Design and Modeling of a 0.4mW/Ch Multi-Channel Integrated Circuit for Infrared Gas Recognition

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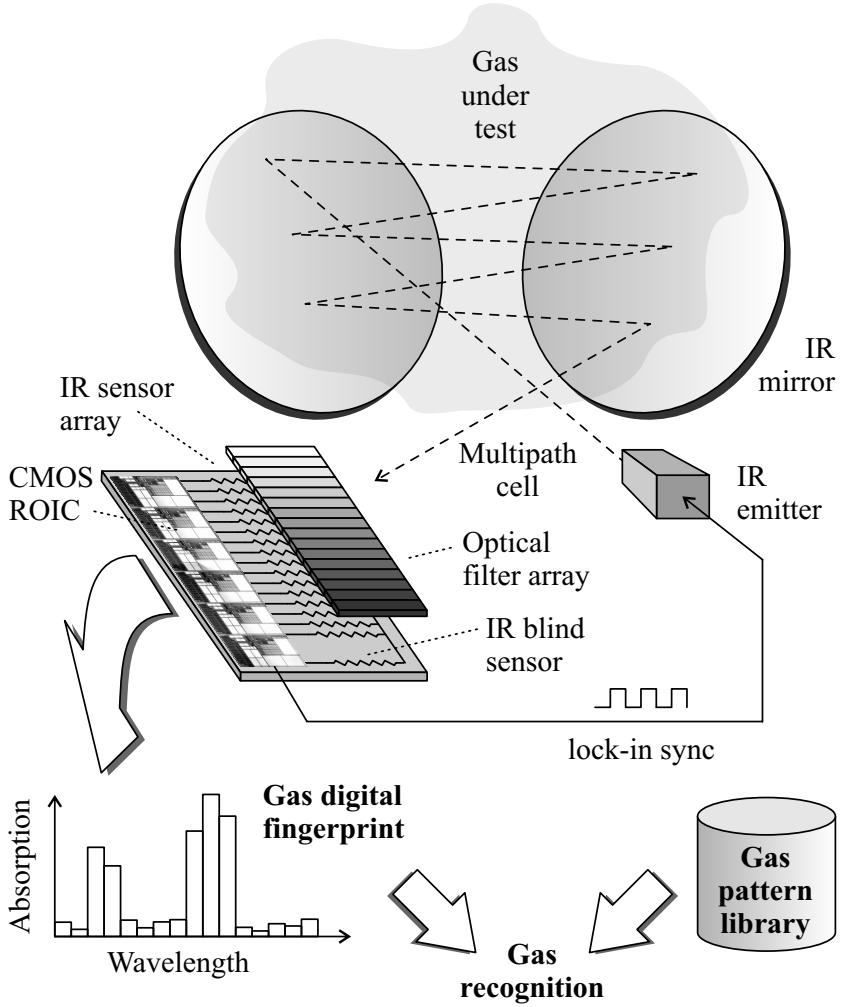
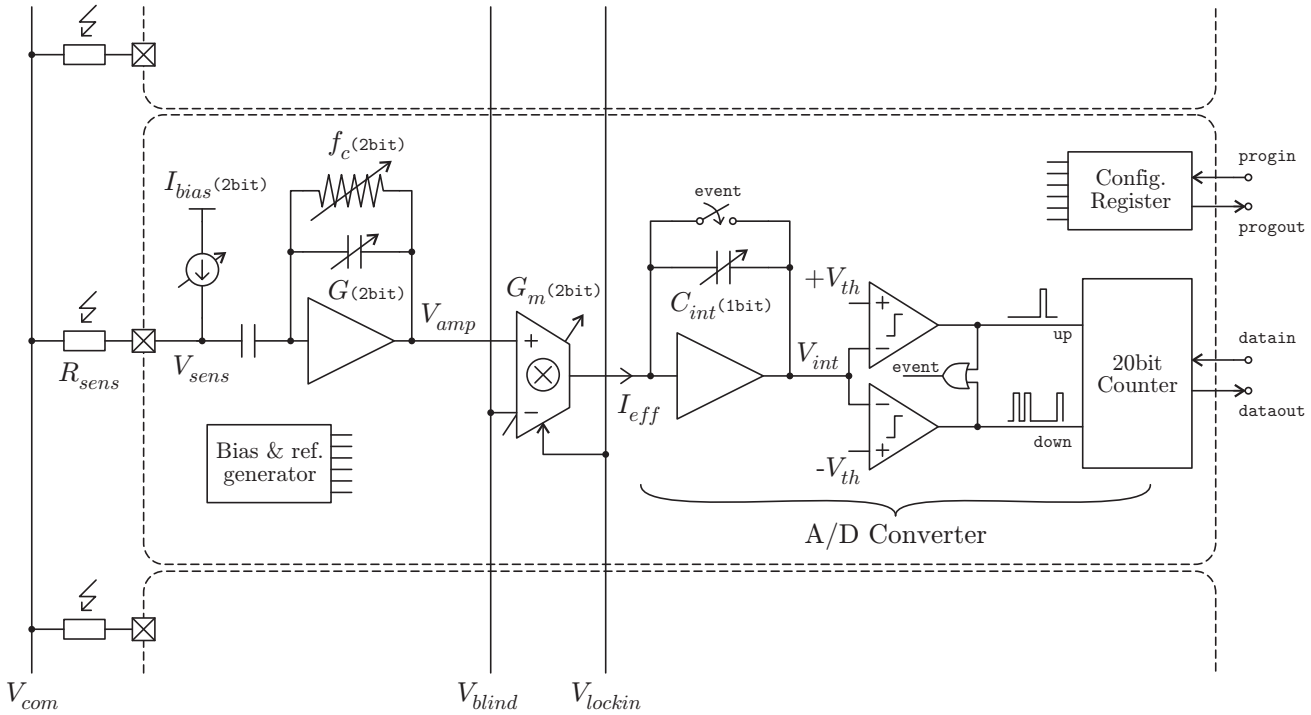
Introduction

- Real-time **gas recognition** for environmental monitoring, toxic gas detection...
- **IR spectroscopic** absorption digital fingerprint
- Thermal μbolometer LWIR **sensing array**
- **Multi-channel** ROIC for fast acquisition and low-noise
- Channel **lock-in** demodulation for high-accuracy
- **Low-power** operation to avoid thermal drifts of IR sensors
- **Compact pitch** for direct sensors-ROIC bonding



ROIC Channel Architecture



- High **programmability**
- **No external** components
- Built-in bias generators for **low crosstalk**
- **Digital only** interface

- External **lock-in synchronization**
- Dedicated **blind channel** for cancellation of common disturbing signals
- **Individual configuration** register per channel

$$\Delta V_{sens} = I_{bias} \Delta R_{sens}$$

Pre-Amplification and Filtering

- **Sub-Hz** high-pass specs
- **Independent** gain and corner programmability required

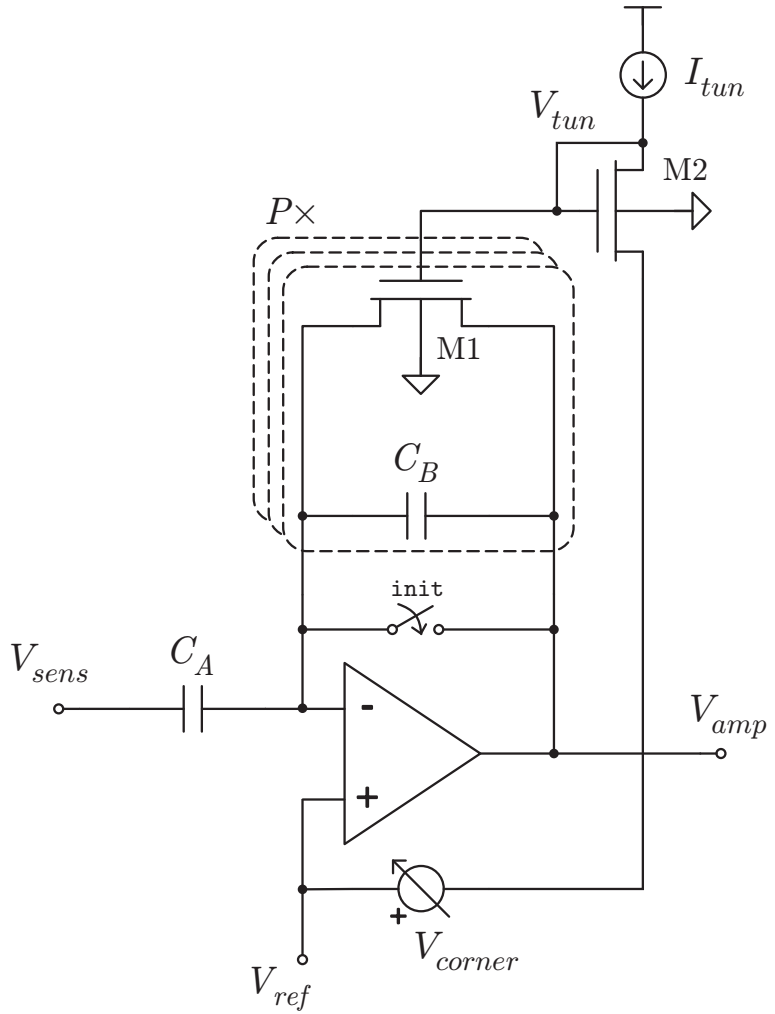
- **Highly linear** cap amplifier:

$$G = \frac{\Delta V_{amp}}{\Delta V_{sens}} = \frac{C_A}{C_B}$$

- **Subthreshold** MRC filtering:

$$f_c = f_{co}\, e^{-\frac{V_{corner}}{U_t}} \qquad f_{co} = \frac{1}{2\pi}\frac{I_{tun(PTAT)}}{C_B\, U_t}$$

- **Fast initialization** switch



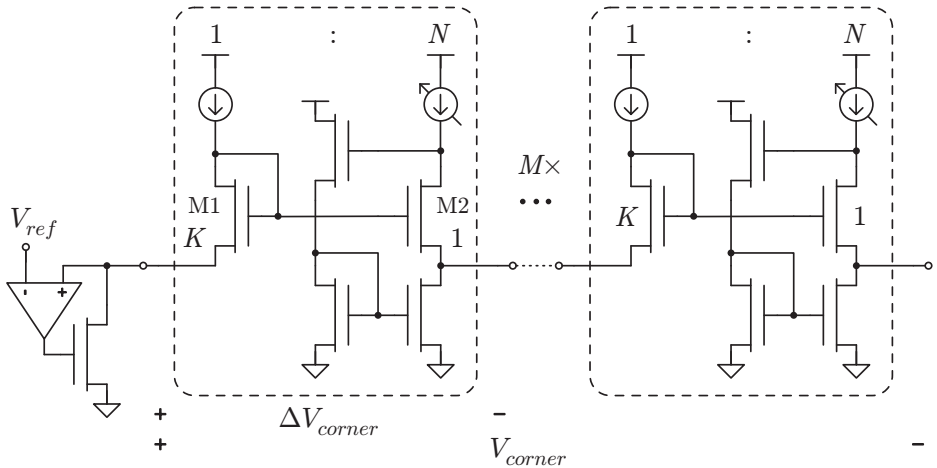
Pre-Amplification and Filtering

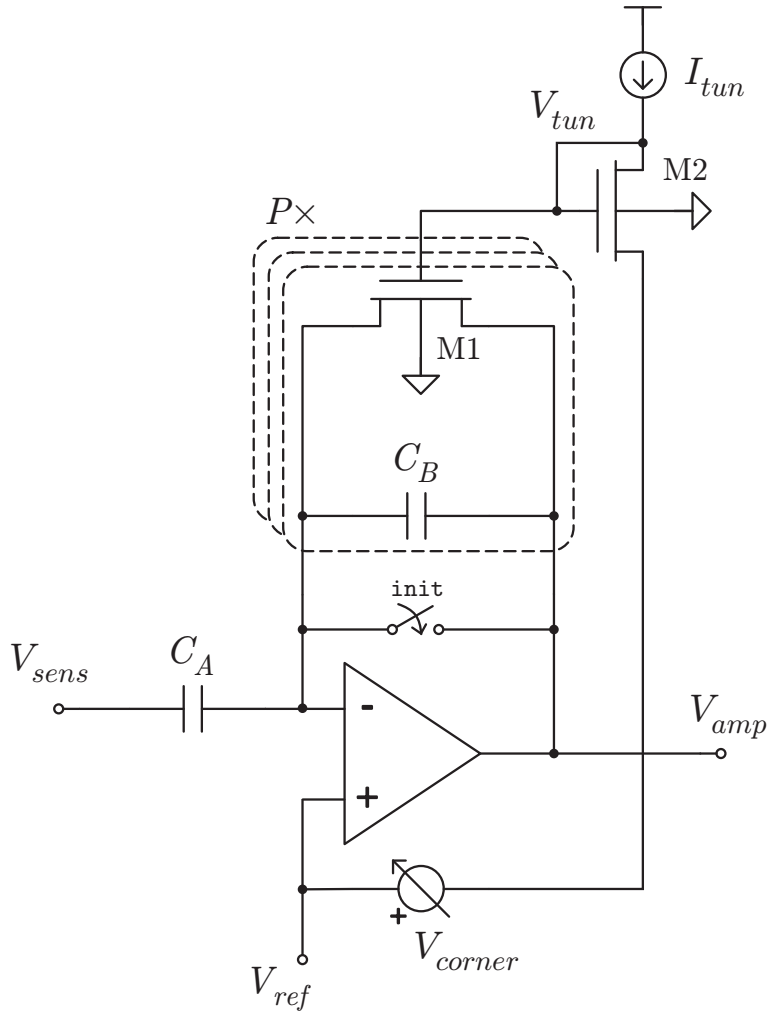
- Gain tuning by P **scaling**
- **Multi-decade** filter log tuning:

$$V_{corner} = M\Delta V_{corner} = MU_t \ln(NK)$$

$$f_c = \frac{f_{co}}{(NK)^M}$$

$$f_c \times 10^{\pm 3} \Leftrightarrow V_{corner} \pm 173\text{mV at } 25°\text{C}$$





Blind Cancellation and Lock-in Demodulation

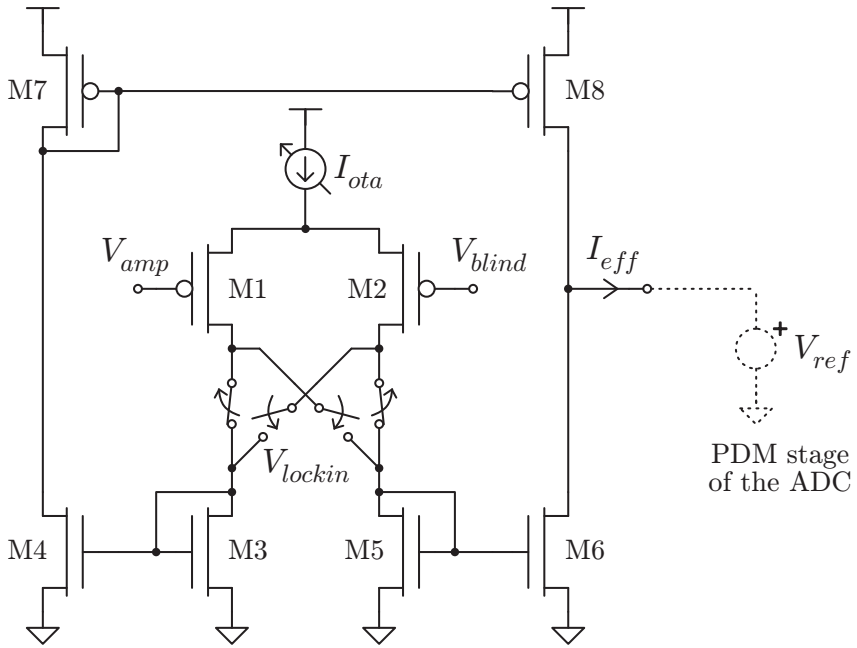
- Differential to **single ended**
- Voltage-to-**current** conversion
- **Lock-in** demodulation

- Low-power subthreshold **OTA**:

$$G_m = \frac{I_{eff}}{\Delta V_{amp}} = \frac{I_{ota}}{2nU_t} \propto U_t$$

$$I_{ota} \propto I_S = 2n\beta U_t^2$$

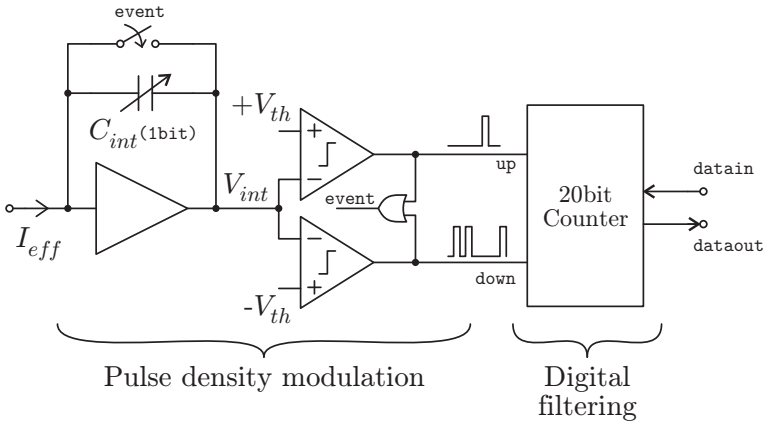
- **Current-domain** lock-in demodulation by cross-coupling
- Voltage log compression allows **fast switching** at low-power



(cascode topology not shown)

Integrating A/D Conversion

- **PDM** noise shaping
- Digital **counter** as low-pass filter
- **Asynchronous** operation for very low-power and low-crosstalk



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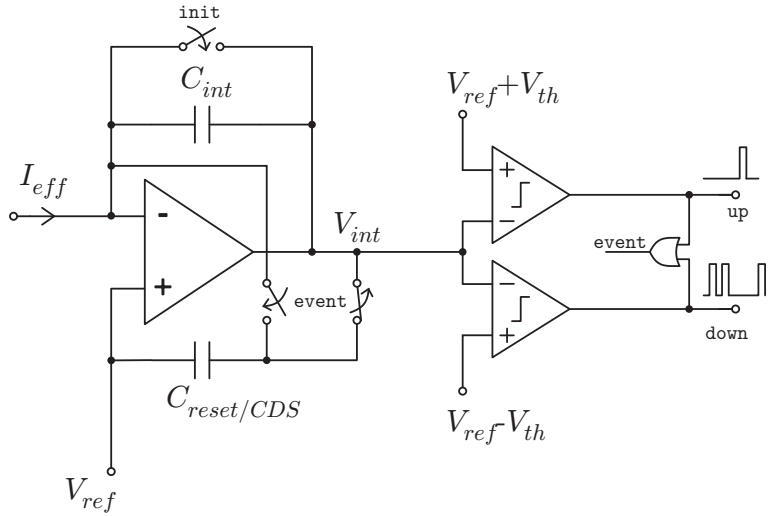
- **Loss-less** analog integrator with **CDS** for high-linearity and noise reduction:

$$f_{PDM} = \frac{I_{eff}}{C_{int}\, V_{th}}$$



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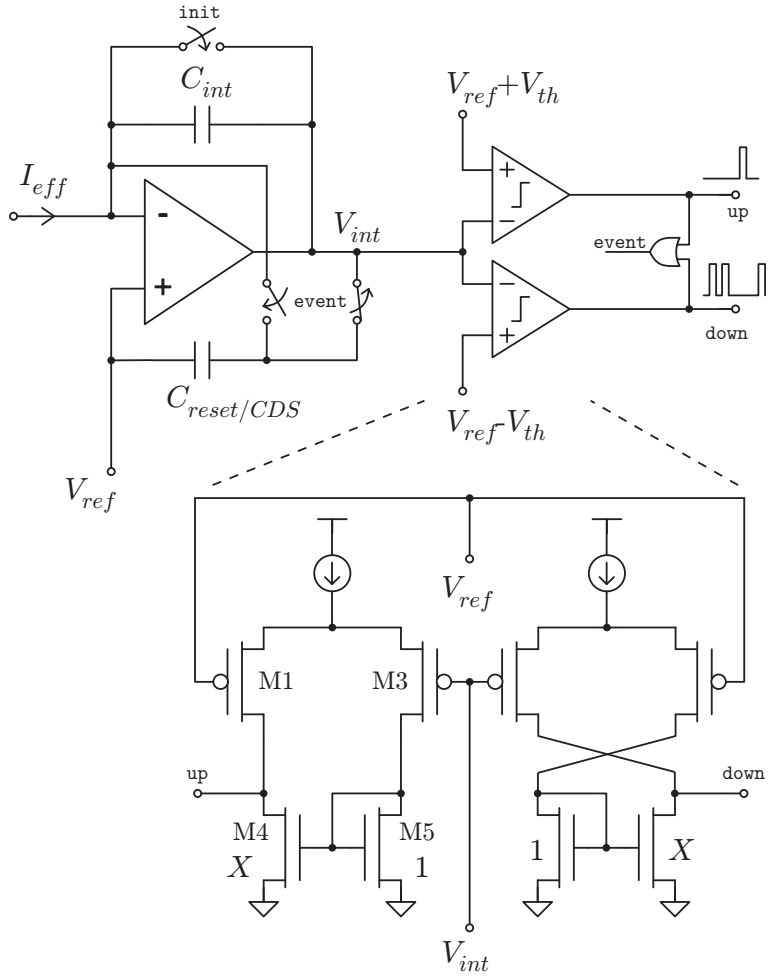
- **Built-in** threshold comparator:

$$V_{th} = nU_t \ln X$$

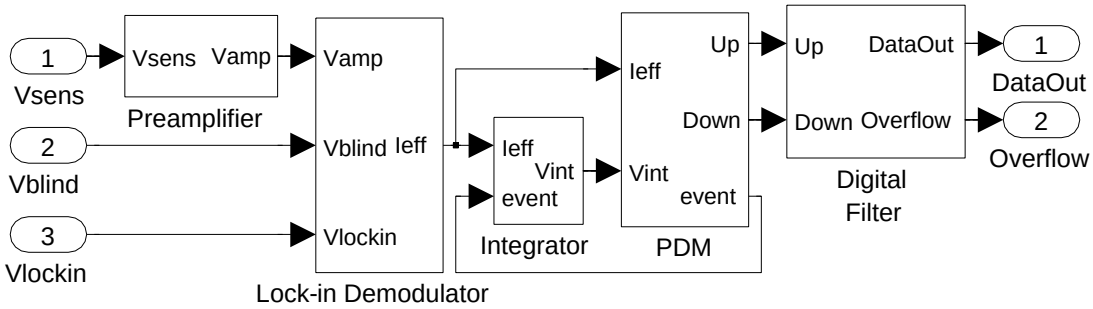
- **Thermal compensation** of G_m:

$$q_{adc} = \lfloor n_{adc} \rfloor \qquad n_{adc} = T_{samp} f_{PDM} = \frac{C_A}{C_B} \frac{G_m}{V_{th}} \frac{T_{samp}}{C_{int}} \Delta R_{sens}$$



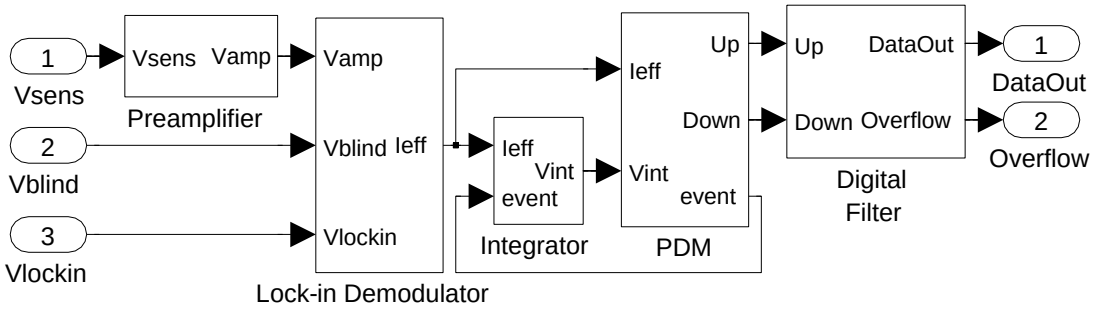
Post Layout High Level Modeling

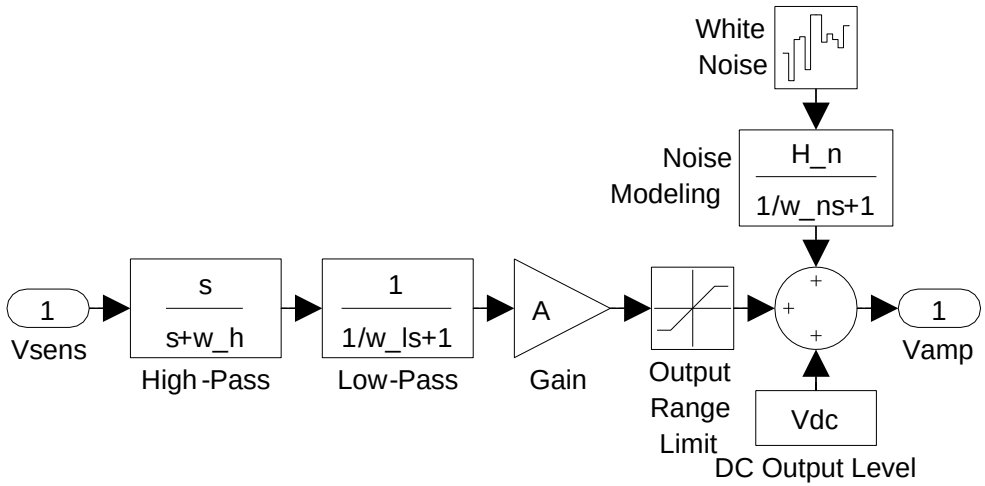
- Simulation **time reduction**
- Complete **read-out channel model**
- Entire set of **channel configurations**



Post Layout High Level Modeling

- Simulation **time reduction**
- Complete **read-out channel model**
- Entire set of **channel configurations**
- Wide range of **nonidealities** modeling
- **Technology process** and **temperature**
- **Flicker** and **thermal noise** options
- External **sensor modeling**

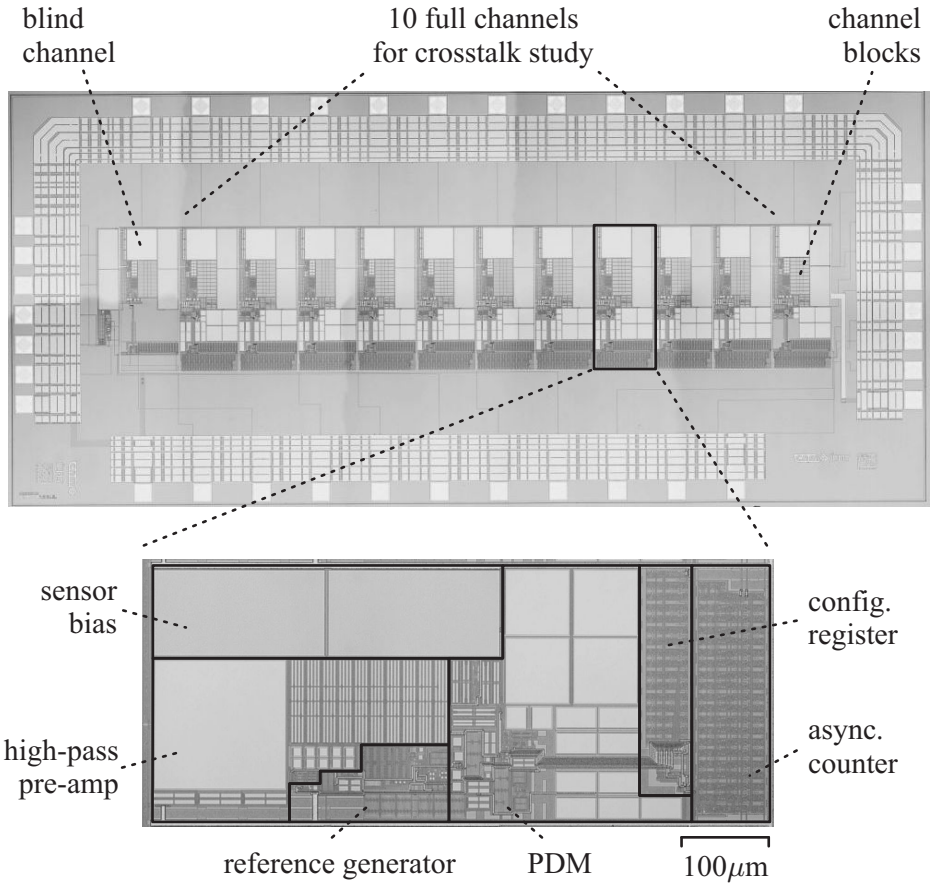




CMOS Integration and Experimental Results

- 0.35μm 2P4M CMOS channel module **test chip**
- Main **design parameters**:

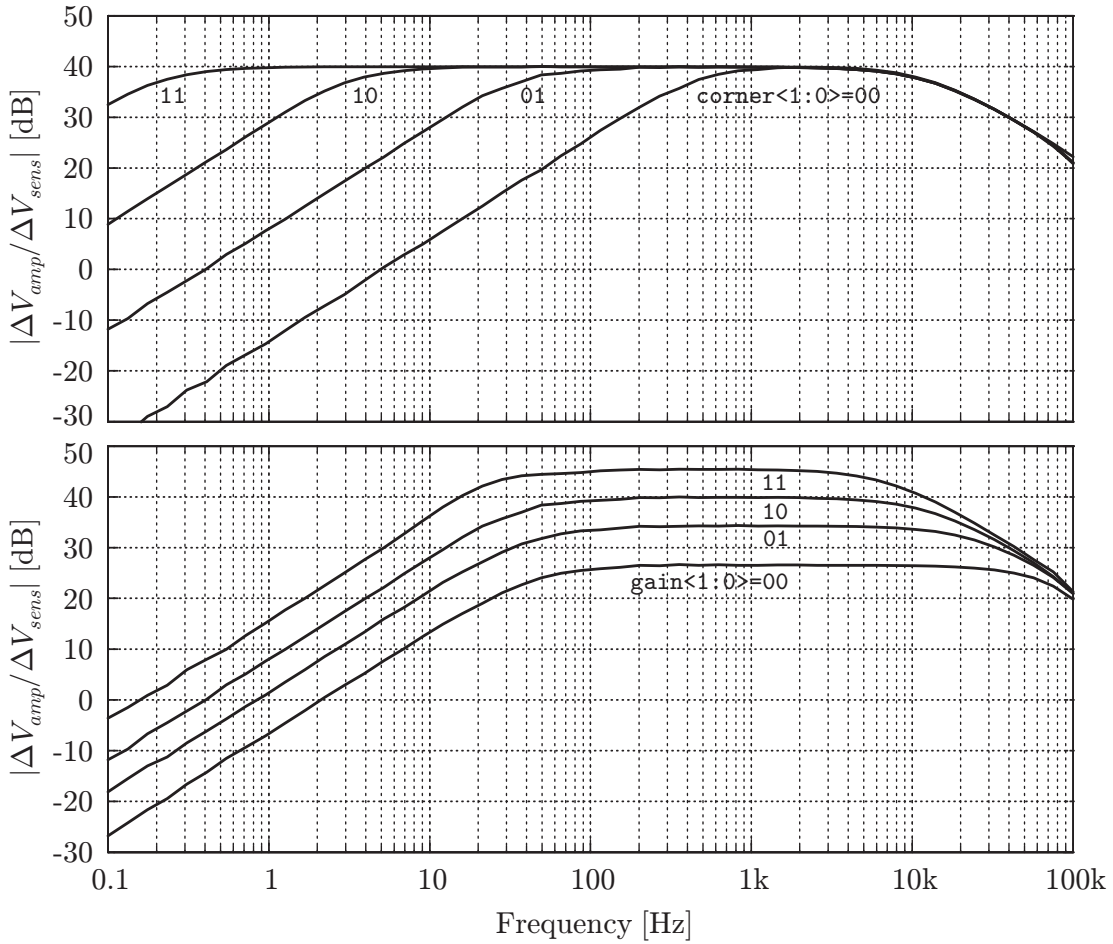
$$C_A = 20\text{pF}$$
$$C_B = \{0.1, 0.2, 0.4, 1\}\text{pF}$$
$$K = 10$$
$$N = \{1, 11\}$$
$$M = 3$$
$$I_{tun} = 100\text{nA}$$
$$I_{ota} = \{1, 2, 5, 10\}\mu\text{A}$$
$$V_{th} = 120\text{mV}$$
$$T_{pulse} = 500\text{ns}$$



- Access to **intermediate stages**

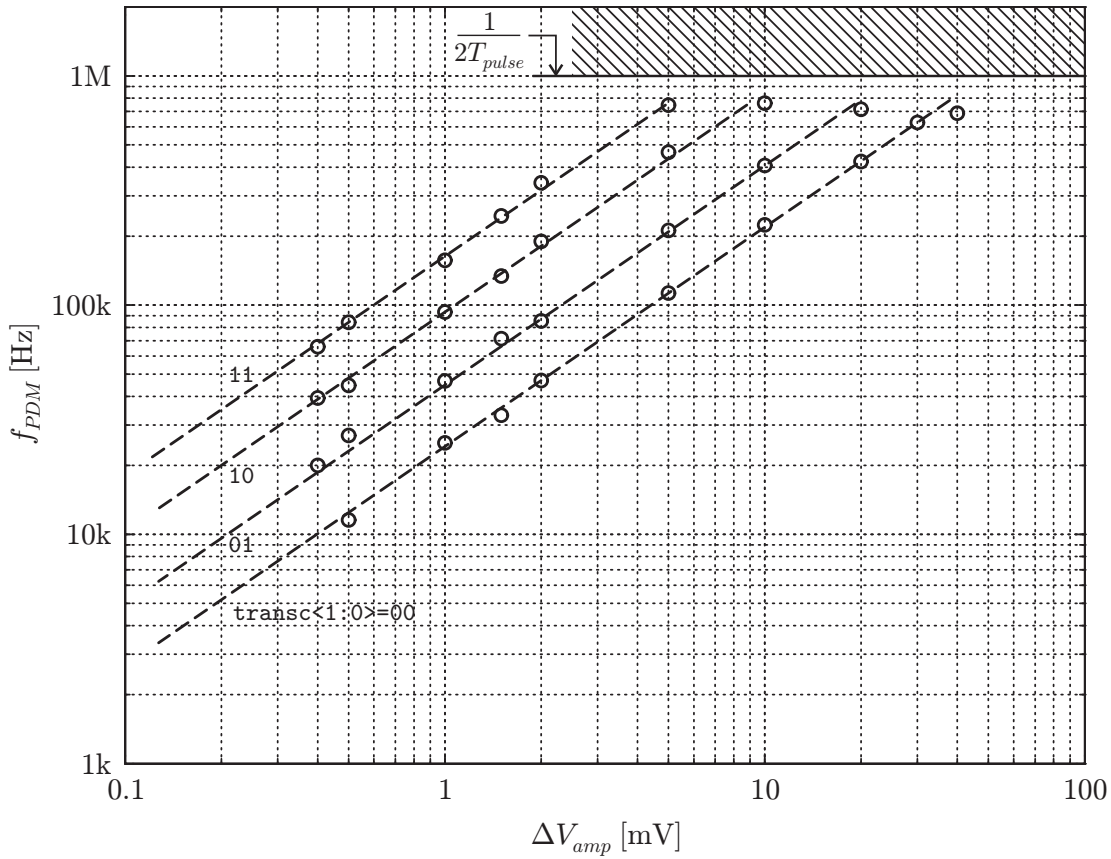
CMOS Integration and Experimental Results

- Sub-Hz **pre-amplifier** independent tuning (16 configurations)



CMOS Integration and Experimental Results

- Sub-Hz **pre-amplifier** independent tuning (16 configurations)
- Highly linear **PDM** up to pulse width hard limit



for `cint<0>=0`

CMOS Integration and Experimental Results

- Sub-Hz **pre-amplifier** independent tuning (16 configurations)
- Highly linear **PDM** up to pulse width hard limit
- 9bit digital **programmability** per channel
- **No crosstalk** observed between channels

experimental (vs simulated) results per channel

Parameter	Value	Units
I_{bias} bias<1:0>=00	0.97 (1)	μA
01	1.9 (2)	
10	4.6 (5)	
11	9.1 (10)	
f_c corner<1:0>=00	0.3 (0.25)	Hz
01	3.9 (4.1)	
10	50 (60)	
11	625 (825)	
G gain<1:0>=00	27 (26)	dB
01	34 (34)	
10	40 (40)	
11	46 (45)	
G_m transc<1:0>=00	(15)	μS
01	(30)	
10	(70)	
11	(130)	
C_{int} cint<0>=0	(5)	pF
1	(10)	pF
Total Harmonic Distortion	$<$0.25	%
Crosstalk	$<$0.5	LSB
V_{nieq} for R_{sens}=300kΩ	(100)	$\mathrm{nV_{rms}}/\sqrt{\mathrm{Hz}}$
Supply voltage	3.3	V
Supply current	100	μA
Silicon area	300$\times$715	$\mu\mathrm{m}^2$

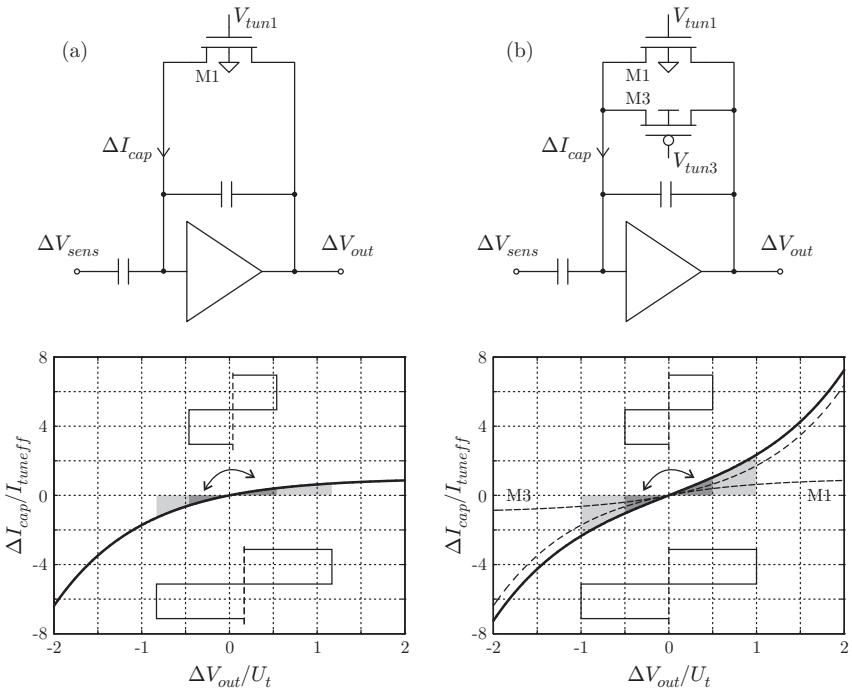
Conclusions

- **Digital read-out** channel for IR spectroscopic gas recognition
- **Fully integrable** sub-Hz high-pass pre-amplification
- **Blind** cancellation and **lock-in** demodulation
- **Highly linear** integrating A/D conversion
- **High-programmability** (9bit) per channel
- **Low-current** (100μA) and **compact** (0.2mm^2) channel module in 0.35μm 2P4M CMOS technology
- Experimental results **agree** with simulated performance
- Post layout **high level modeling**
- **No-crosstalk** reported between channels

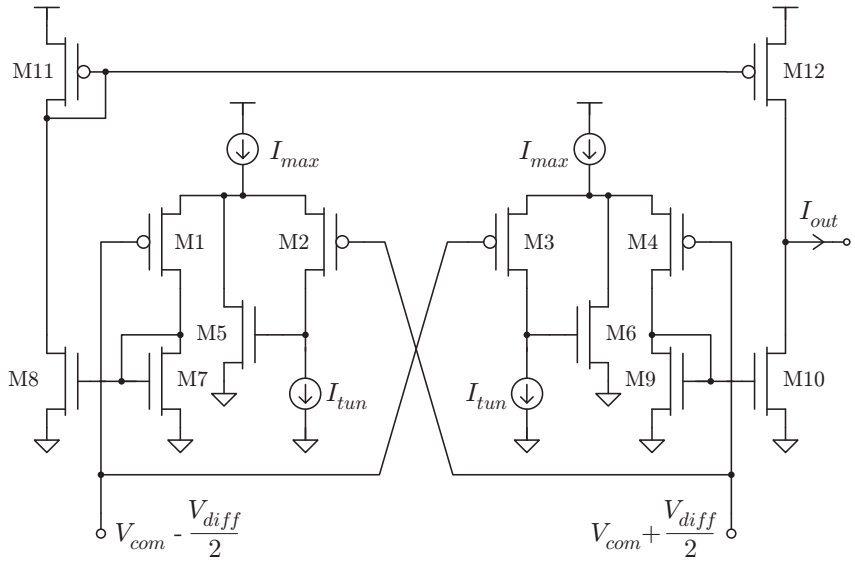
. . . thanks for your attention!

Improvements?

- Pre-amplifier dynamic offset



- OTA linear range



- A **32-channel** ROIC is under development!