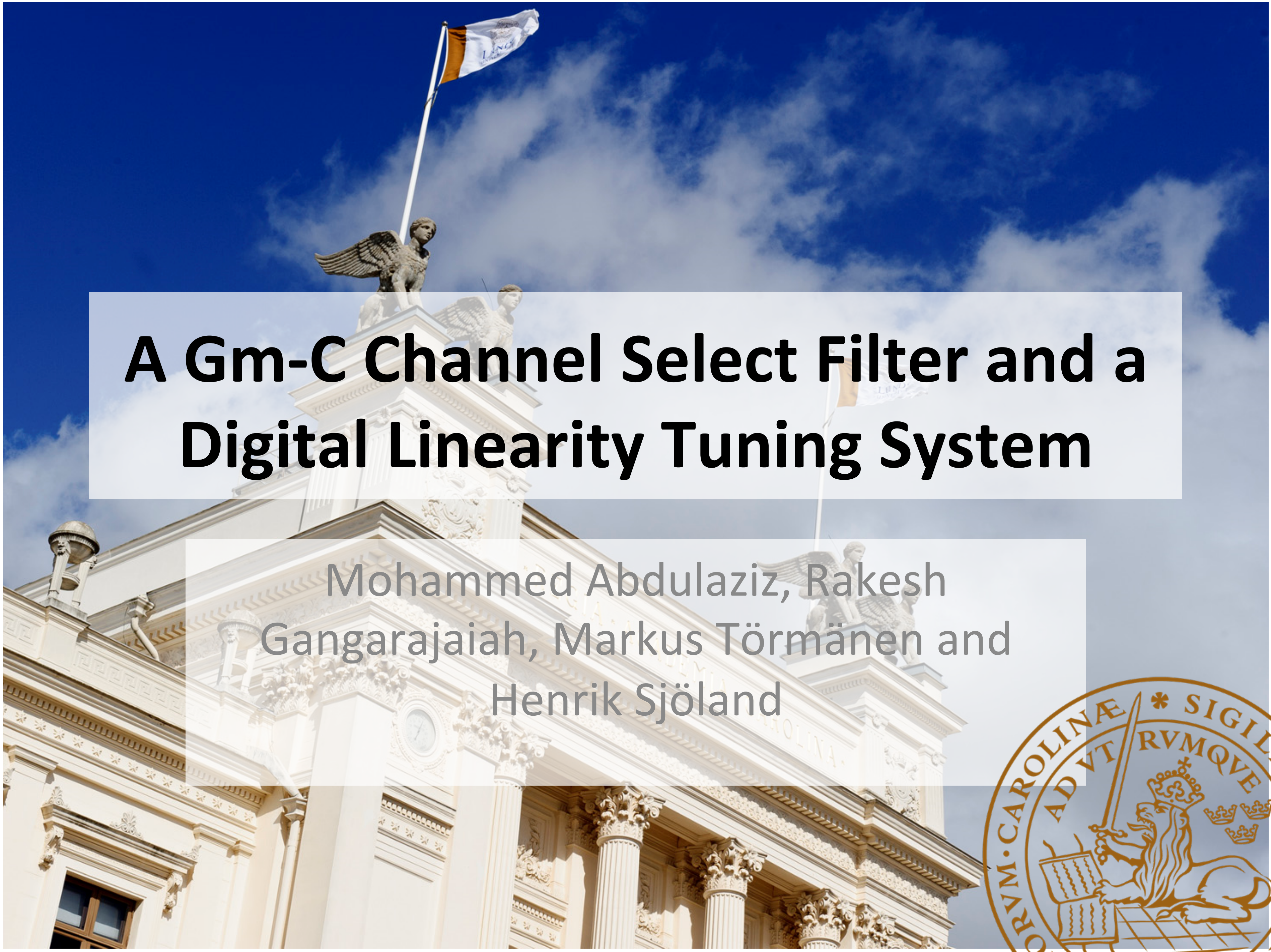

# A Gm-C Channel Select Filter and a Digital Linearity Tuning System

Mohammed Abdulaziz, Rakesh Gangarajaiah, Markus Törmänen and Henrik Sjöland

# Outline

- Motivation
- System Linearization
- OTA Design
- Gm-C Filter
- Simulations and Measurements
- Non Linearity tuning algorithm

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# Motivation

- Analog design in advanced CMOS nodes:
  - Voltage headroom 
  - Intrinsic gain 
  - Higher $f_T$ 
- Gm-C filters:
  - Noise 
  - Frequency 
  - Linearity 

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# System Linearization

- Feedback
  - Stability 
  - High loop gain 
  - Robust 
- Cancelation
  - Power efficient 
  - High linearity 
  - Adaptive tuning 

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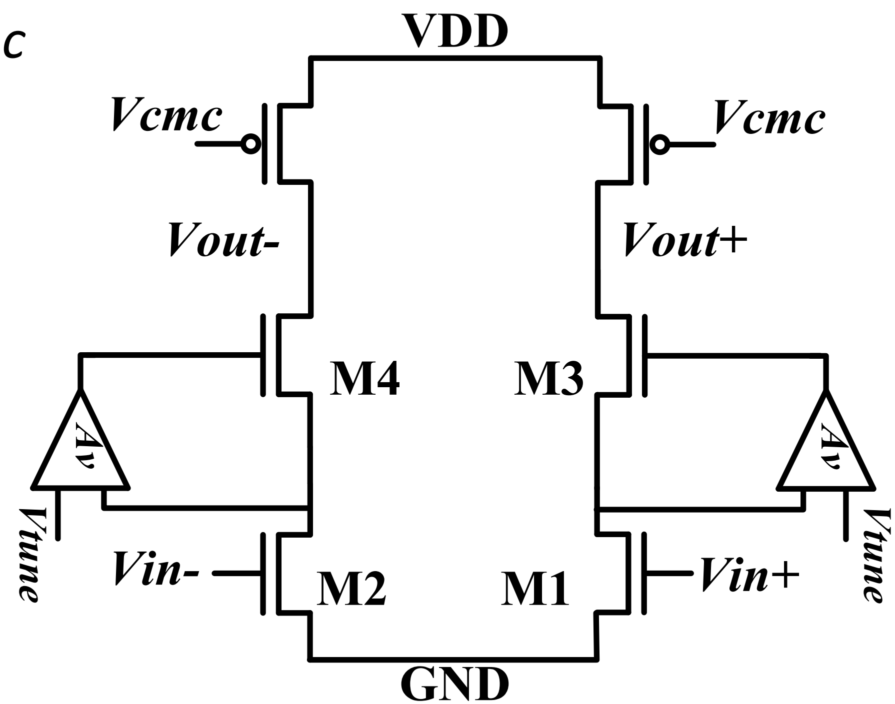
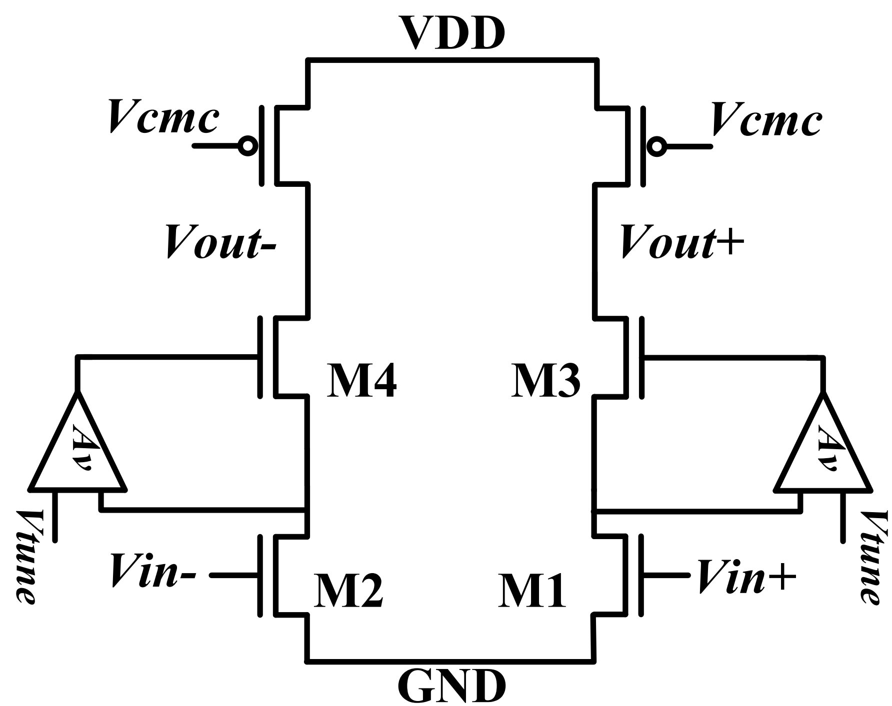
# Triode Transconductance Amplifier (OTA)-1

- Suitable for medium $\omega_c$
- Constant $V_{ds}$ OTA
  [Pennok, EL 1985]
  $i_D \simeq (a_0 + a_1 \cdot v_{in}) \cdot (V_{DS})$
  - $Av$↑HD↓
  - Stability
  - High gain
  - Power consumption



# Triode Transconductance Amplifier (OTA)-2

- New CMOS technology (short channel MOS, thin oxide..)
  - $M_{1,2}$ generate own nonlinearities.
    $i_D \simeq (a_0 + a_1 \cdot v_{in} + a_2 \cdot v_{in}^2 - a_3 \cdot v_{in}^3 + \ldots) \cdot (V_{DS})$
  - Constant $V_{ds}$ has not much effect.



# Triode Transconductance Amplifier (OTA)-3

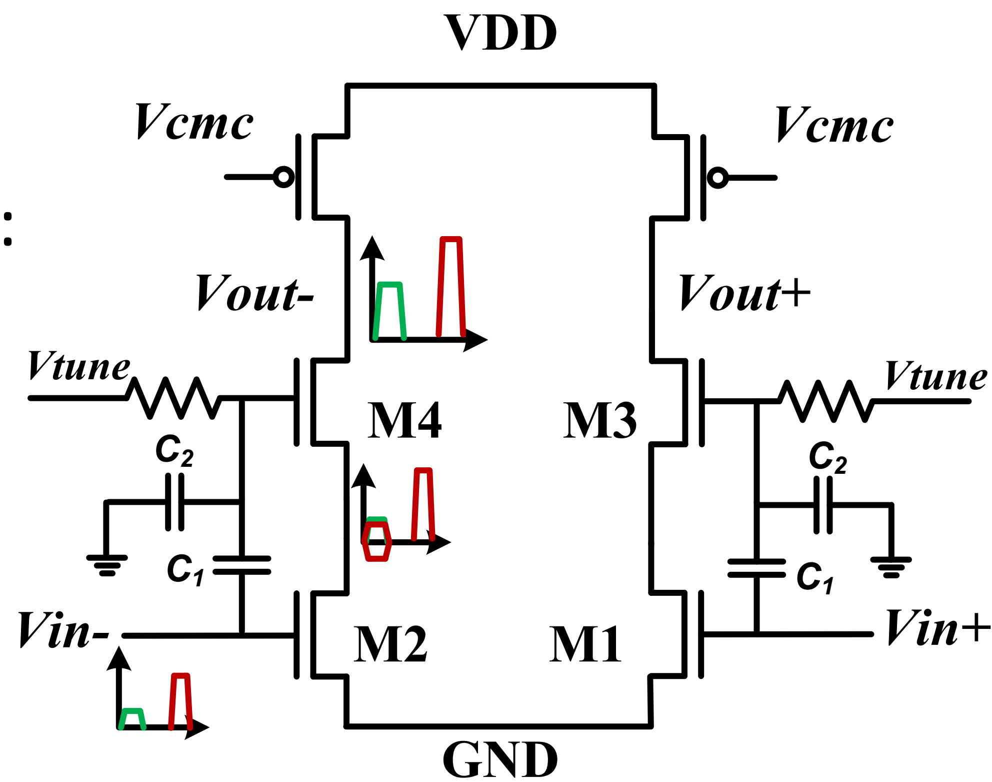
- Feed forward *Vin* to $M_{3,4}$:
  - If α is the attenuation:

    $$i_D \simeq (a_0 + a_1 \cdot v_{in} + a_2 \cdot v_{in}^2 - a_3 \cdot v_{in}^3 + \dots) \cdot (V_{DS} + \alpha \cdot vin)$$

  - IM3 is canceled if:

    $$a_3 \cdot V_{DS} = a_2 \cdot \alpha$$

  - *Vtune* is a control voltage



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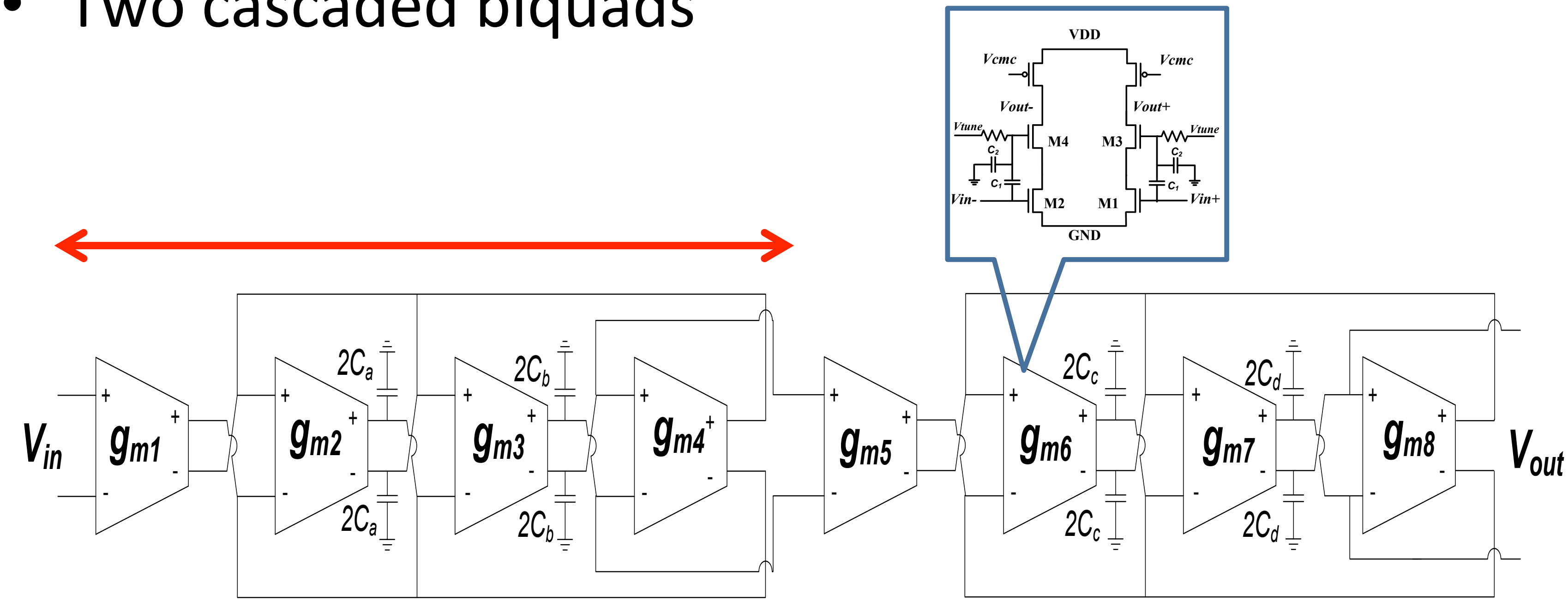
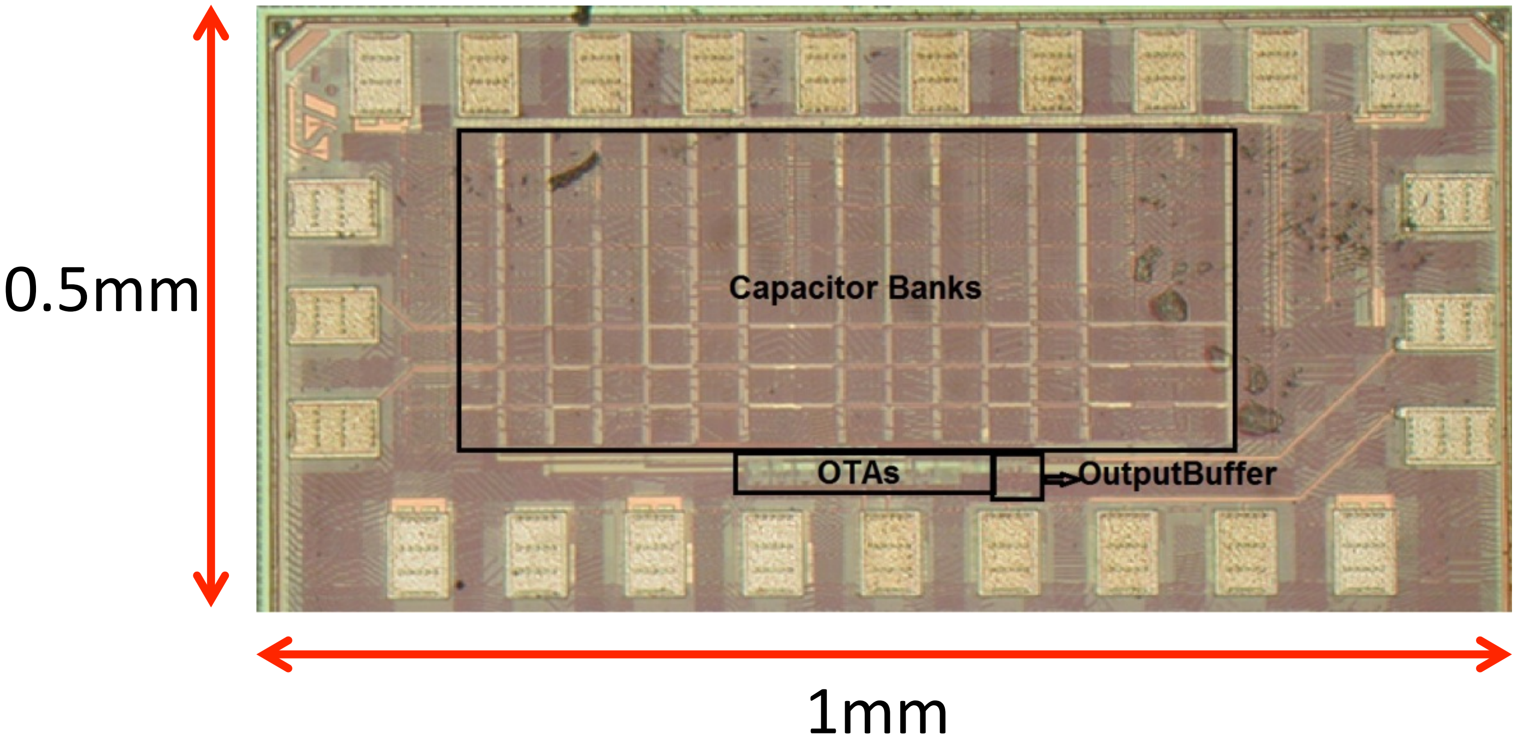
# 4th Order Gm-C Filter

- Two cascaded biquads



# Implementation

- $4^{th}$ Order Butterworth implemented in 65nm CMOS.
- All transistors are digital with no extra options.



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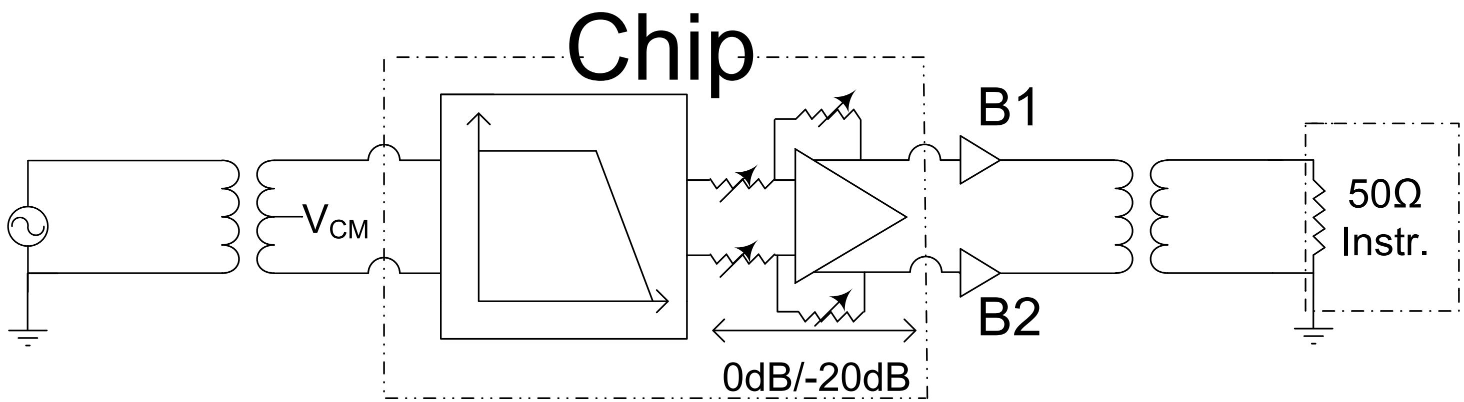
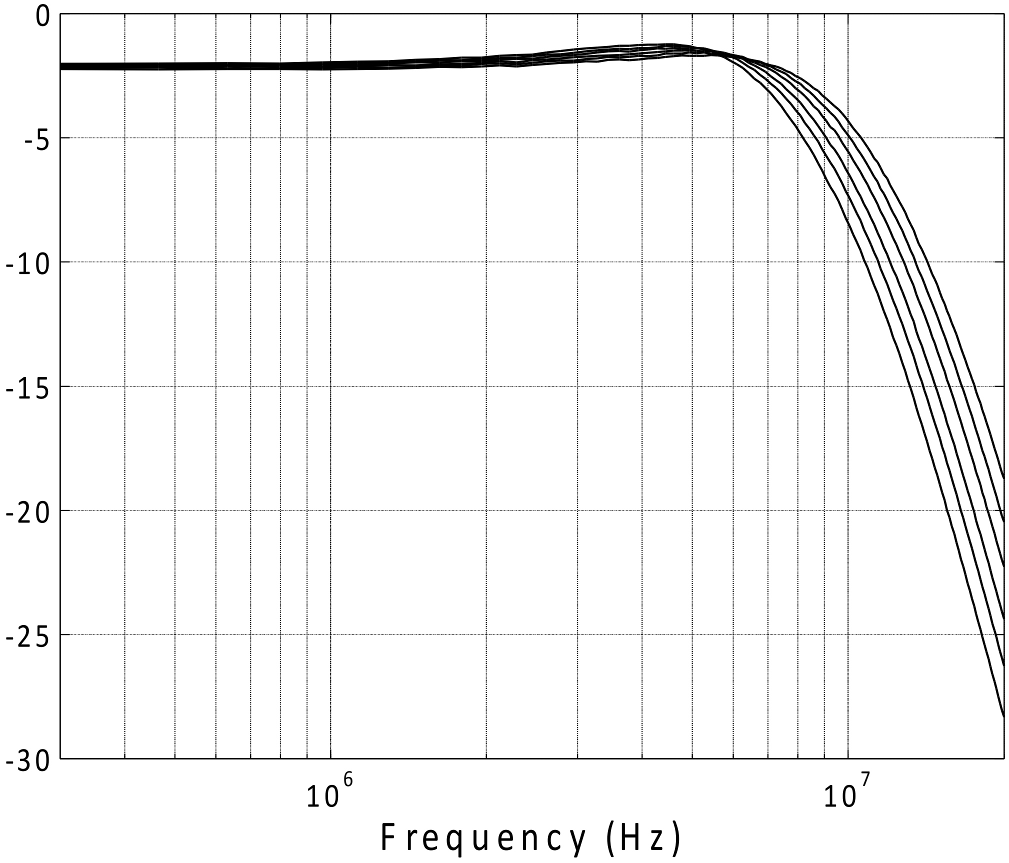
# Simulations and Measurement

- 0/20dB attenuation output buffer.
- Very low IM3 levels undetectable.



# Response

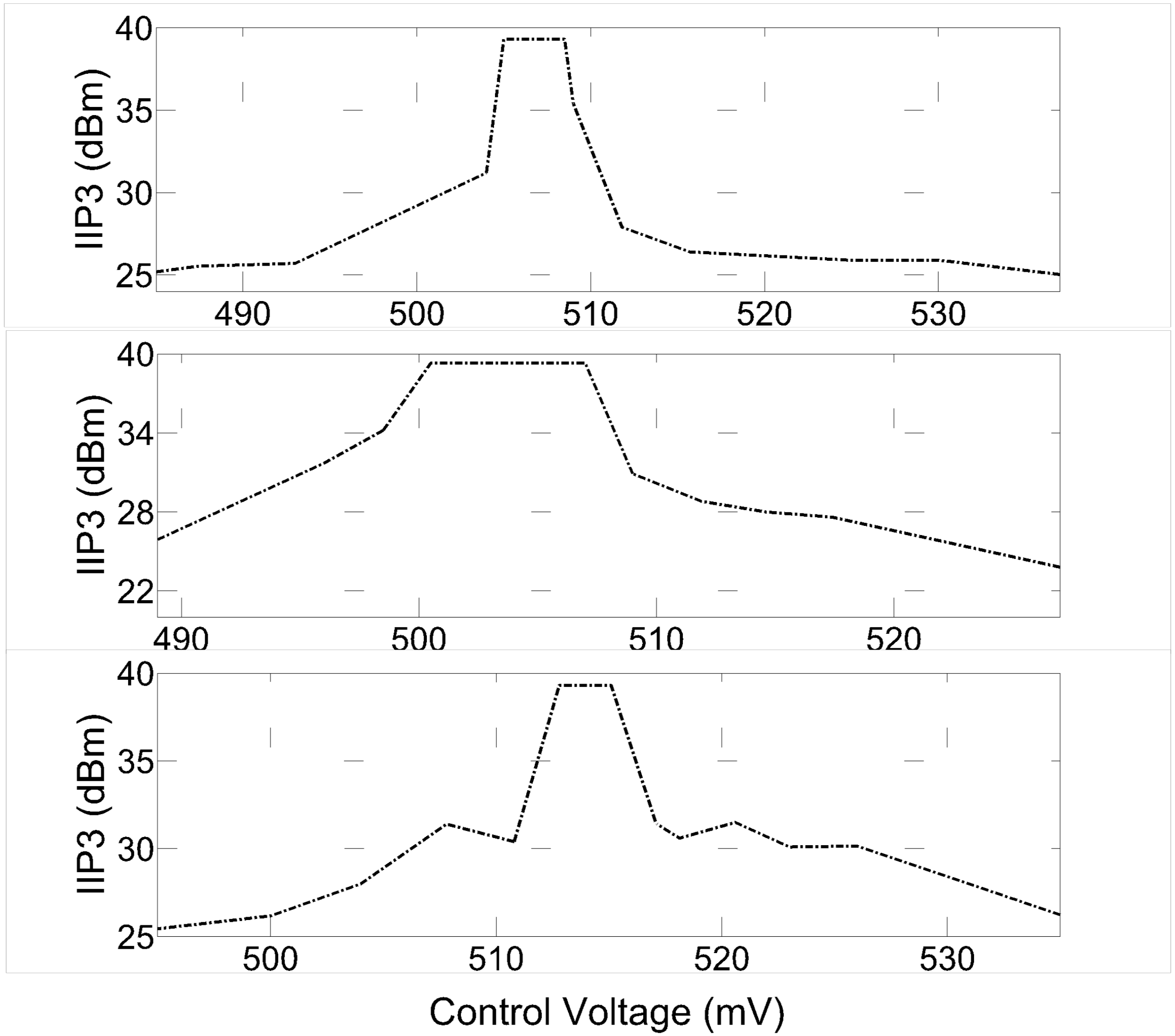


# IIP3 vs. temp

0C°

40C°

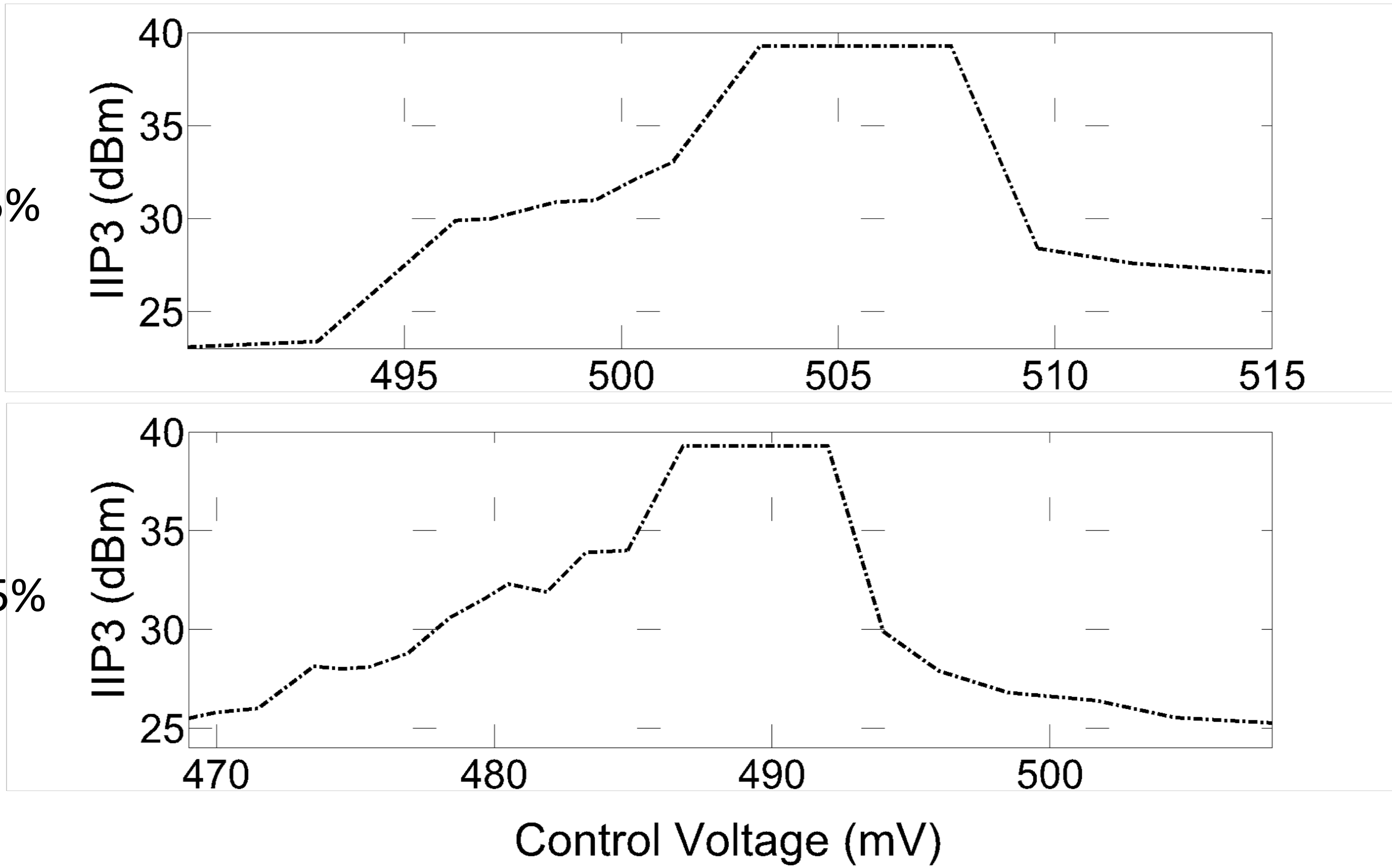
80C°



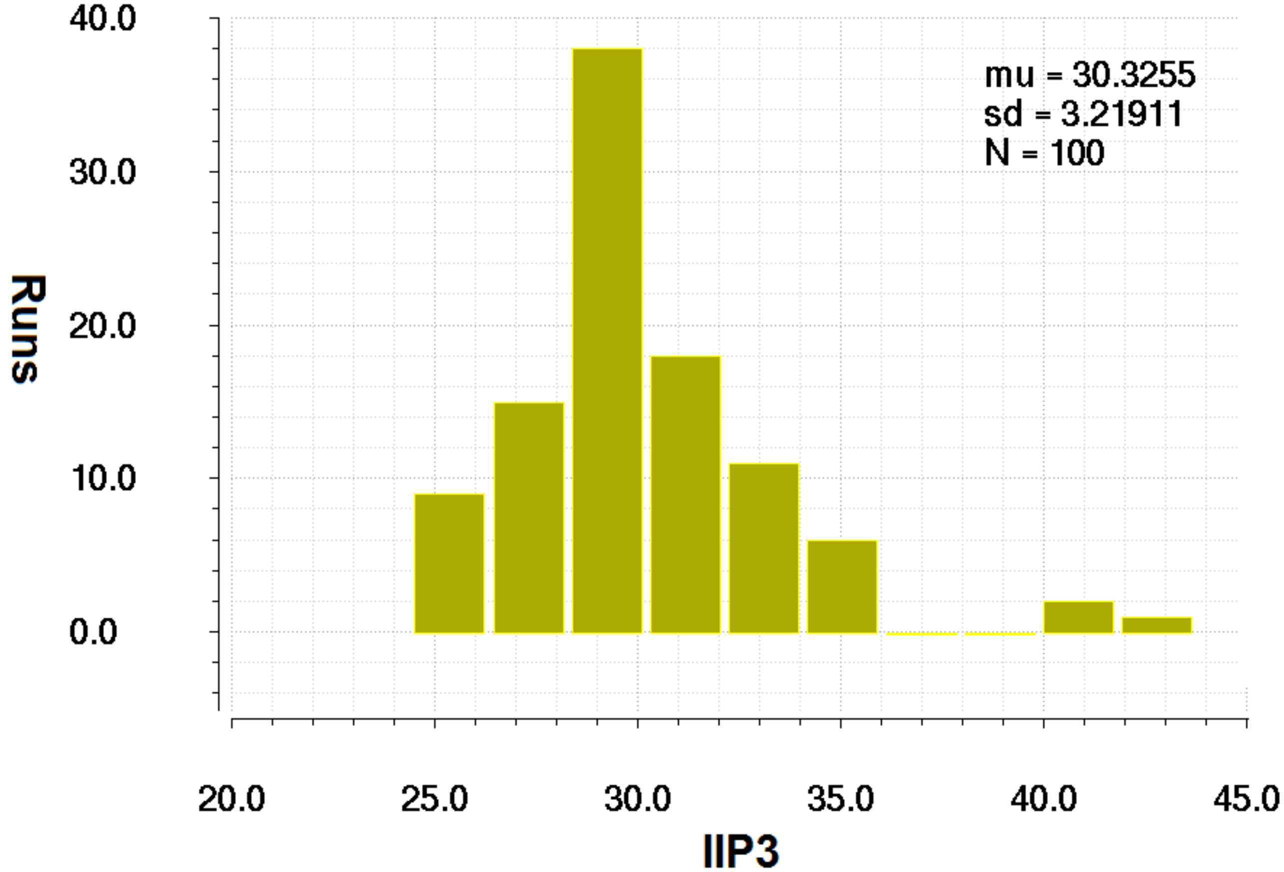
# IIP3 vs. VDD variation

VDD-5%

VDD+5%



# Mismatch and process variation




Control voltage is used to tune the IIP3 back

# Performance summary

TABLE I
COMPARISON WITH OTHER WORKS

| Parameter | JSSC'10 [5] | ISSCC'12 [6] | JSSC'11 [7] | This Work |
|---|---|---|---|---|
| Tech. (nm) | 90 | 90 | 90 | 65 |
| Area ($mm^2$) | 0.23 | 0.29 | 0.239 | 0.19 |
| Order | $4^{th}$ | $4^{th}$ | $6^{th}$ | $4^{th}$ |
| Supply (V) | 2.5 | 0.55-0.9 | 1 | 1.2 |
| Power (mW) | 1.26 | 2.9-19.1 | 4.35 | 4.2 |
| Bandwidth (MHz) | 2.8 | 7-30 | 13.5 | 10 |
| IIP3 (dBm) * | 10 | - | 22.1 | 39.3 |
| IIP3 (dBm) ** | 36 | - | 18.9 | 34 |
| Noise (nV/$\sqrt{Hz}$) | 19 | 23.7-32.8 | 75 | 31.3 |
| SFDR (dB) * | 58 | 67.6 | 53.4 | 70.9 |
| SFDR (dB) ** | 75 | - | 51.4 | 67.4 |
| FoM (dB) * | -157.5 | -167.4 | -156 | -170.8 |
| FoM (dB) ** | -174 | - | -154 | -167.2 |

*In-band **Out-of-band

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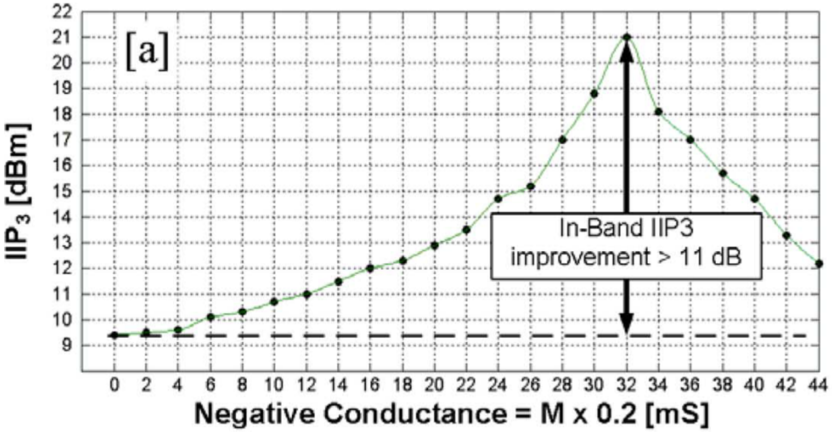
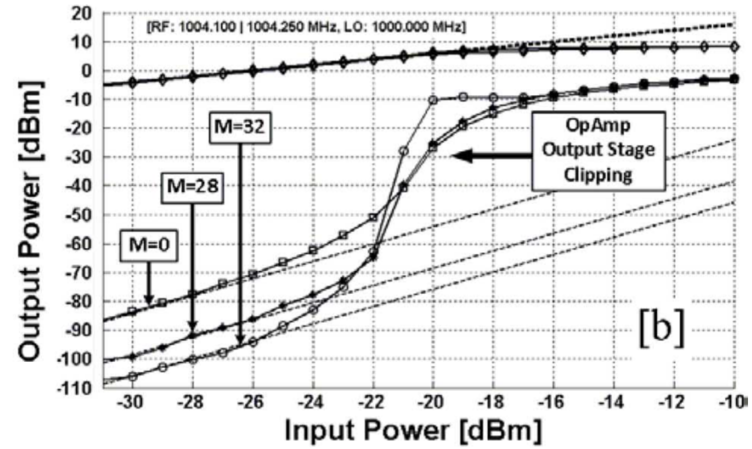
# What's next?

- Good enough vs. Optimal.

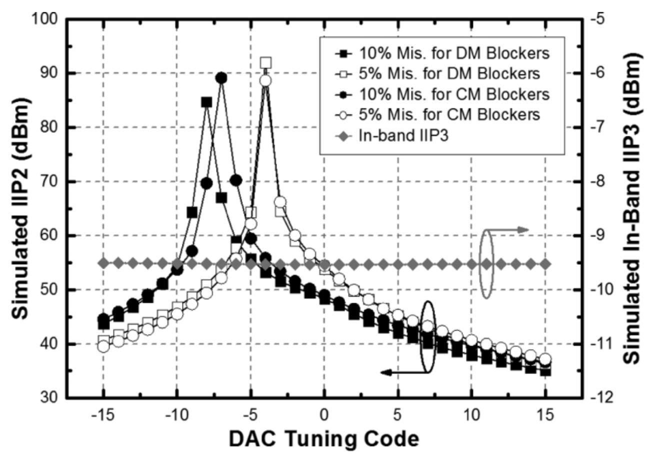
- Tuning algorithm:
  - Fast.
  - Background.
  - Less frequent calibration.

# Sweet spot

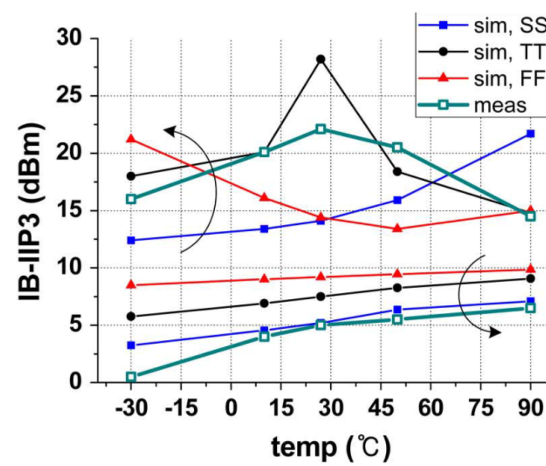



[MAHROF *et al.*, JSSC 2014]

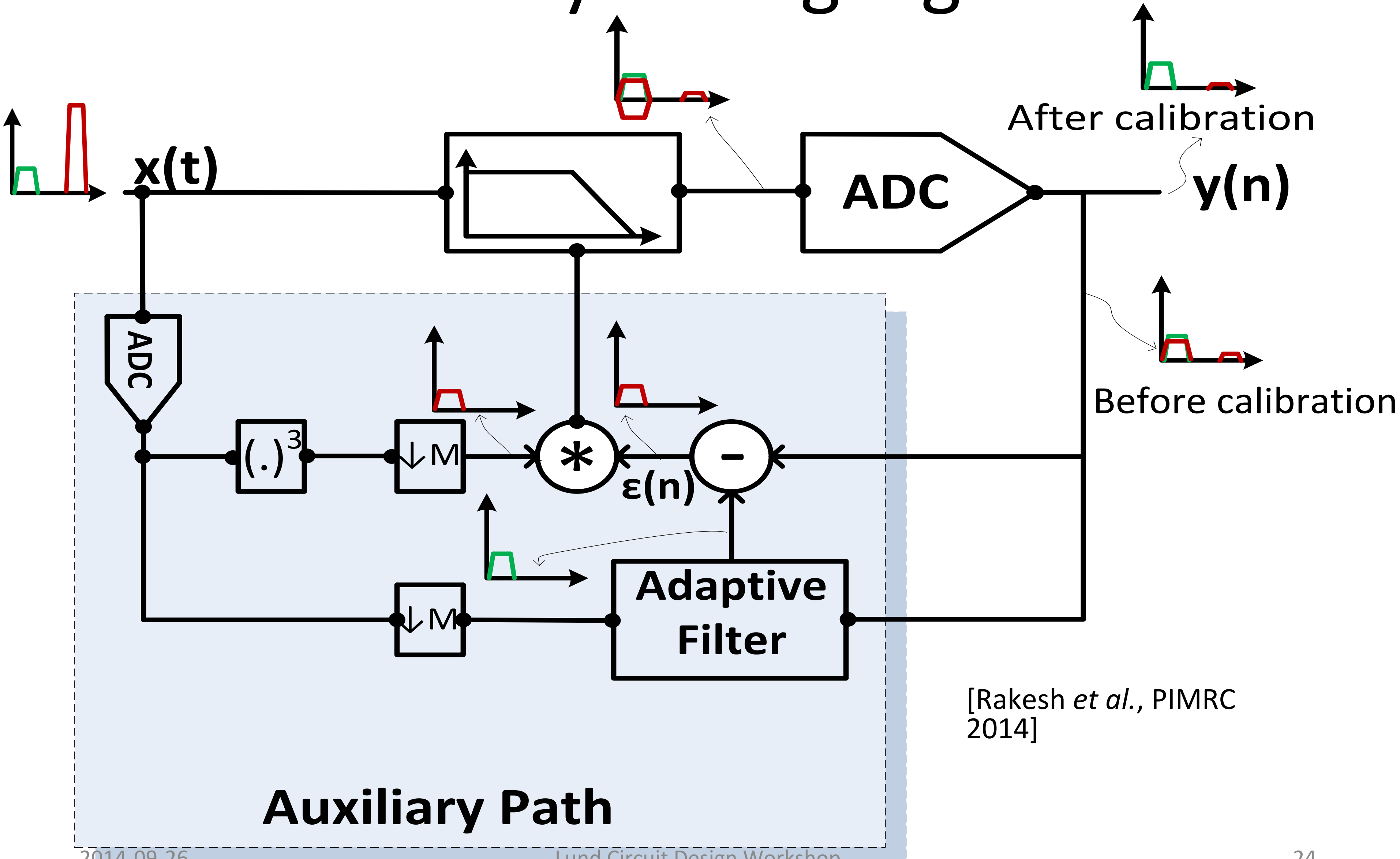



[HAN AND KWON, TCAS I 2014]



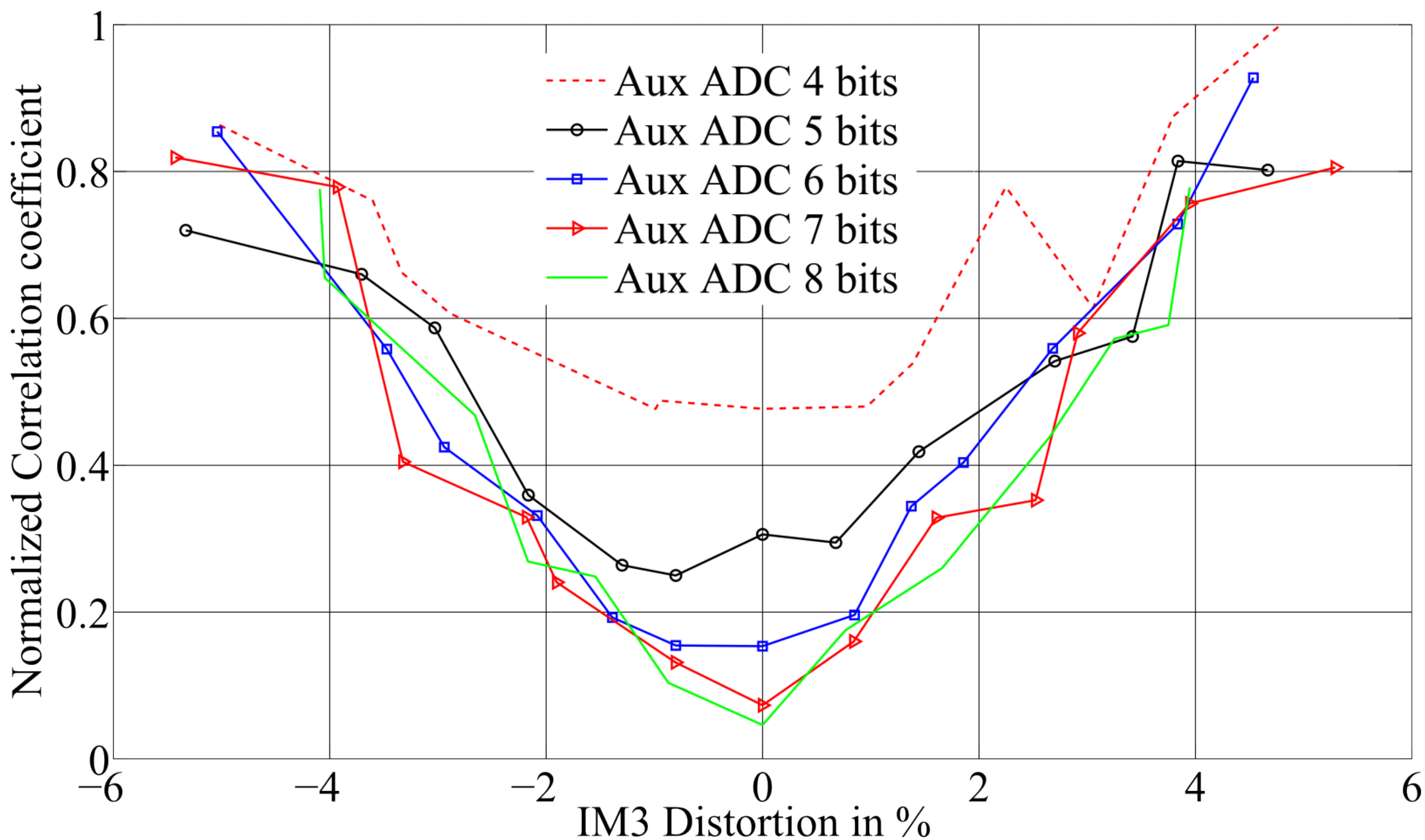

[Kim *et al.*, JSSC 2014]

# Non Linearity tuning algorithm-1

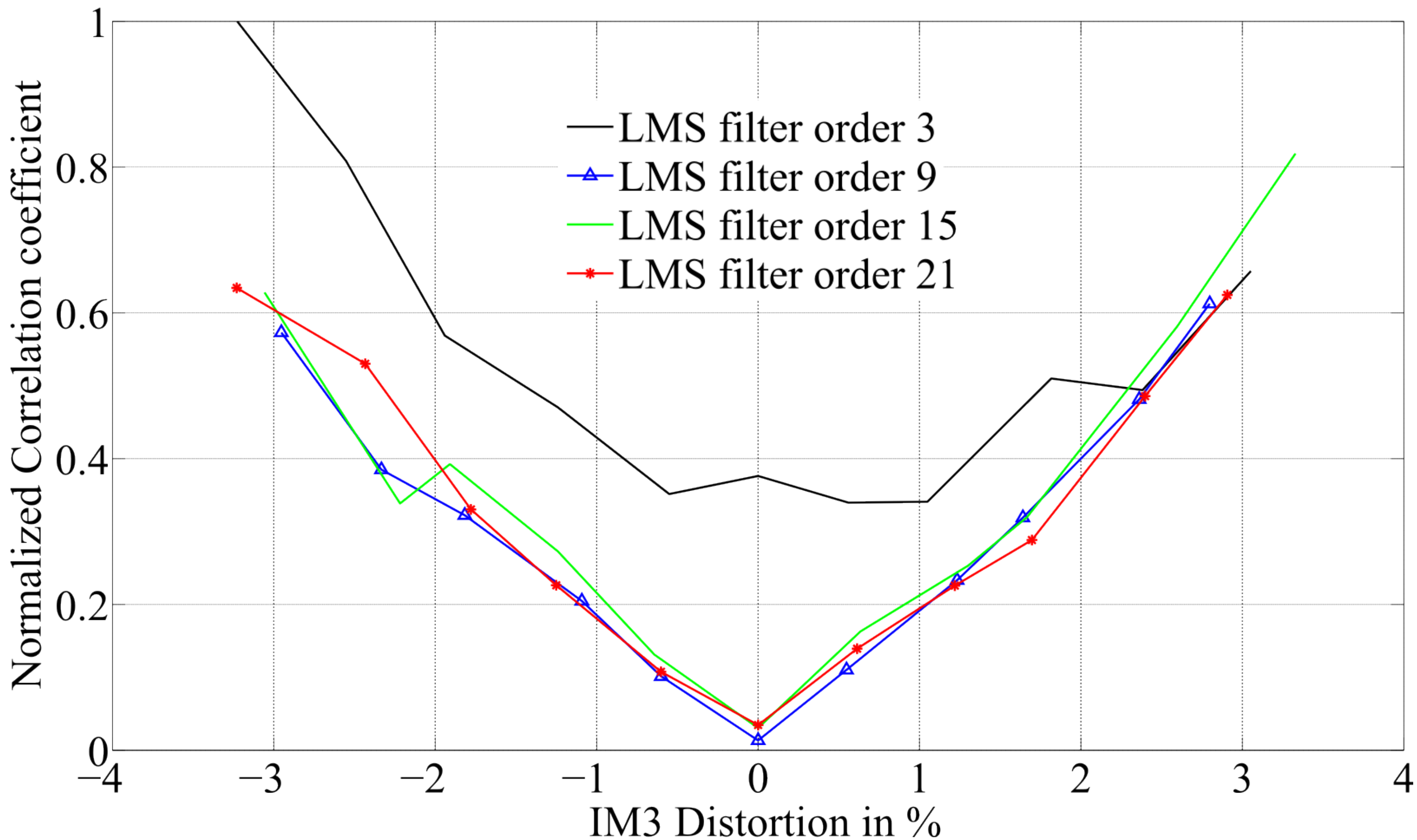



[Rakesh *et al.*, PIMRC 2014]

# Simulations-1



# Simulations-2



# Conclusions

- A 4th order Gm-C filter with 10MHz bandwidth is presented.
- A nonlinearity  cancelation scheme was used to improve the OTA's linearity.
- For robust linearity, adaptive tuning algorithm is presented.
- Simulations show that the overhead of the algorithm is minimized.
- Tuning algorithm can be used to tune any component in the Rx chain.

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# Thank you!

LUND UNIVERSITY