# A 100$\mu$A/Ch Fully-Integrable Lock-in Multi-Channel Frontend for Infrared Spectroscopic Gas Recognition

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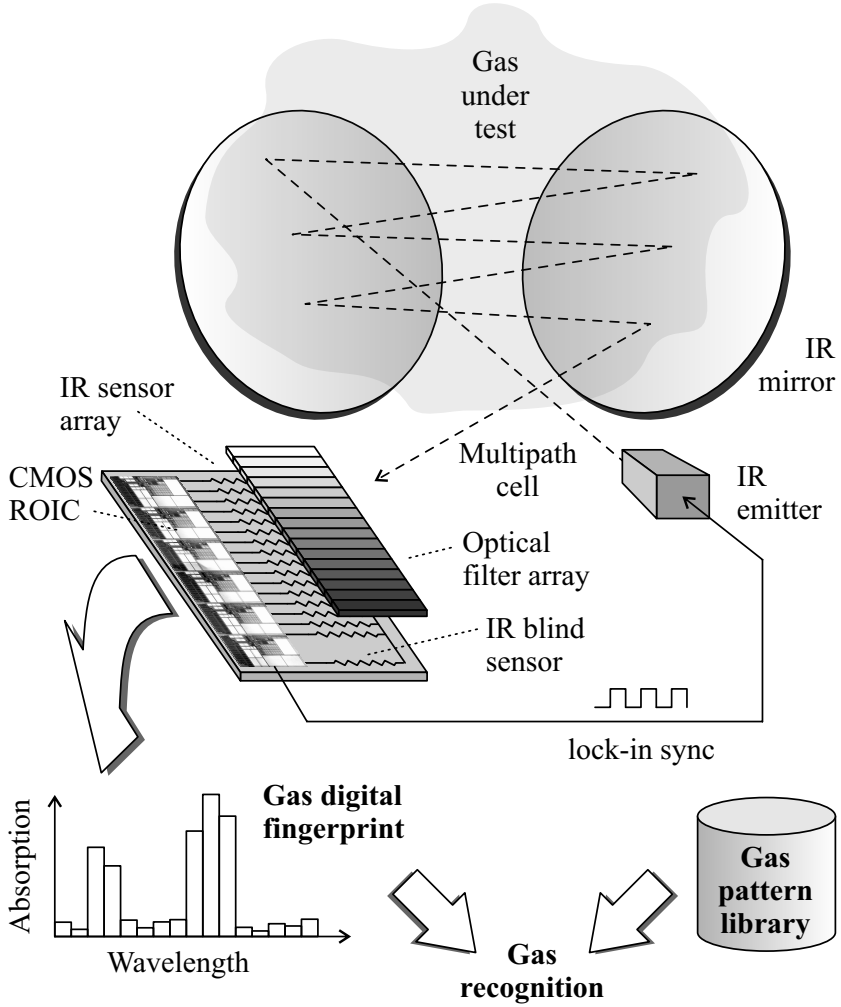
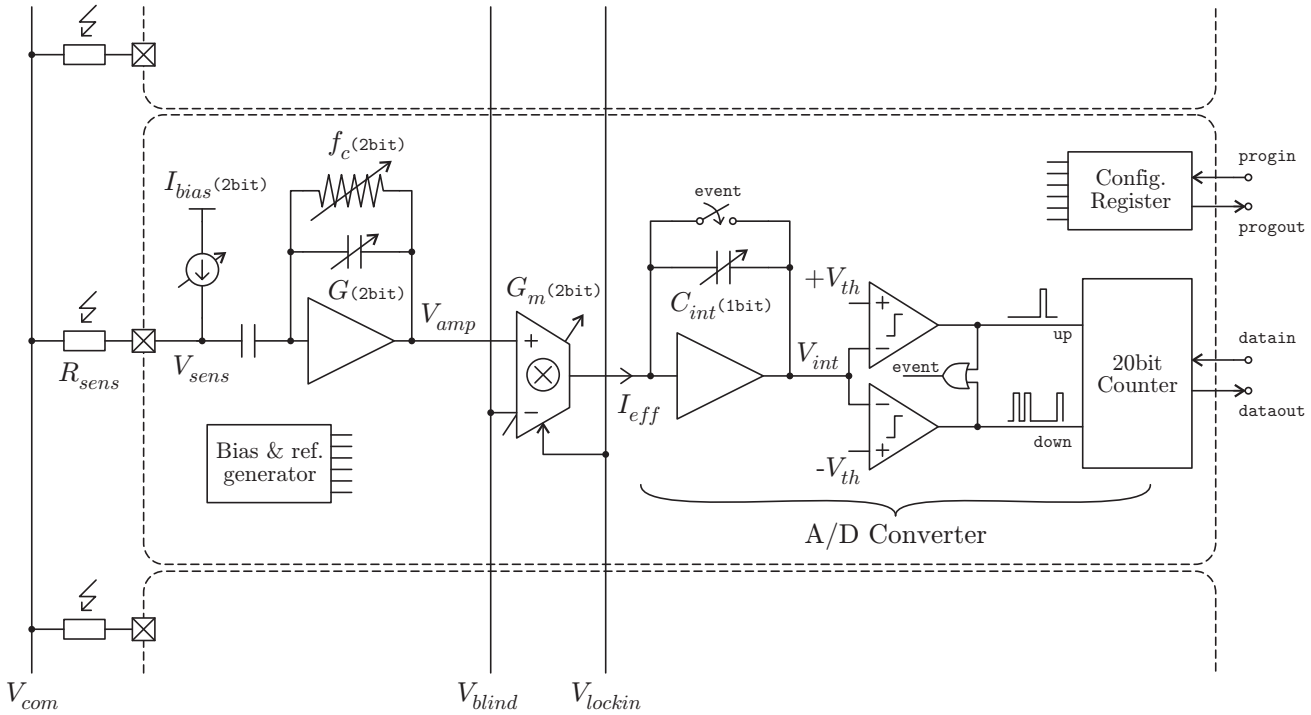
# Introduction

- Real-time **gas recognition** for environmental monitoring, toxic gas detection...
- **IR spectroscopic** absorption digital fingerprint
- Thermal $\mu$bolometer 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

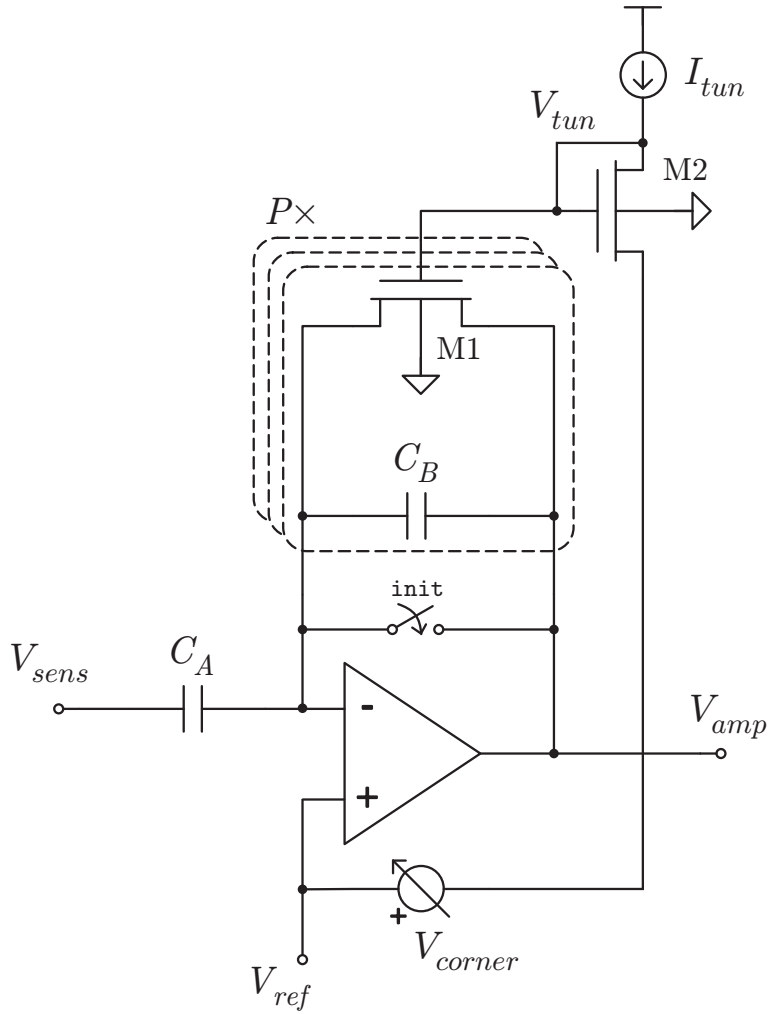
- **Highly linear** cap amplifier:

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

- **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



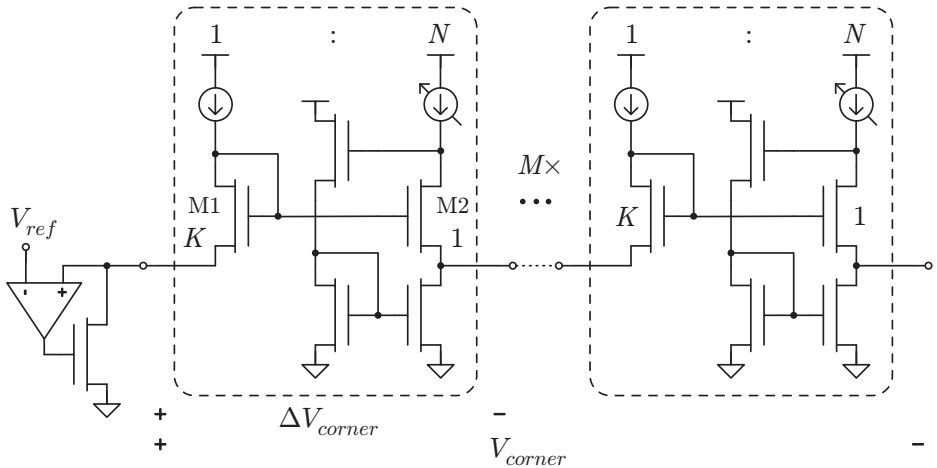
# Pre-Amplification and Filtering

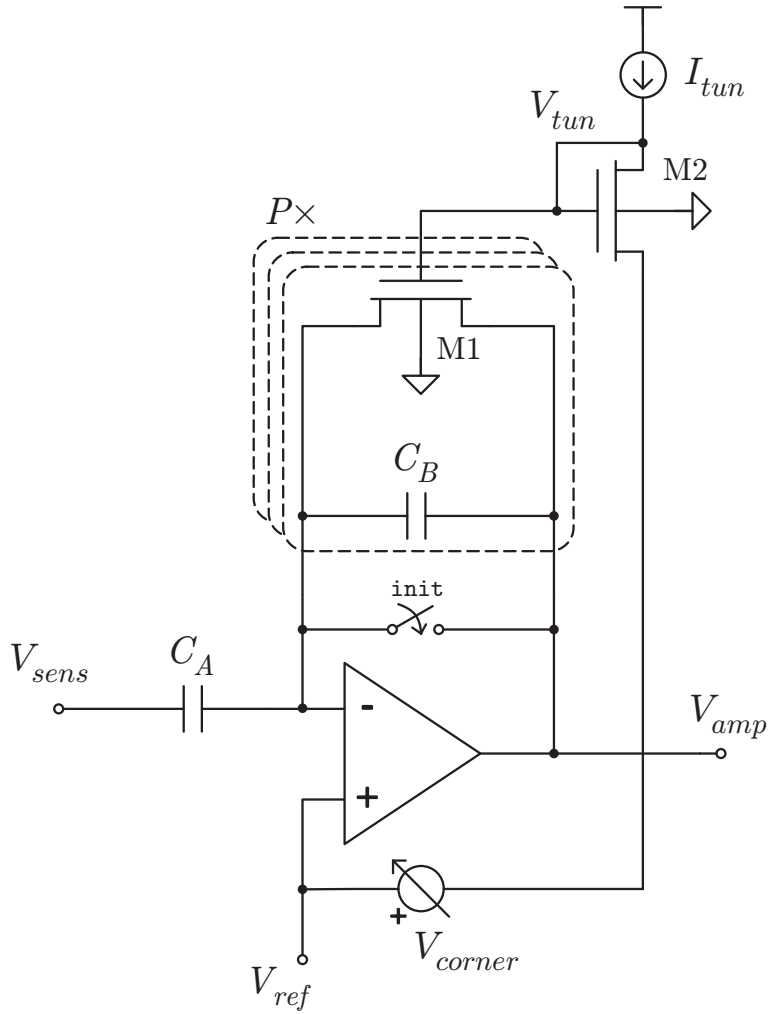
- Gain tuning by $P$ **scaling**
- **Multi-decade** filter log tuning:

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

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

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



# Blind Cancellation and Lock-in Demodulation

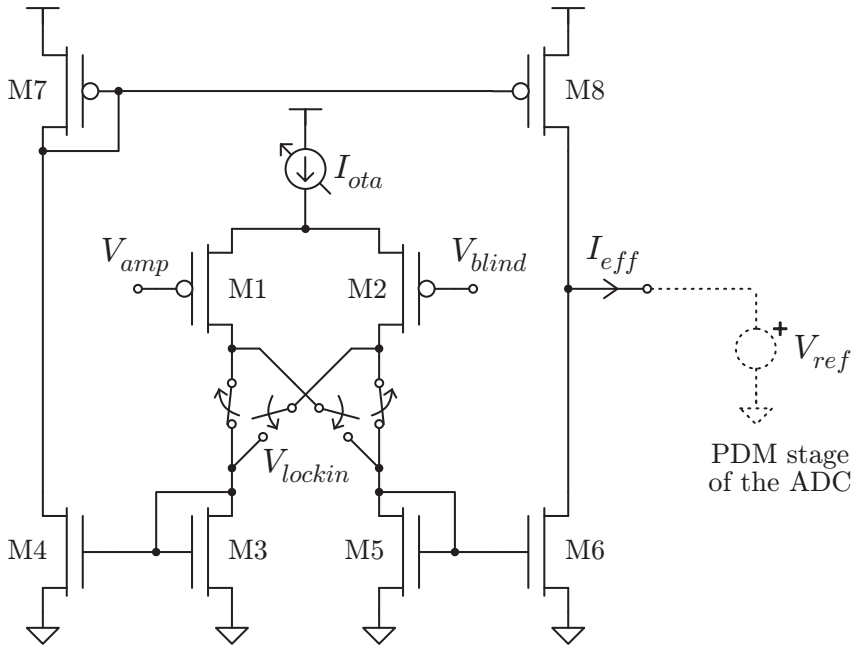
- Differential to **single ended**
- Voltage-to-**current** conversion
- **Lock-in** demodulation

- Low-power subthreshold **OTA**:

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

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

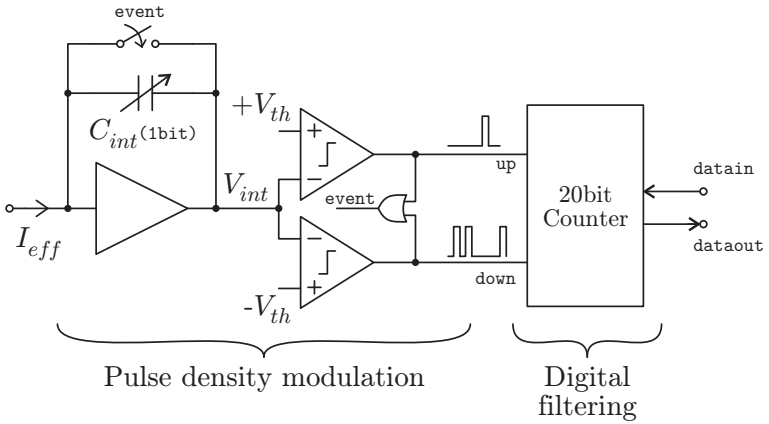
- **Current-domain** lock-in demodulation by cross-coupling
- Voltage log compression allows **fast switching** at low-power




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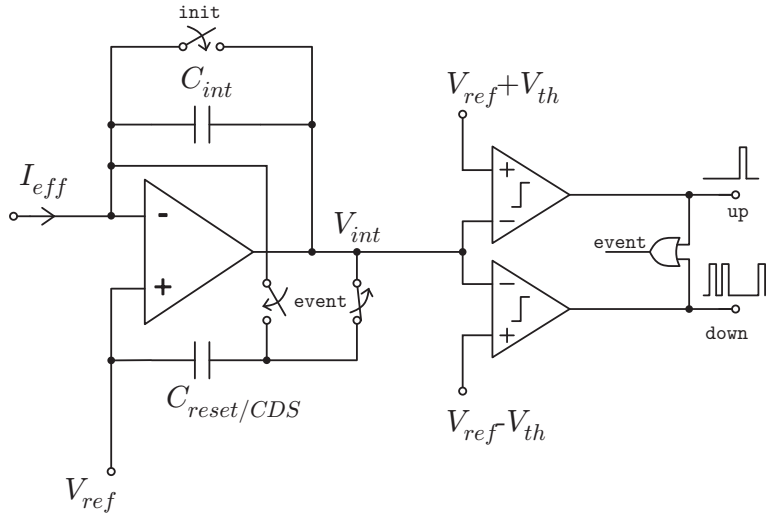
$$f_{PDM} = \frac{I_{eff}}{C_{int}\, V_{th}}$$



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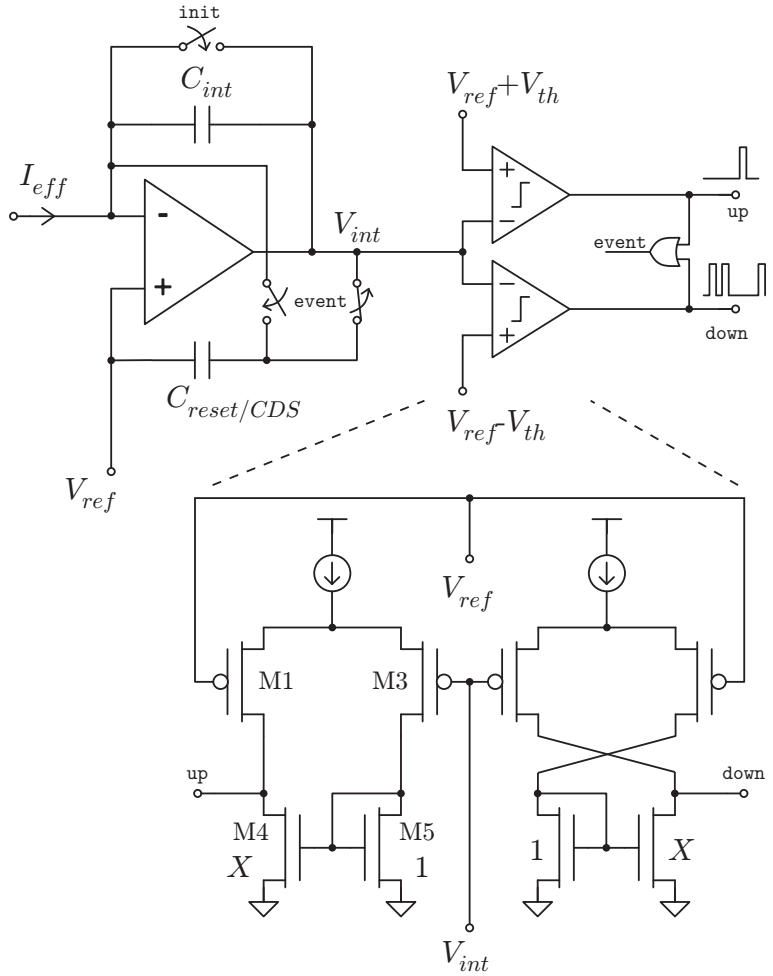
- **Built-in** threshold comparator:

$$V_{th} = n U_t \ln X$$

- **Thermal compensation** of $G_m$:

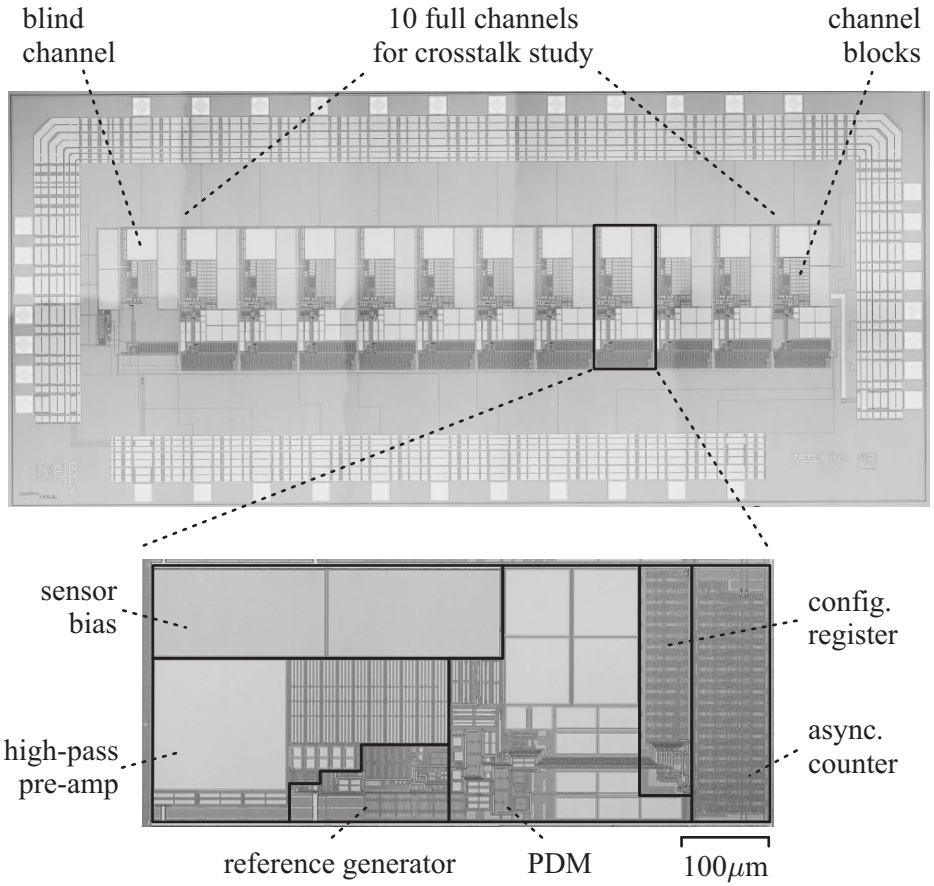
$$q_{adc} = \lfloor n_{adc} \rfloor \qquad n_{adc} = T_{samp} f_{PDM} = \frac{C_A}{C_B} \frac{G_m}{V_{th}} \frac{T_{samp}}{C_{int}} \Delta R_{sens}$$



# CMOS Integration and Experimental Results

- 0.35$\mu$m 2P4M CMOS channel module **test chip**
- Main **design parameters**:

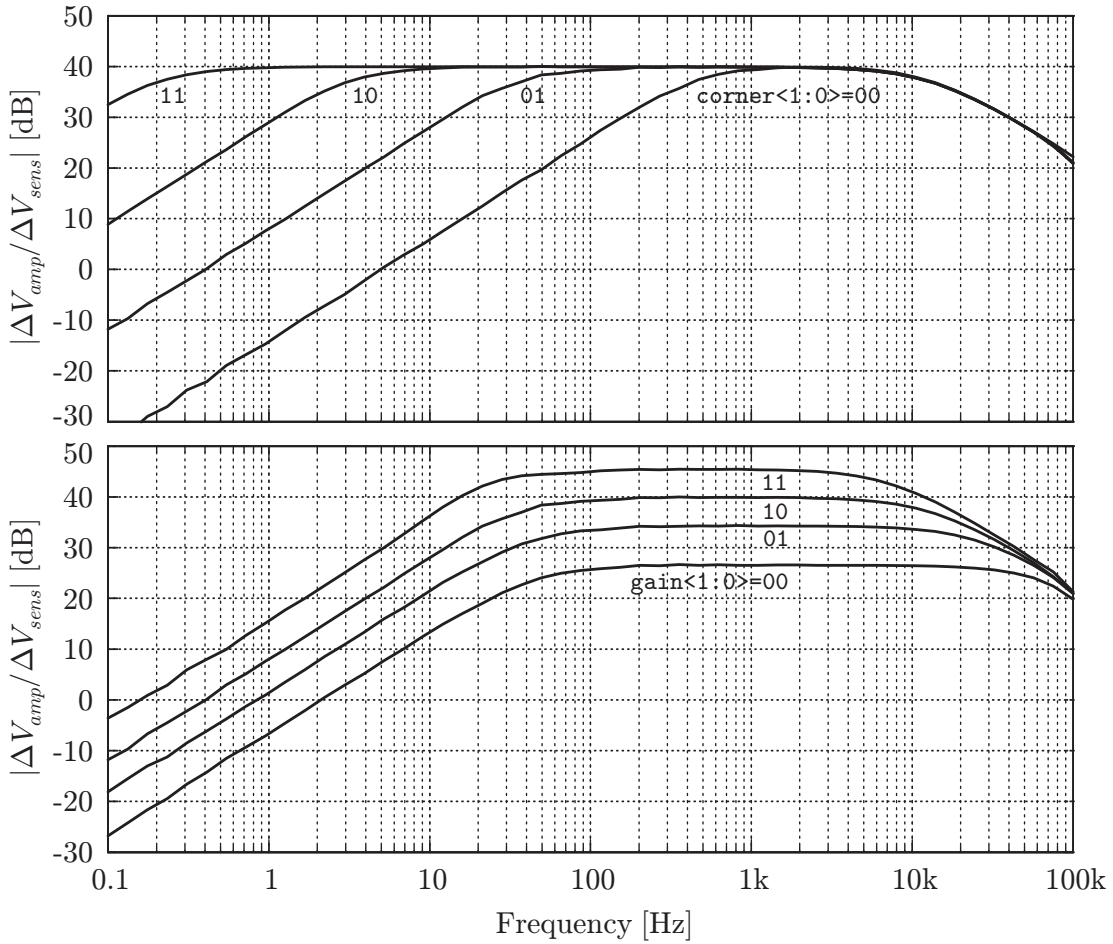
$$C_A = 20\text{pF}$$
$$C_B = \{0.1, 0.2, 0.4, 1\}\text{pF}$$
$$K = 10$$
$$N = \{1, 11\}$$
$$M = 3$$
$$I_{tun} = 100\text{nA}$$
$$I_{ota} = \{1, 2, 5, 10\}\mu\text{A}$$
$$V_{th} = 120\text{mV}$$
$$T_{pulse} = 500\text{ns}$$




- Access to **intermediate stages**

# CMOS Integration and Experimental Results

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



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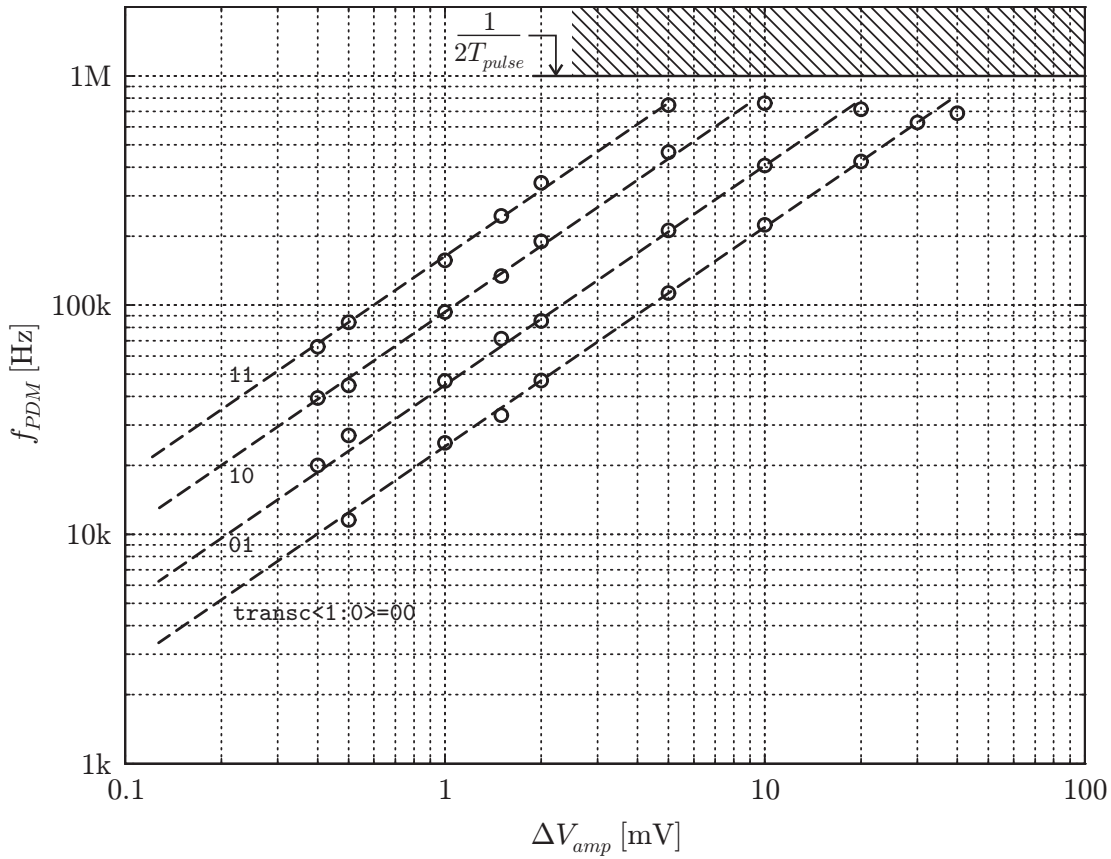
- Highly linear **PDM** up to pulse width hard limit




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) | $\mu$A |
| 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) | $\mu$S |
| 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 $R_{sens}$=300k$\Omega$ | (100) | $\text{nV}_{\text{rms}}/\sqrt{\text{Hz}}$ |
| Supply voltage | 3.3 | V |
| Supply current | 100 | $\mu$A |
| Silicon area | 300$\times$715 | $\mu\text{m}^2$ |

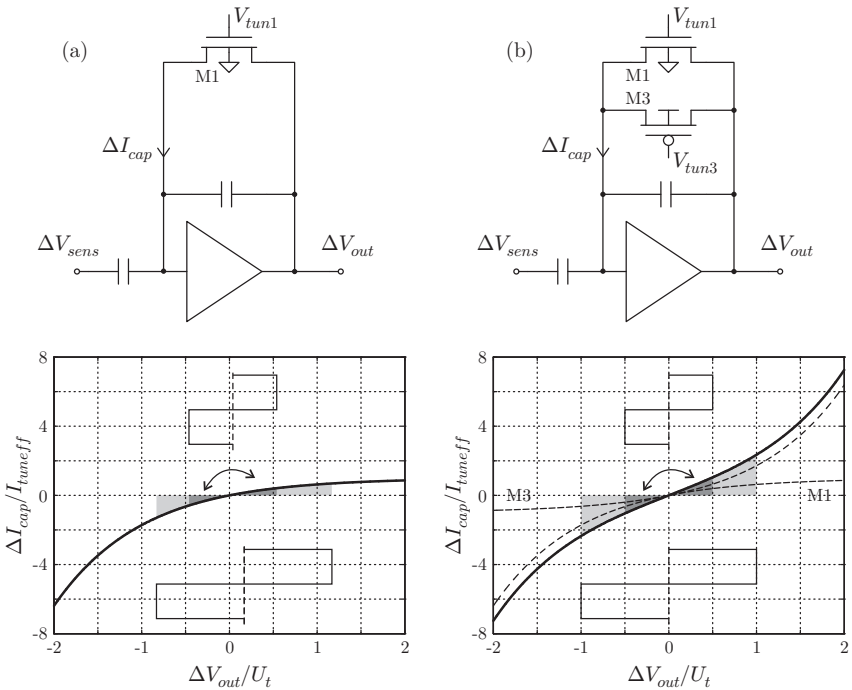
# Conclusions

- **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** ($100\mu$A) and **compact** ($0.2\text{mm}^2$) channel module in $0.35\mu$m 2P4M CMOS technology
- Experimental results **agree** with simulated performance
- **No-crosstalk** reported between channels

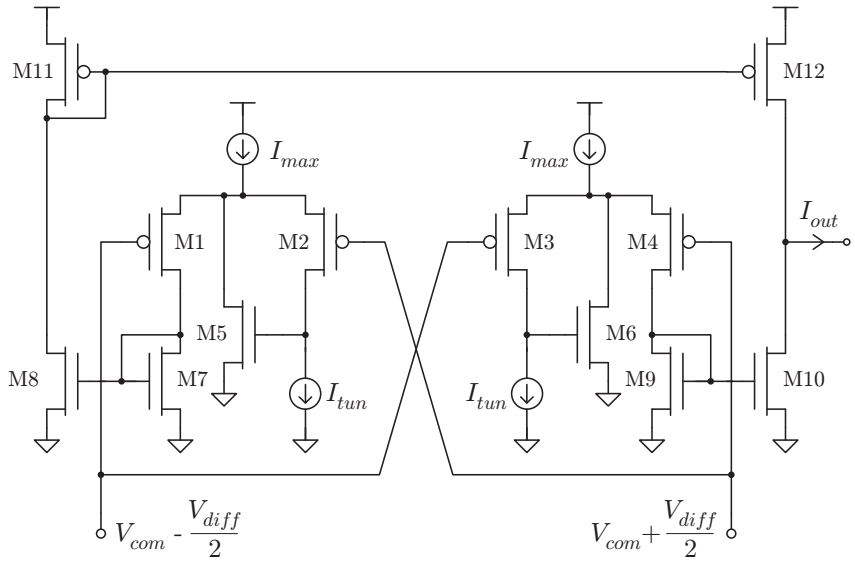
**. . . thanks for your attention!**

# Improvements?

- Pre-amplifier dynamic offset




- OTA linear range




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