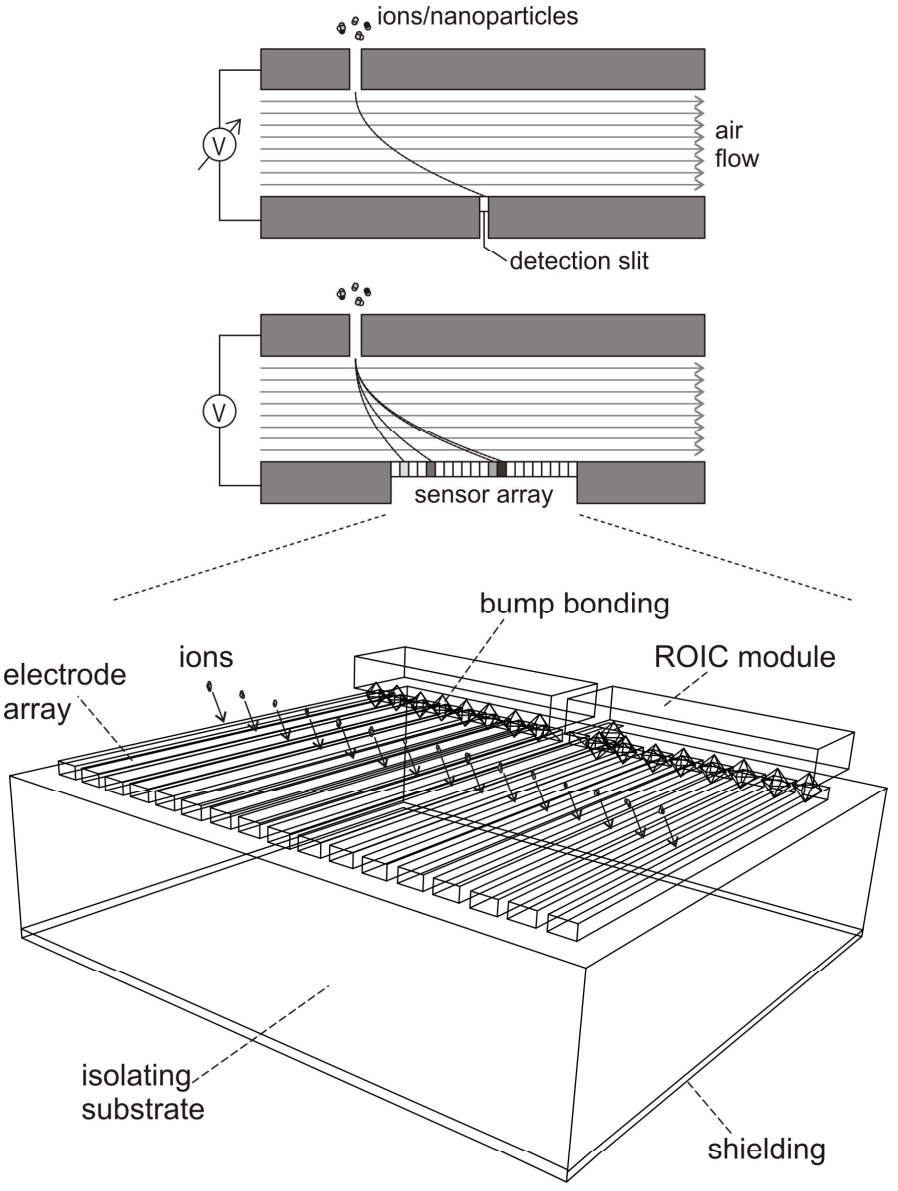
Introduction

- Aerosol identification for medicine, biology, environment monitoring, security…
- Differential Mobility Analyzer (DMA): ion/particle classification according to mass and charge
- Long acquisition time (several seconds)



Introduction

- Aerosol identification for medicine, biology, environment monitoring, security…
- Differential Mobility Analyzer (DMA): ion/particle classification according to mass and charge
- Long acquisition time (several seconds)
- Array of independent and separated microelectrodes
- Parallel signal processing
- Fast acquisition time (ms) for the same noise bandwidth

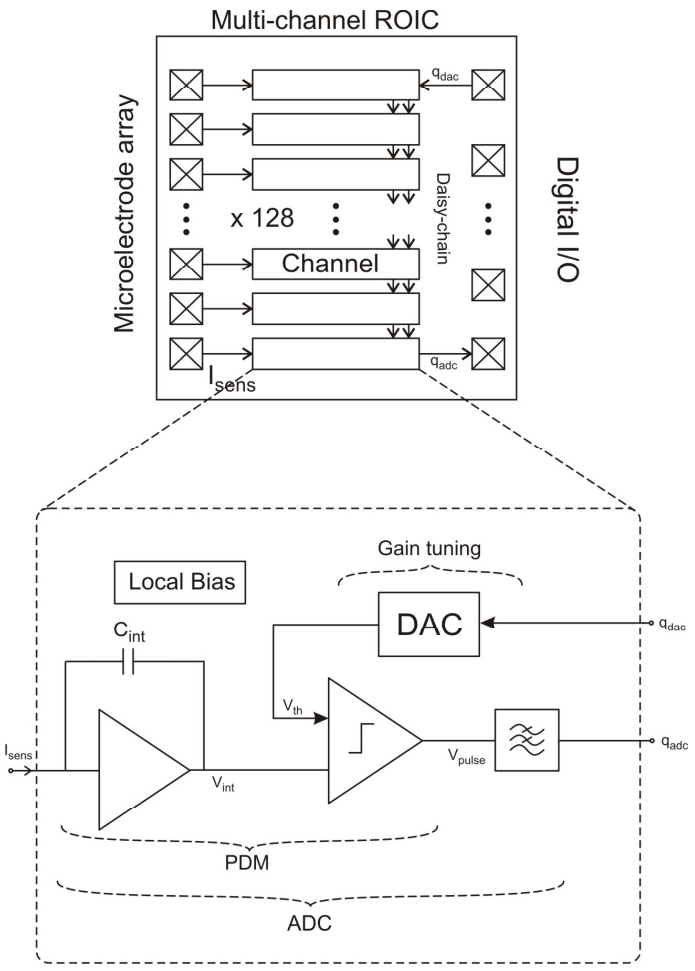


ROIC Channel Architecture

Parameter	Value	Units
Channel pitch	50	µm
Micro-electrode resistance	≤50	Ω
Micro-electrode capacitance	≤2	pF
Acquisition time	1 : 100	ms
Input resolution (@100ms)	±1	fA
Input dynamic range	80	dB
Supply voltage	3.3	V
Power consumption	< 0.5	mW/Ch
Temperature (@100ms)	-20:0:30	ºC

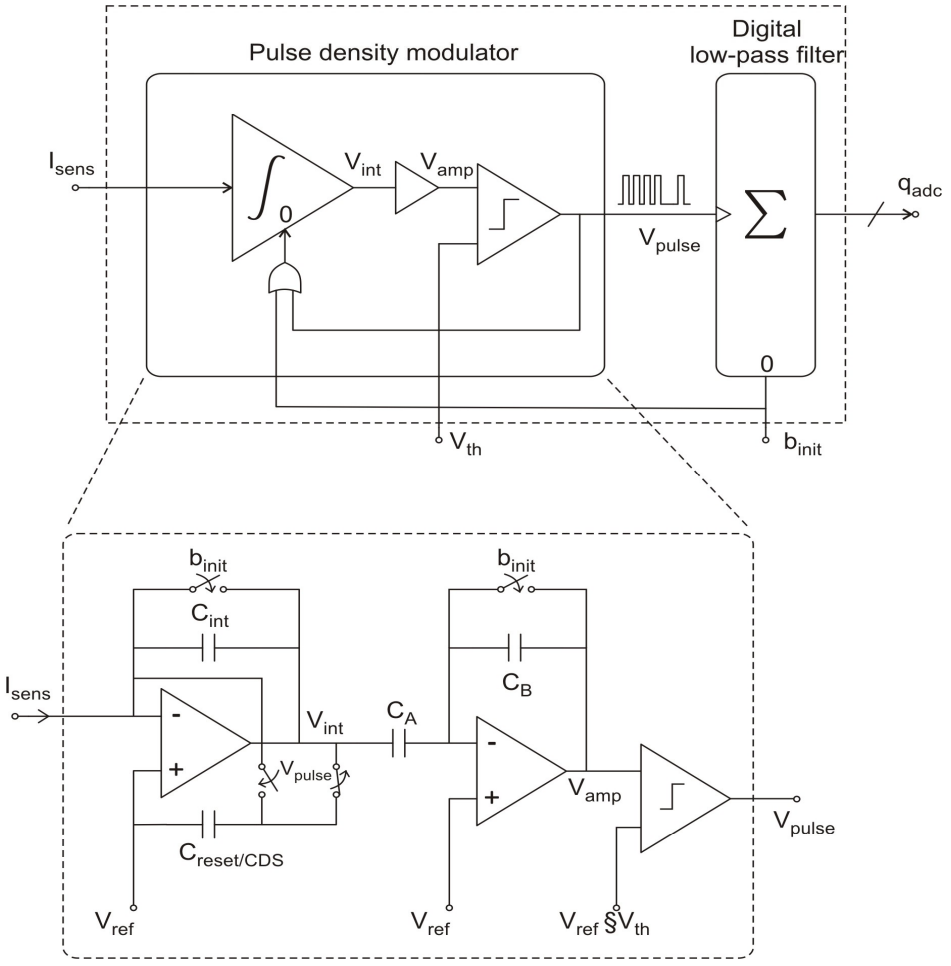
- Main specifications of the ROIC
- Compact channel area
- Short acquisition time
- High current sensitivity
- Wide dynamic range
- Low-power operation

ROIC Channel Architecture



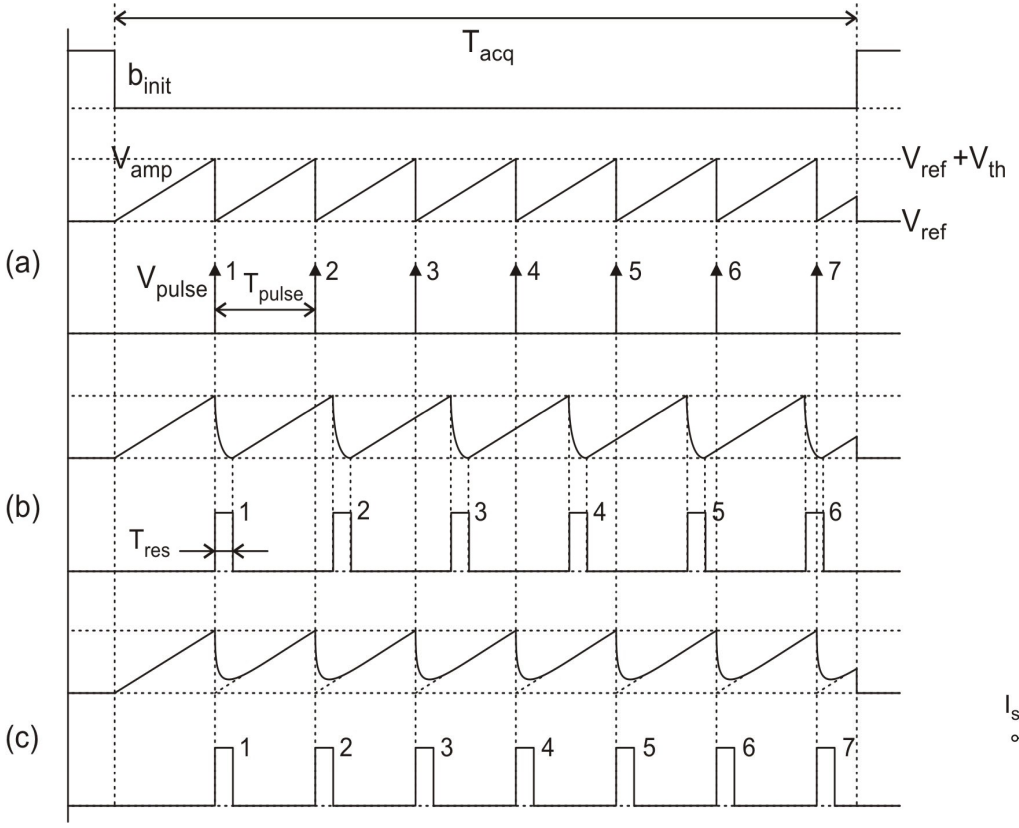
- Integrating A/D Conversion
- Full-parallel signal processing.
- No input signal multiplexing is required.
- Narrow noise bandwidth.
- Minimum crosstalk.
- Fixed pattern noise compensation.
- Low power CMOS and compact circuits required.

Reset Times

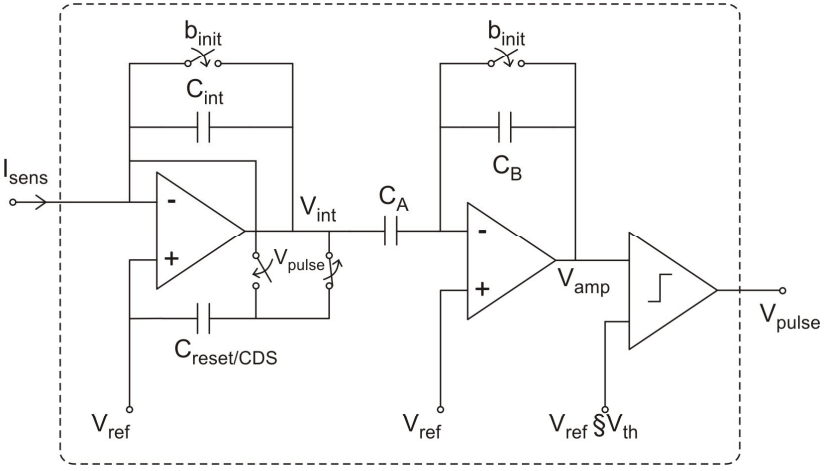


- Novel integration scheme for in-channel ADC conversion.
  - High linearity.
  - Correlated Double Sampling (CDS).
  - Compact CMOS circuits.

Reset Times

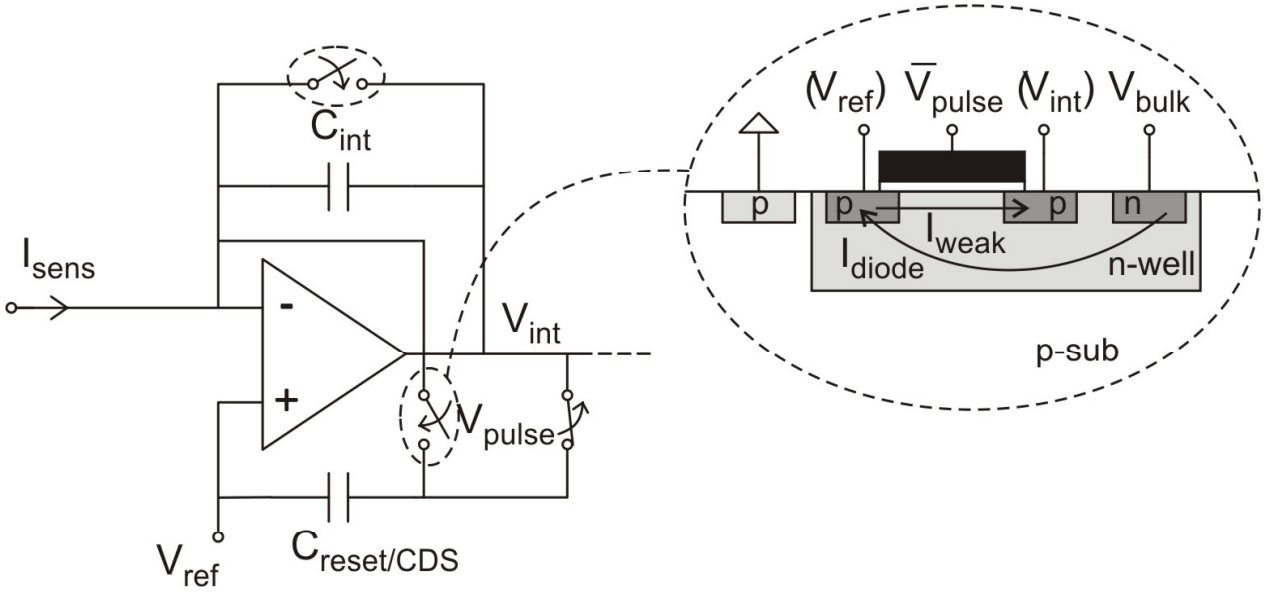


- Novel PDM scheme for minimum reset time during integration:
  - High linearity.
  - Correlated double sampling (CDS).
  - Robust.
  - Compact CMOS circuits.



Switch Leakage

- MOSFET switch non-idealities:
  - Subthreshold conduction
  - D/S diffusion diodes leakage

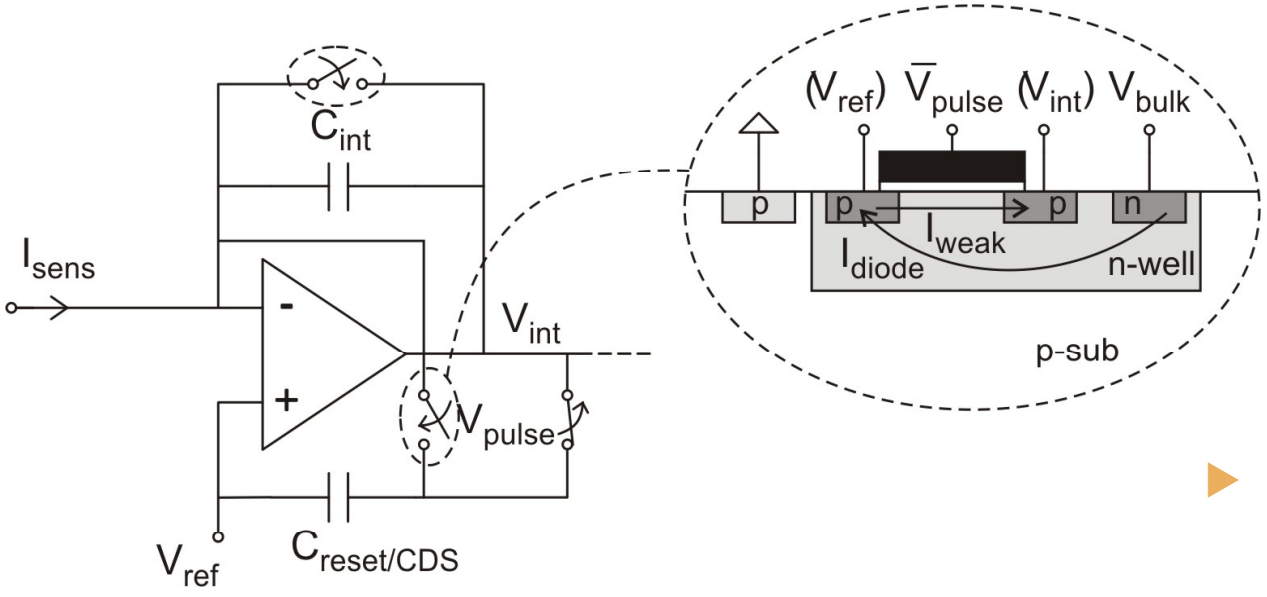


$$I_{leak} = I_{weak} - I_{diode}$$

$$I_{weak} = I_{SM} e^{\frac{V_{bulk} - V_{DD} + V_{TO}}{nU_t}} e^{\frac{V_{ref} - V_{bulk}}{U_t}} \qquad I_{diode} = I_{SD}\left(1 - e^{-\frac{V_{bulk} - V_{ref}}{U_t}}\right)$$

Switch Leakage

- MOSFET switch non-idealities:

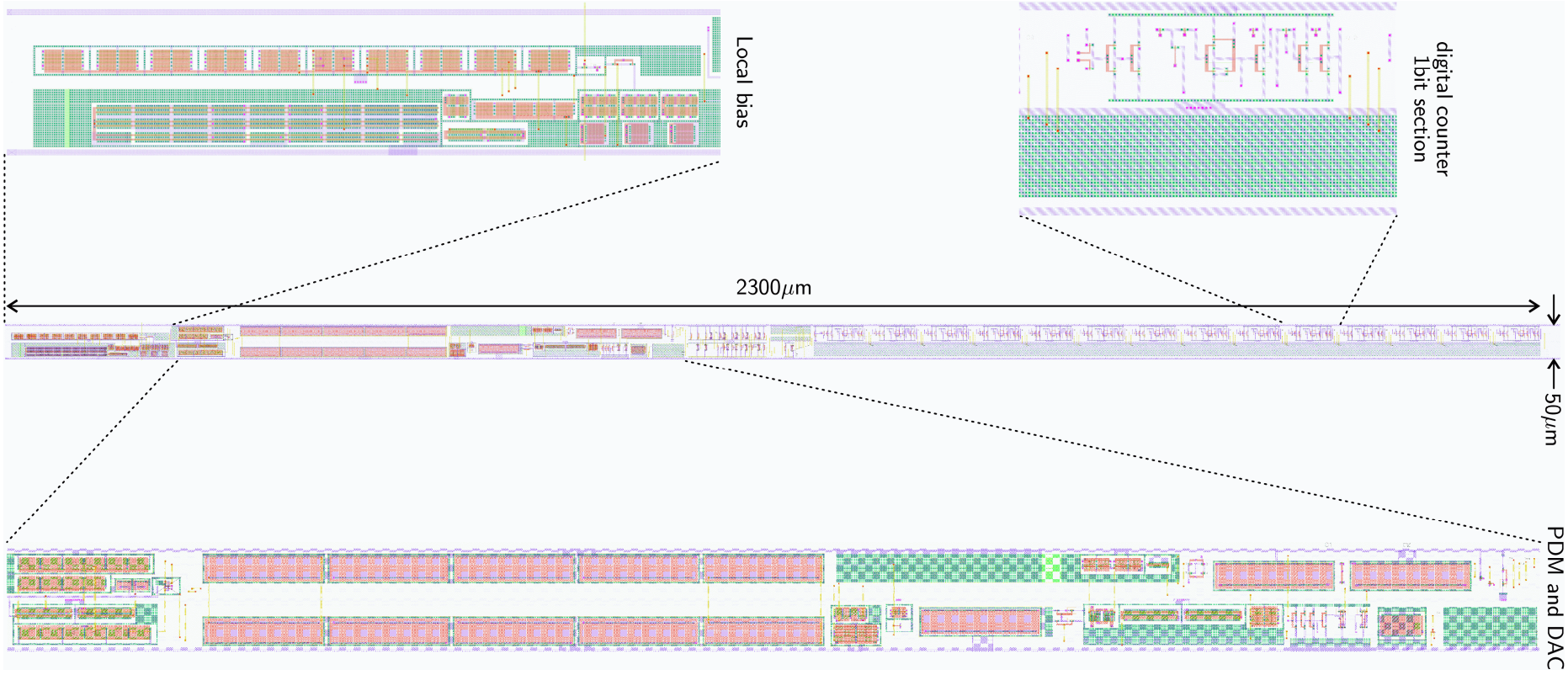


- Proper n-well biasing (V_{bulk})
- $I_{leak} \leq 0.5$ fA

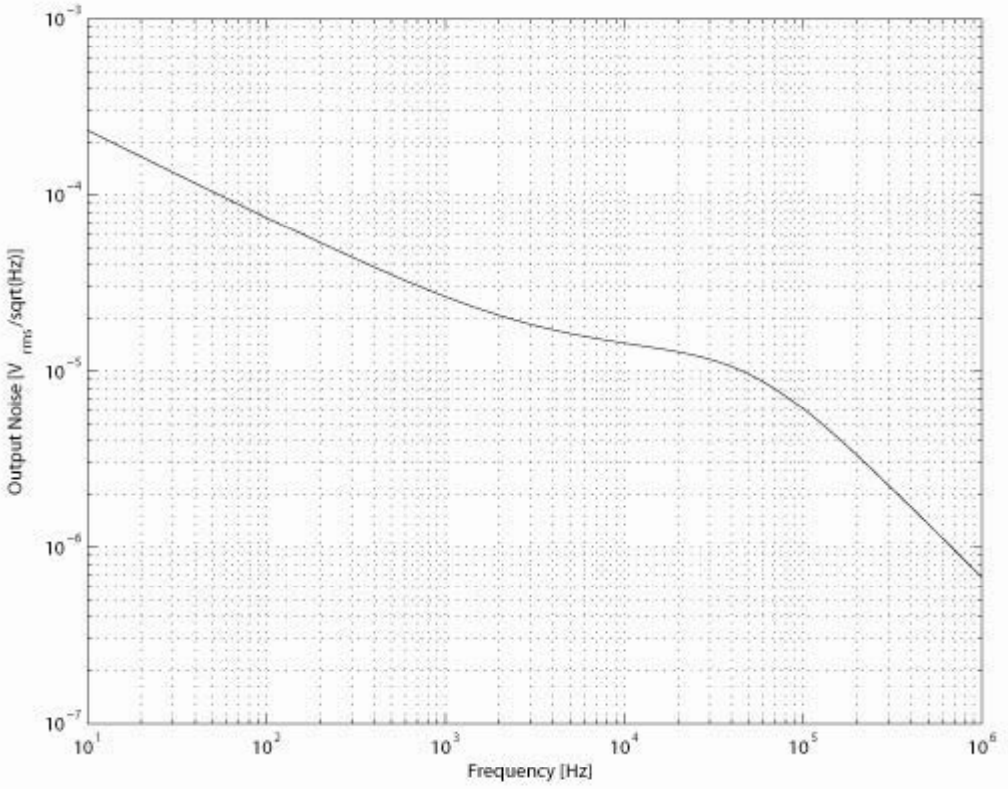
$$I_{leak} < I_{SM} e^{\frac{V_{ref} - V_{DD} + V_{TO}}{nU_t}} \quad \text{for} \quad V_{bulk} \equiv V_{ref}$$

CMOS Integration and Simulation Results

- Full channel layout in 0.35 µm 2P4M CMOS technology:



CMOS Integration and Simulation Results



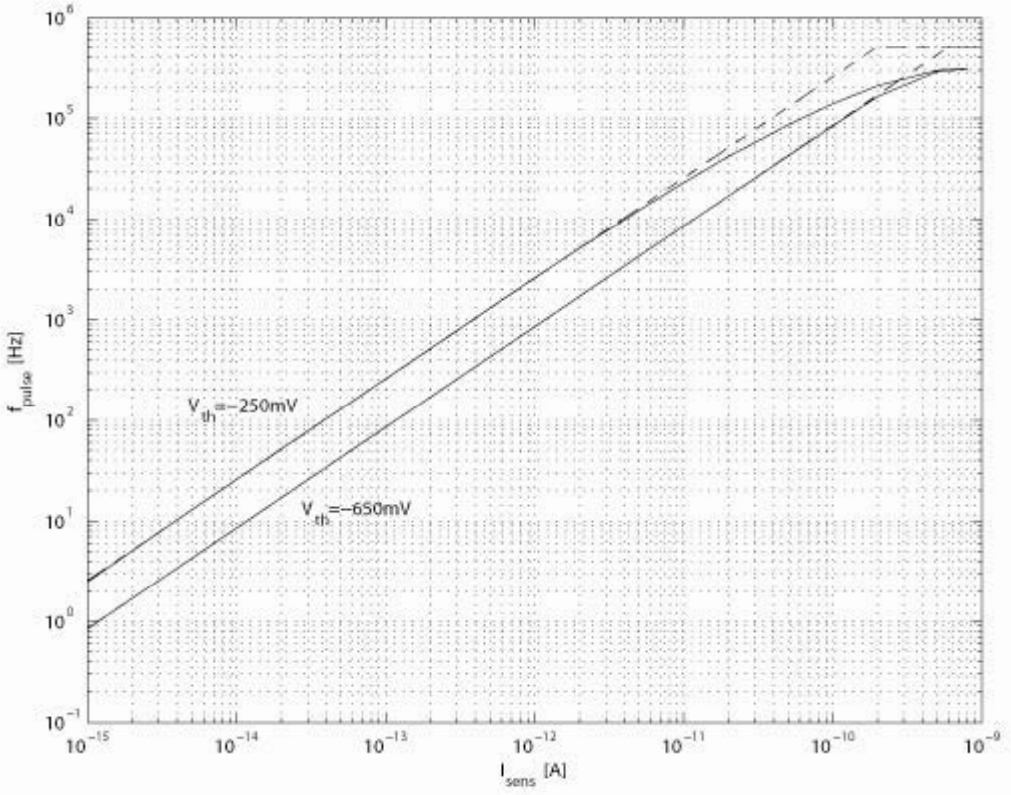
- CMOS noise dominate over electrode noise
- 65% thermal and 35% flicker

$$ENC = C_{int}V_{intn} \simeq 10\text{fF} \times 4\text{mV}_{\text{rms}} = 40\text{aC}_{\text{rms}} = 250e^-_{\text{rms}}$$

$$I_{sensn} = \frac{ENC}{T_{acq}} = \frac{40\text{aC}_{\text{rms}}}{100\text{ms}} = 0.4\text{fA}_{\text{rms}}$$

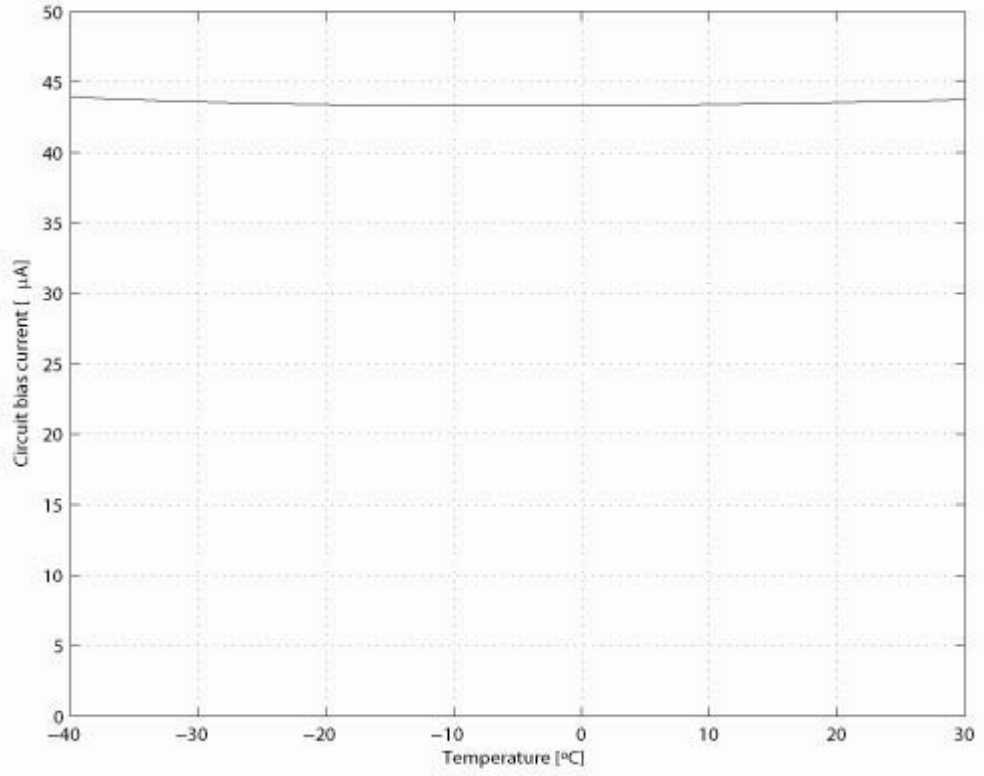
- Adequate LSB for 1 fA resolution

CMOS Integration and Simulation Results



- PDM transfer function
- Poor linearity at full-scale

CMOS Integration and Simulation Results



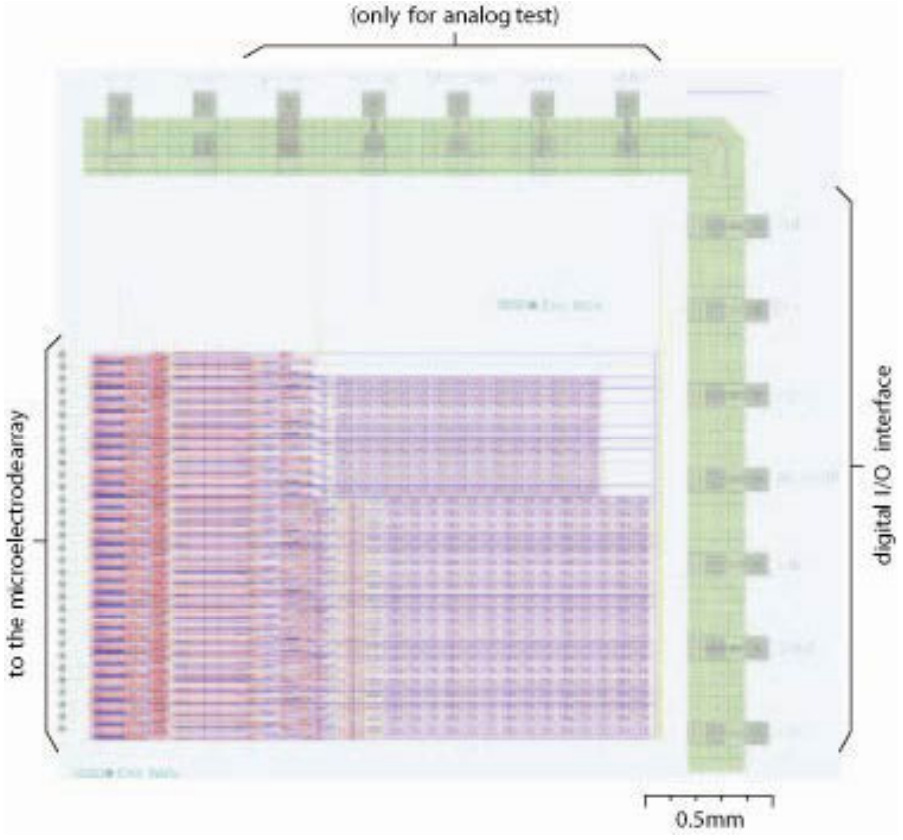
- Local bias generator
- Flat temperature sensitivity

CMOS Integration and Simulation Results

Parameter	Value	Units
Channel pitch	50	µm
Silicon area	0.12	mm^2
Acquisition time	1 : 100	ms
Equivalent input noise (@100ms)	0.4	fA_{rms}
Instantaneous dynamic range	84	dB
Overall dynamic range	100	dB
Threshold range (V_{th})	±250 : ±650	mV
Threshold step (ΔV_{th})	±10	mV
Supply voltage	3.3	V
Current consumption	110	µA

- Main performance parameters of the ROIC channel module

CMOS Integration and Simulation Results

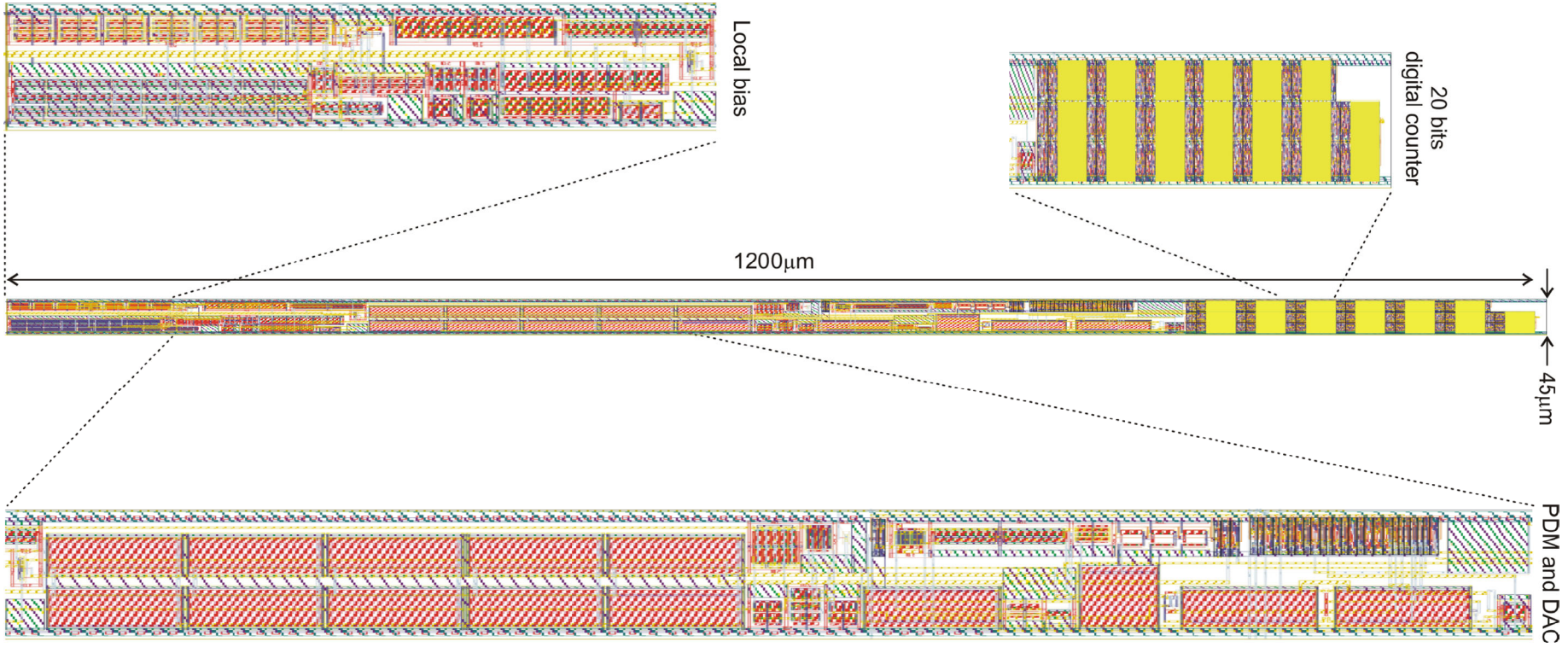


2950µm x 2850µm = 8.4mm^2

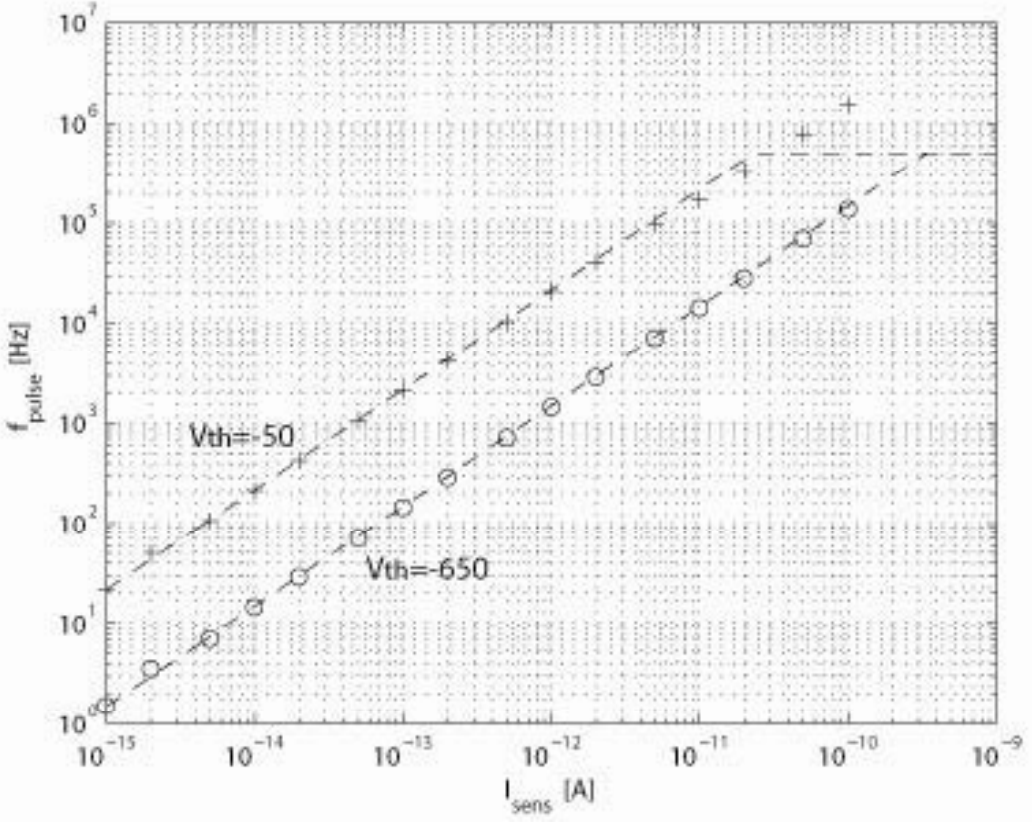
- First test vehicle prototype:
  - 1 pre-amp block
  - 1 PDM block
  - 10 operative channels with external programming
  - 20 full channels with serial interface
- 035um CMOS 2P 4M technology (AMS-C35)
- Bump bonding

CMOS Integration and Simulation Results

- Second version with enhanced performance and compact layout:



CMOS Integration and Simulation Results



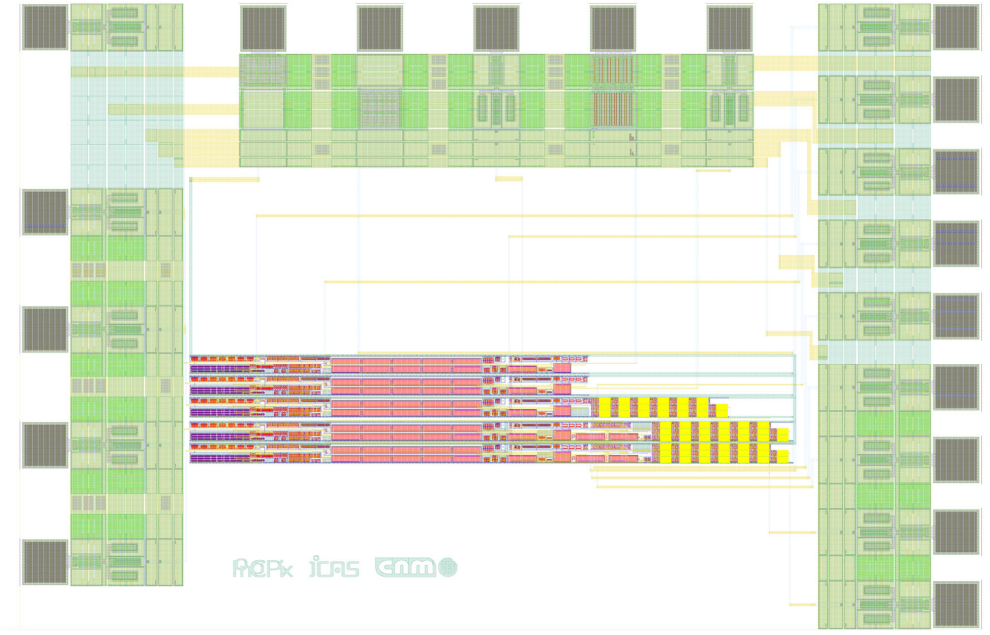
- High Linearity of the PDM
- High sensitivity (20Hz/fA)

CMOS Integration and Simulation Results

Parameter	Value	Units
Channel pitch	45	µm
Silicon area	0.054	mm^2
Acquisition time	1 : 100	ms
Equivalent input noise (@100ms)	0.4	fA_{rms}
Instantaneous dynamic range	120	dB
Overall dynamic range	100	dB
Threshold range (V_{th})	±50 : ±650	mV
Threshold step (ΔV_{th})	±10	mV
Supply voltage	3.3	V
Current consumption	110	µA

- Main performance parameters of the ROIC channel module

CMOS Integration and Simulation Results

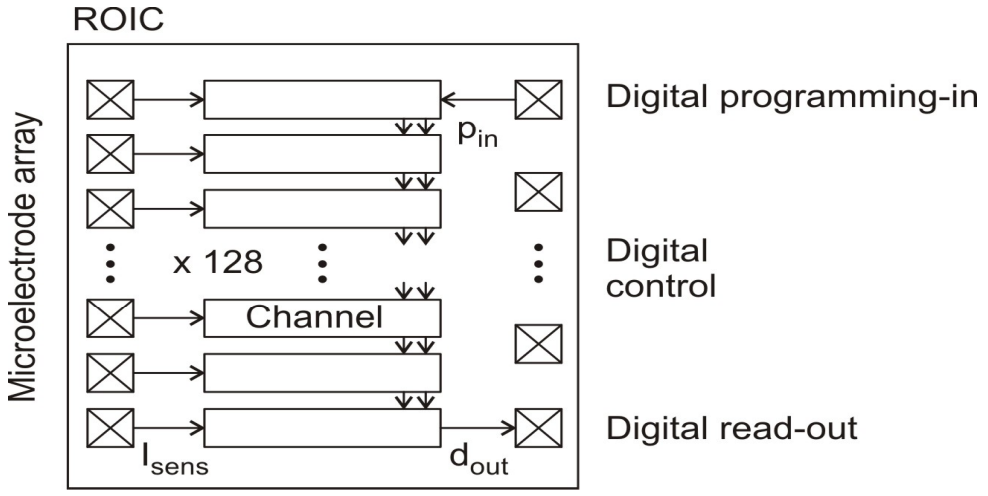


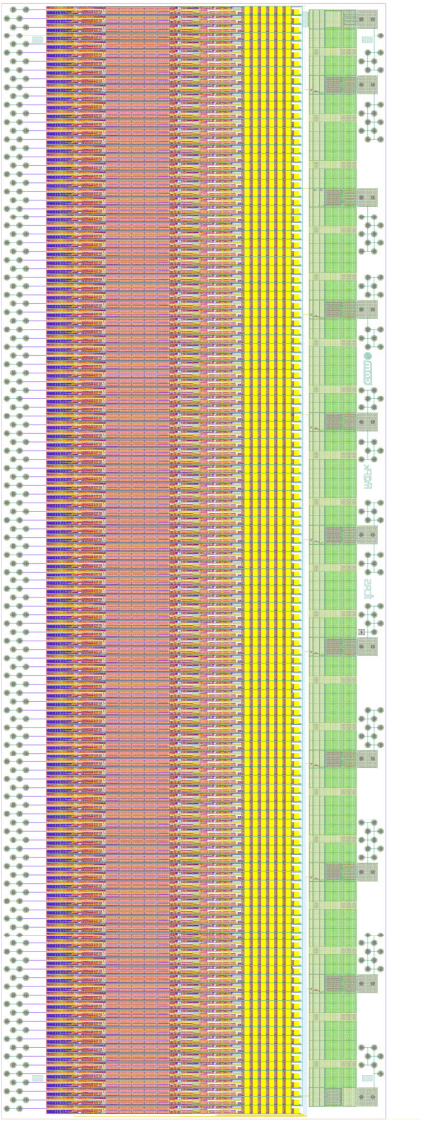
2000µm x 1300µm = 2.6mm²

- Second test vehicle prototype:
  - 1 pre-amp block
  - 1 PDM block
  - 1 operative channel with external programming
  - 2 full channels with serial interface
- 035um CMOS 2P 4M technology (AMS-C35)
- Wire bonding

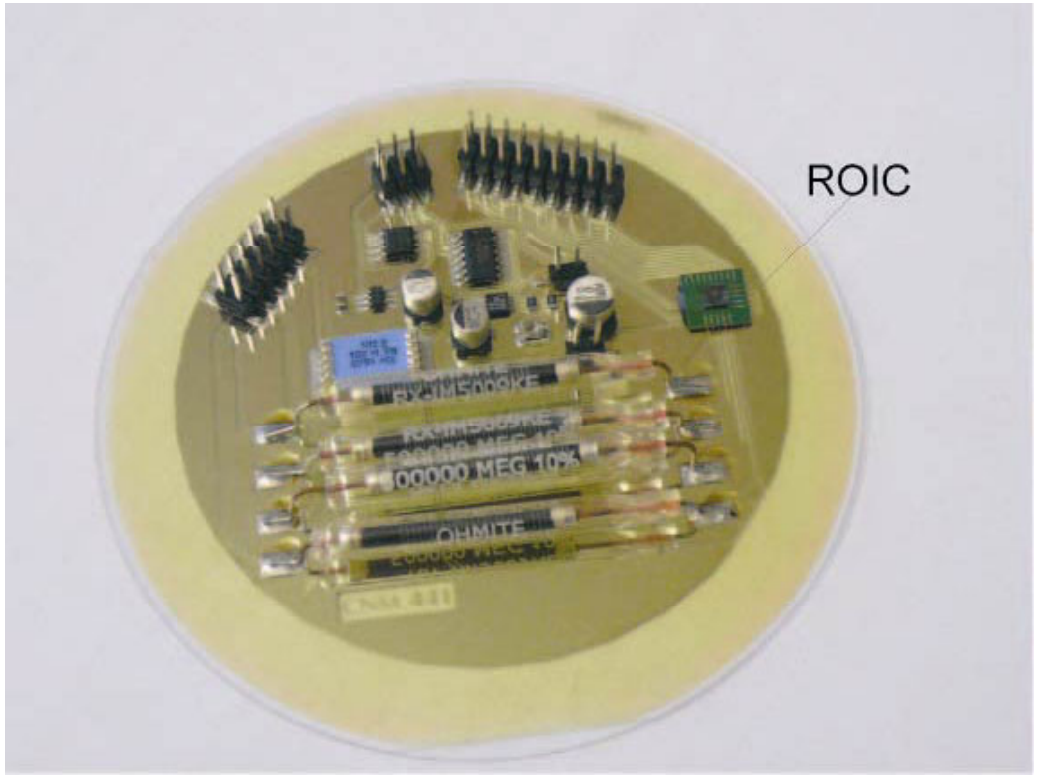
CMOS Integration and Simulation Results

- Complete 128-channel ROIC
- 035um CMOS 2P 4M technology (AMS-C35)
- Bump bonding
- Size: 5800µm x 1890µm = 10.96mm2





Test Environment



- SiO_2 wafer substrate for low leakage
- Flip-chip ROIC
- Wire-bonded ROIC carrier for multiple sample testing
- SMD bonding by screen printing
- 500 GΩ glass sealed hermetic resistors for fA stimulus

Conclusions

- Digital multi-channel read-out integrated circuit for differential mobility analyzers
- Dedicated PDM ADC with independent gain programmability and thermal compensation
- Low current (110 µA) and compact (0.054 mm^2) channel model in 0.35µm 2P4M CMOS technology
- Simulation results agrees with the main specifications of the ROIC
- Experimental results are expected in short

…thanks for your attention!