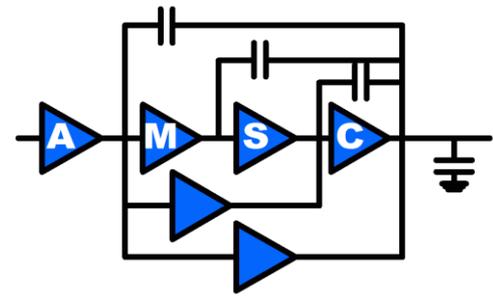


ECEN 622
Fall'13
Edgar Sánchez-Sinencio



LOW COST, LOW POWER, MULTI-STANDARD Flexible Baseband Filter

This material has been provided by [Hesam Amir-Aslanzadeh](#)

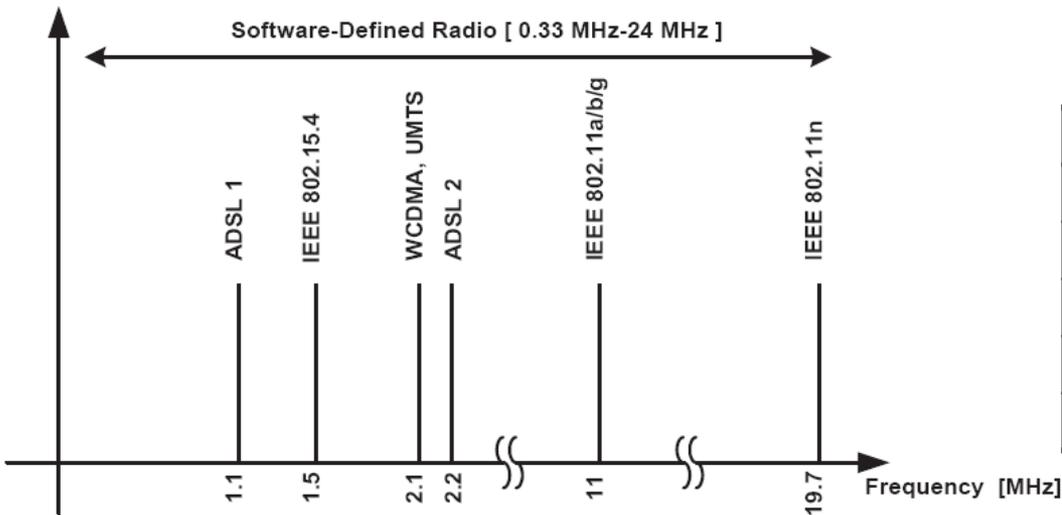
Analog and Mixed Signal Center
Department of Electrical and Computer Engineering
Texas A&M University

Flexible Baseband Filter

- Analog baseband filter for multi-standard or software-defined radios
 - Digitally assisted filters
 - Programmable BW
 - Selectable Type (filter approximation)
 - Selectable order
 - Highly linear
 - Adjustable power

. Motivation

- Multi-standard applications
- IP reuse
- Variety of applications in 1-20 MHz range

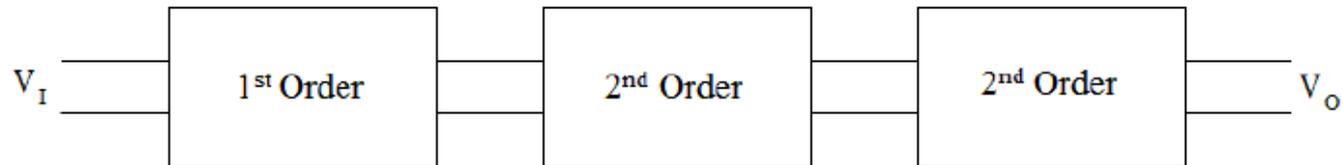


Standard	BW [MHz]	IIP3 [dBm]
Bluetooth	1	17.3
UMTS TDD	1.28	18.4
UMTS FDD	3.84	20.42
DVB-H	7.6	17.9
WLAN 802.11a/b/g/n	10/20	21.5

Key Filter Aspects

- System Level
 - Architecture
 - Stability Theory
- Circuit Level
 - Reconfiguration (type selection)
 - Continuous Frequency Tuning
 - Power Adjustable opamp
 - Low-voltage operation
- Layout level
 - Layout techniques to block cross-talks

. Cascaded Architecture

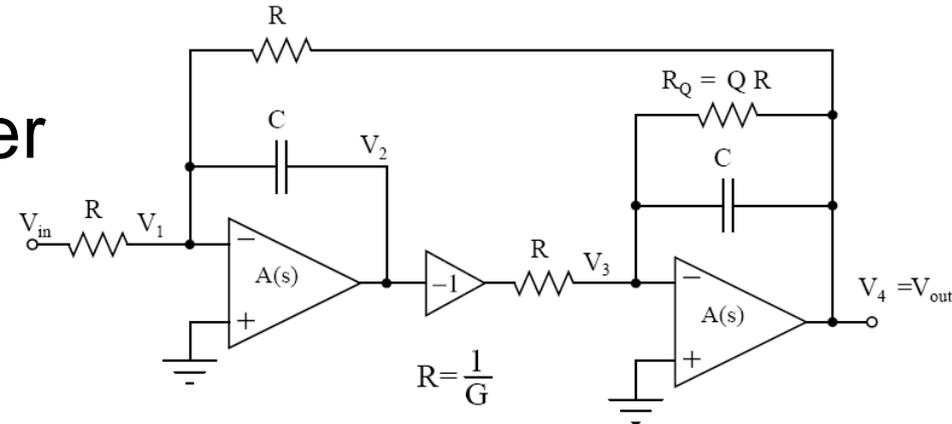


$$H_{tot}(s) = \frac{1}{\underbrace{\left(1 + \frac{s}{\omega_{o0}}\right)}_{1\text{st-order}}} \frac{\omega_{o1}^2}{\underbrace{\left(s^2 + \frac{\omega_{o1}}{Q}s + \omega_{o1}^2\right)}_{3\text{rd-order}}} \frac{\omega_{o2}^2}{\underbrace{\left(s^2 + \frac{\omega_{o2}}{Q}s + \omega_{o2}^2\right)}_{5\text{th-order}}}$$

- Cascaded architecture
 - Ease of tuning
- Three stages (1st, 3rd, 5th orders)
 - One mono
 - Two biquads

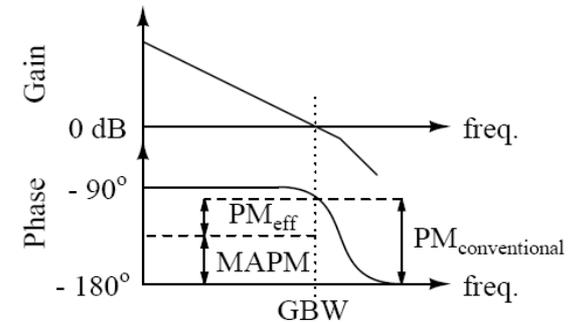
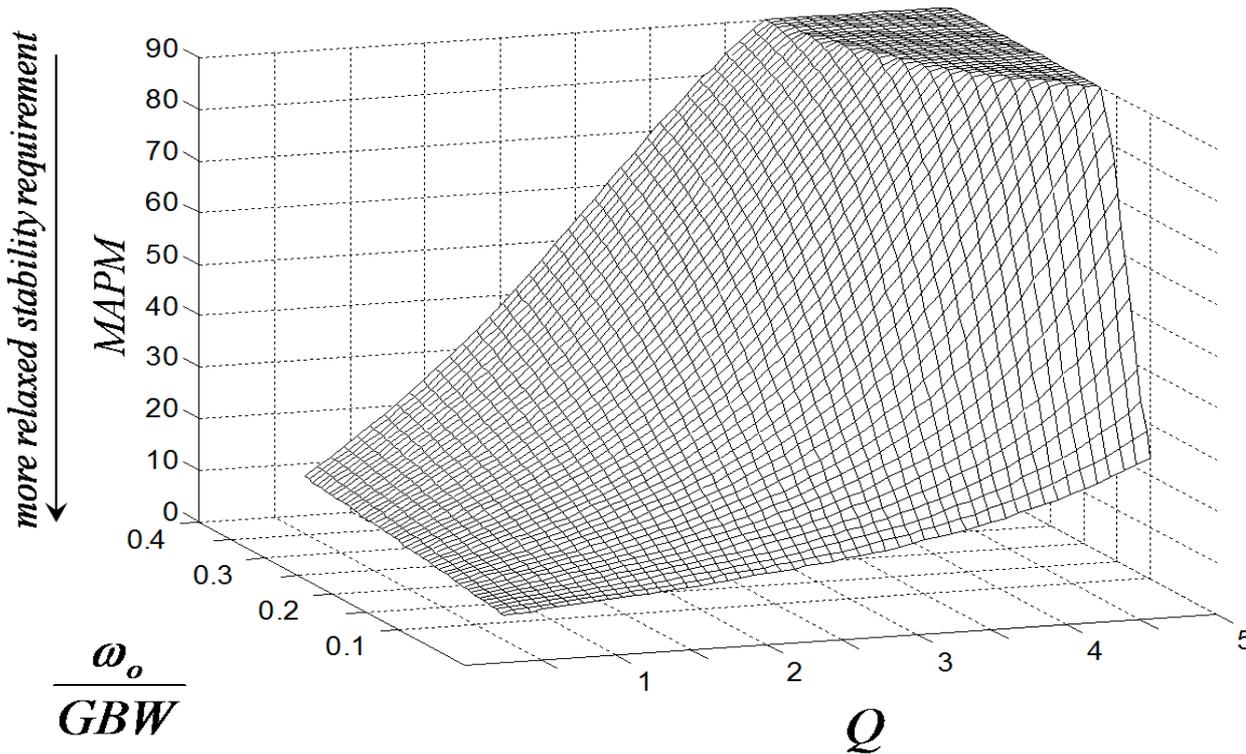
Stability Analysis

- Ensure stability of the filter
 - Through variation of
 - Biquad's bandwidth (ω_0)
 - Biquad's Quality factor (Q)
 - Opamp's GBW
 - Opamp's PM
- Analyzing the denominator of the transfer function



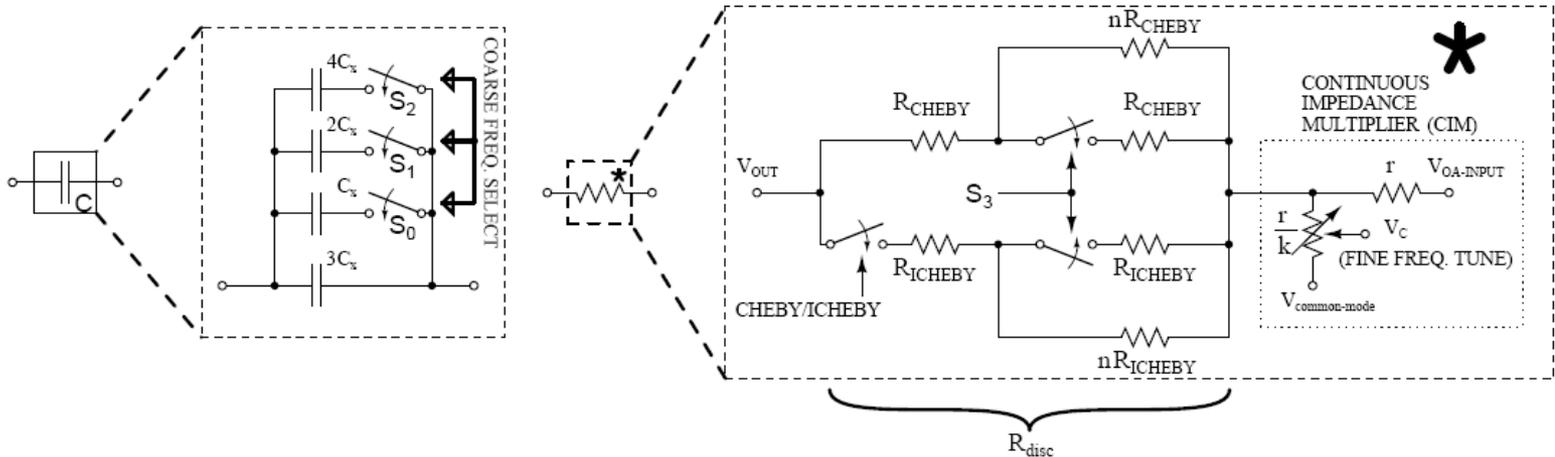
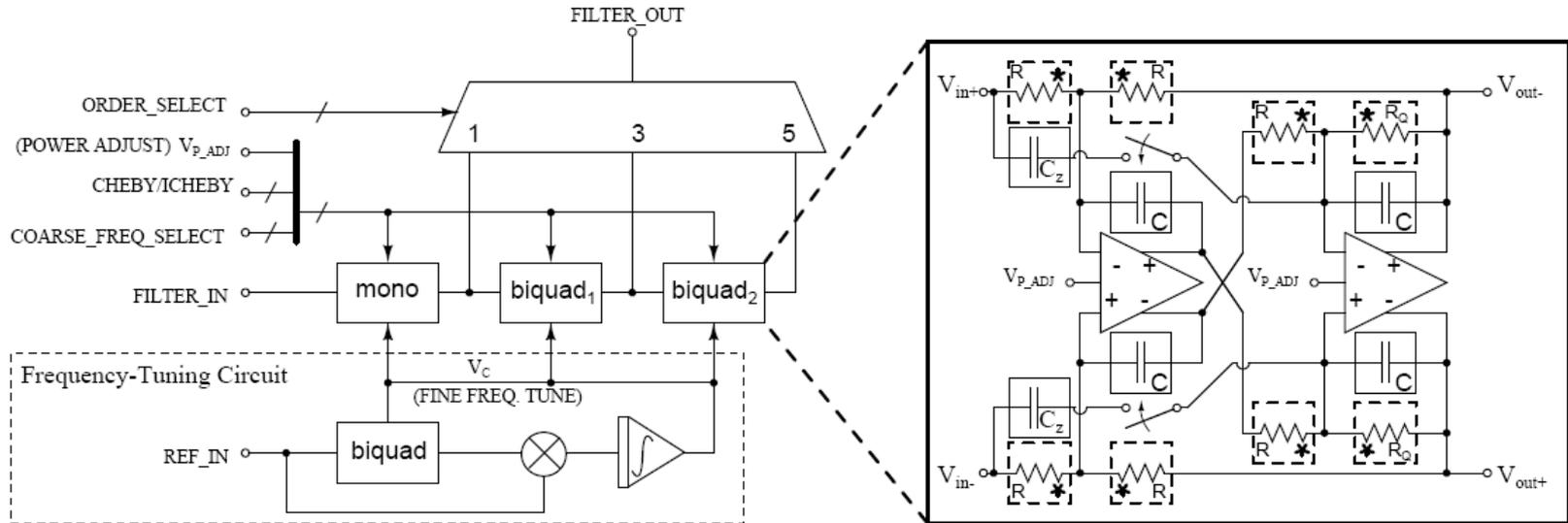
$$H_{biquad}(s) \equiv \frac{V_4}{V_{in}} = \frac{-G^2}{D_{tot}(s)}$$

Stability Theory



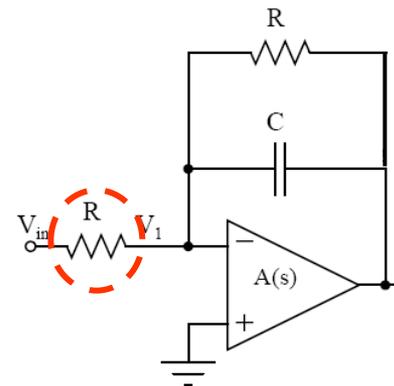
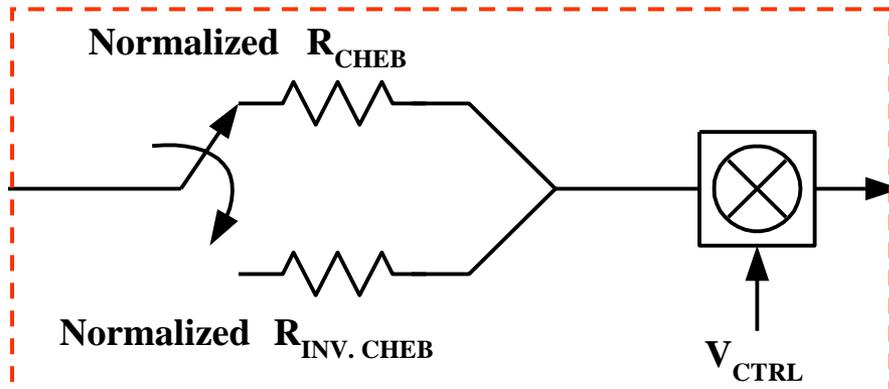
- MAPM increases with
 - Higher Q
 - Higher ω_0
 - Lower GBW
- With certain high Qs and higher ω_0/GBW , impossible stability

Overall Filter Architecture



Reconfiguration

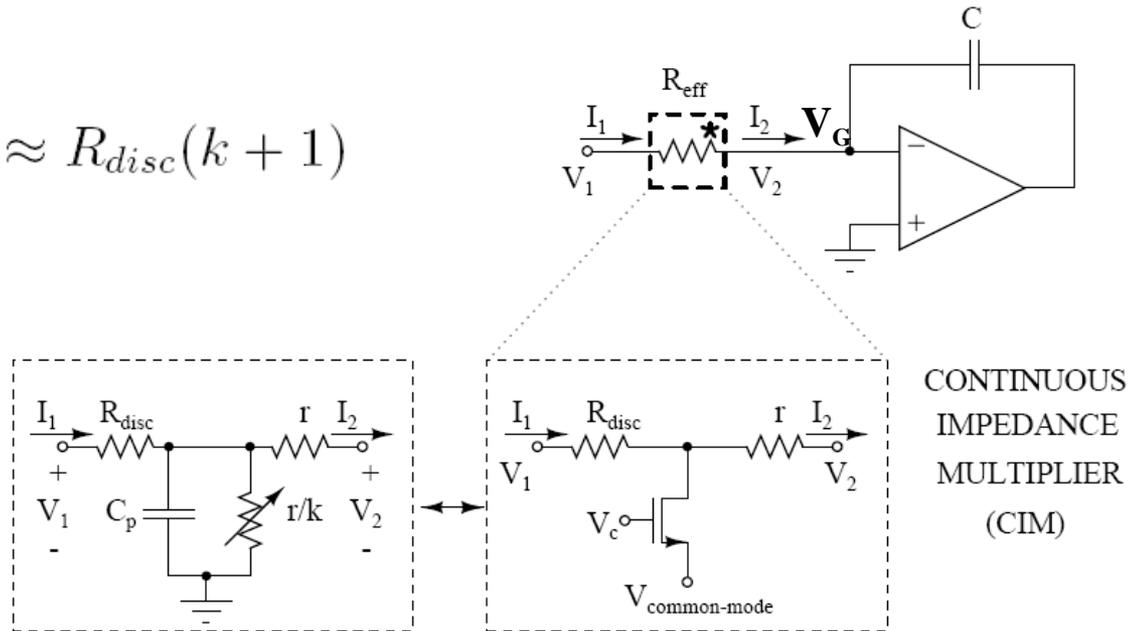
- Chebyshev vs. Inverse Chebyshev
- Normalized Filter
- Scale $R \Rightarrow$ Scale Frequency
- Adding zeros in Inverse Chebyshev
- Zeros will scale exactly with poles keeping a constant ratio



. Continuous Impedance Multiplier (CIM)

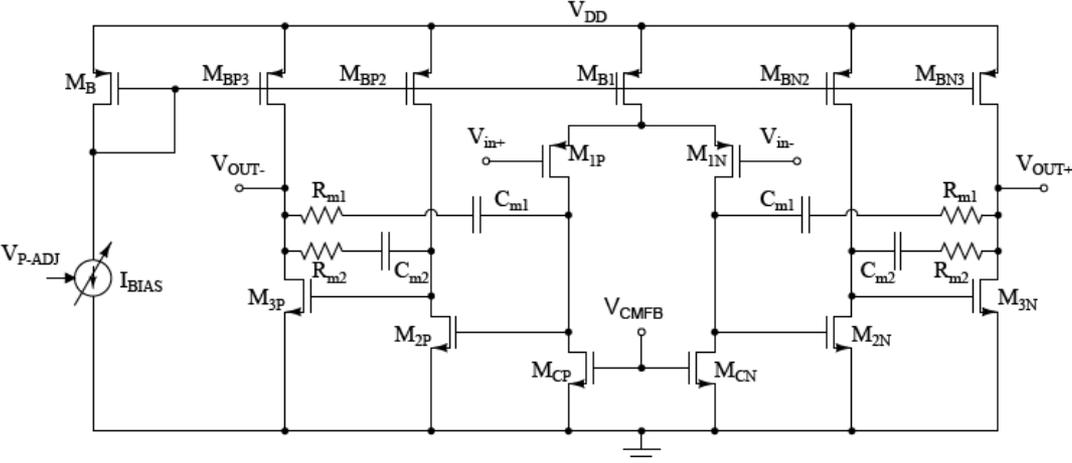
$$R_{eff} = \frac{V_1}{I_2} \approx R_{disc}(k + 1)$$

$$r \ll R_{Disc} \ll (sC_p)^{-1}$$

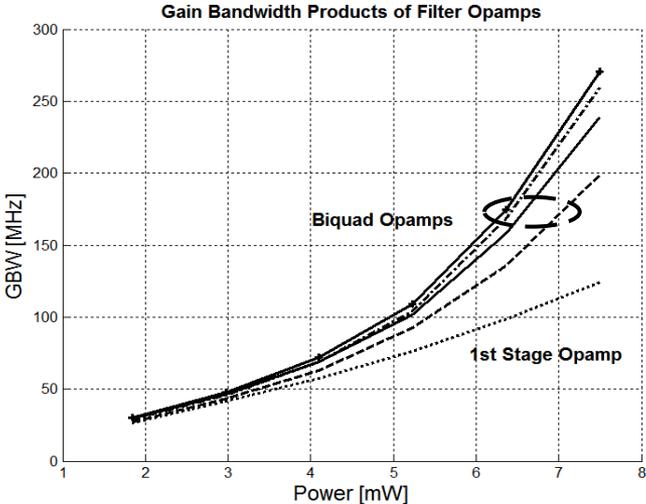


- V_G should be a good AC ground
- V_c should be larger than $V_{common-mode}$
- Always in *triode*
- Size such that parasitic at highest frequency is negligible compared to R_{disc}

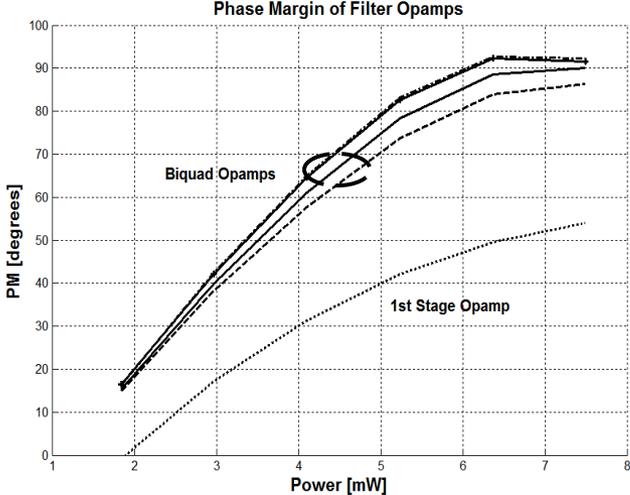
Opamp and Power Adjustment



(a) Opamp schematic

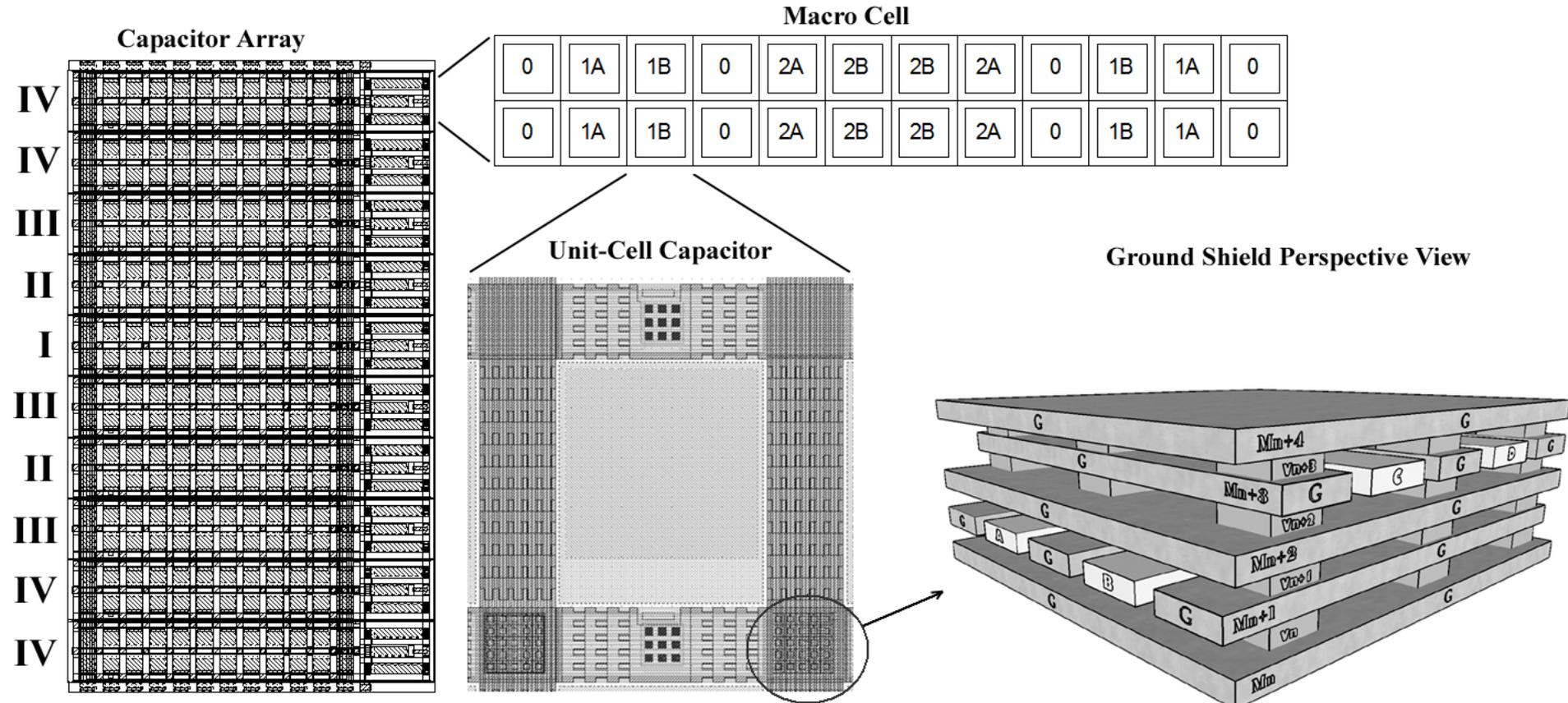
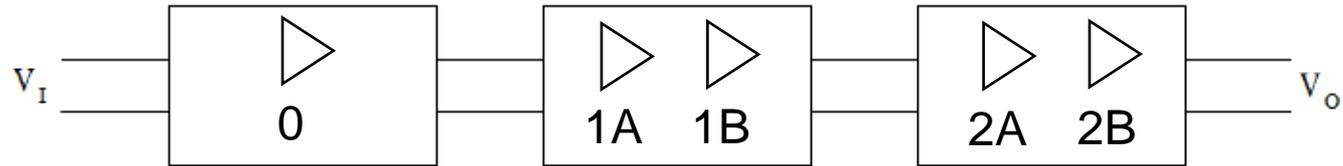


(b) GBW of opamps in diff. stages vs. Power



(c) PM of opamps in diff. filter stages vs. Power

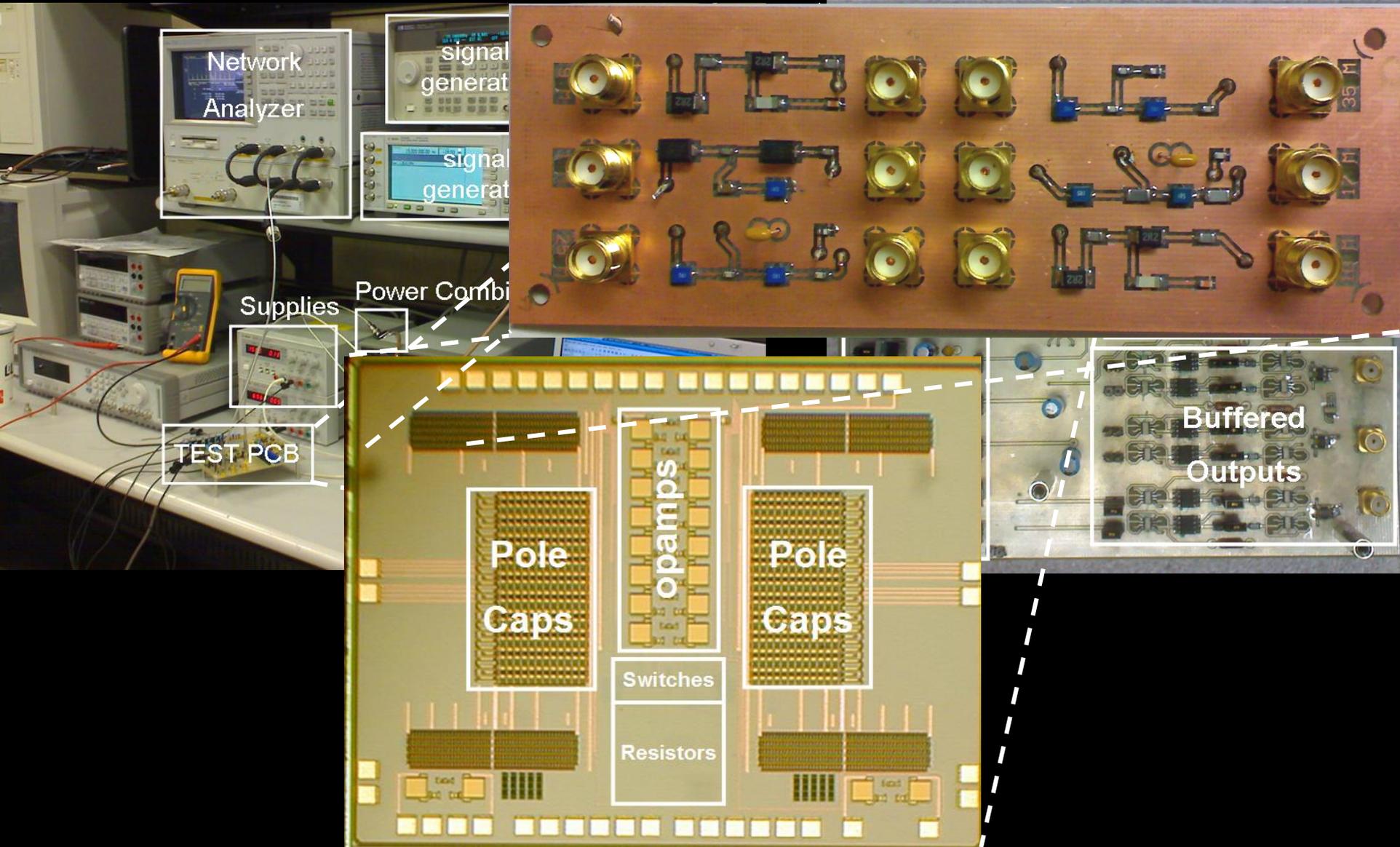
Layout Techniques



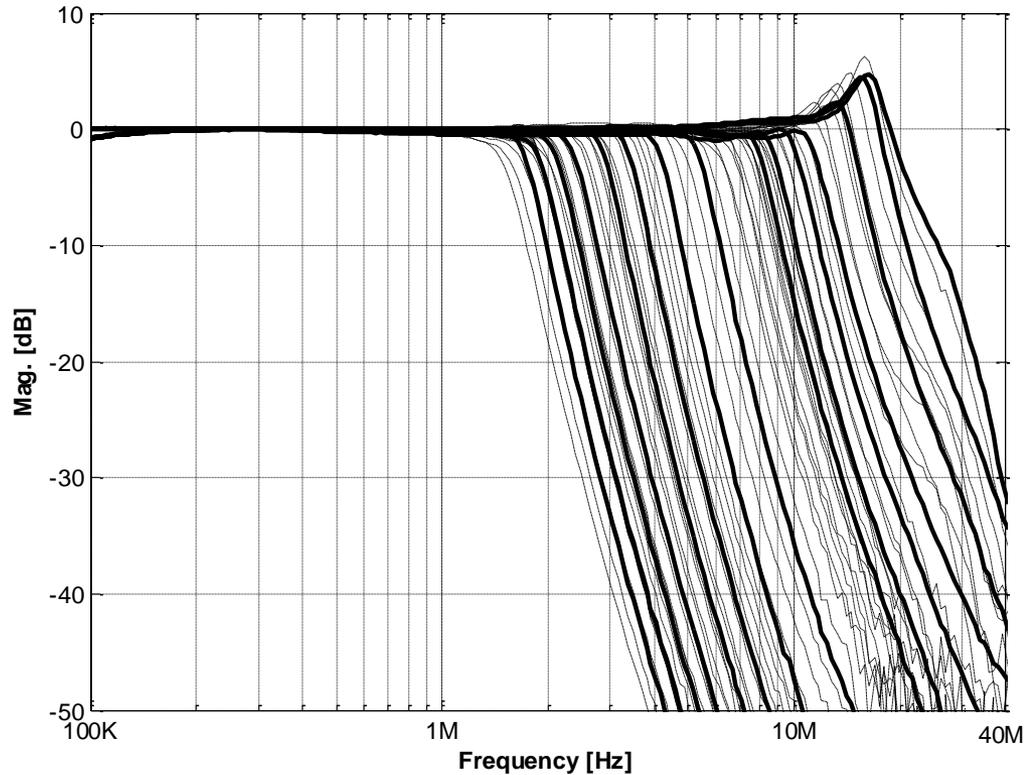
Outline

- 1) Introduction
- 2) Direct-Modulation Transmitter
- 3) Self-Tuning System
- 4) Experimental Results
- 5) Continuously-tunable Active-RC Filter
- **6) Experimental Results**
- 7) Conclusion

Filter Measurement setup/Die photo



Frequency Response

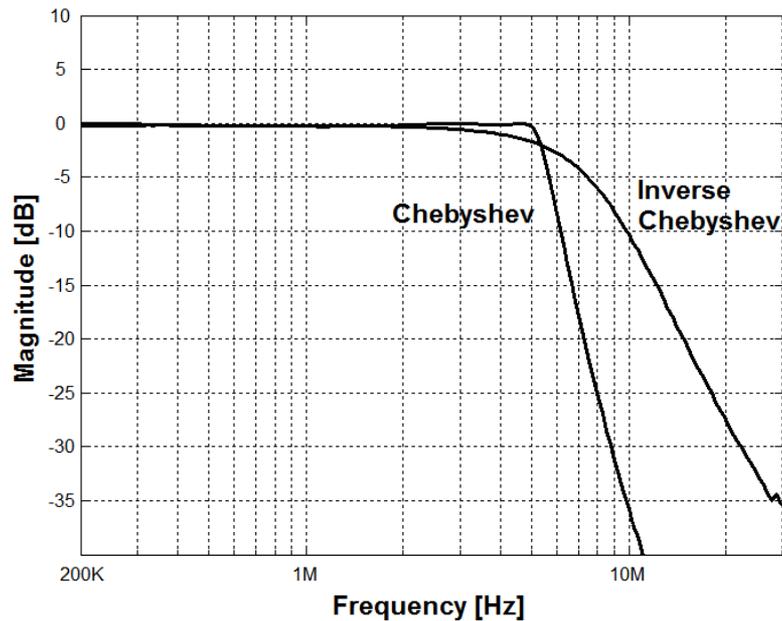


Discrete Freq. Selection : Solid line

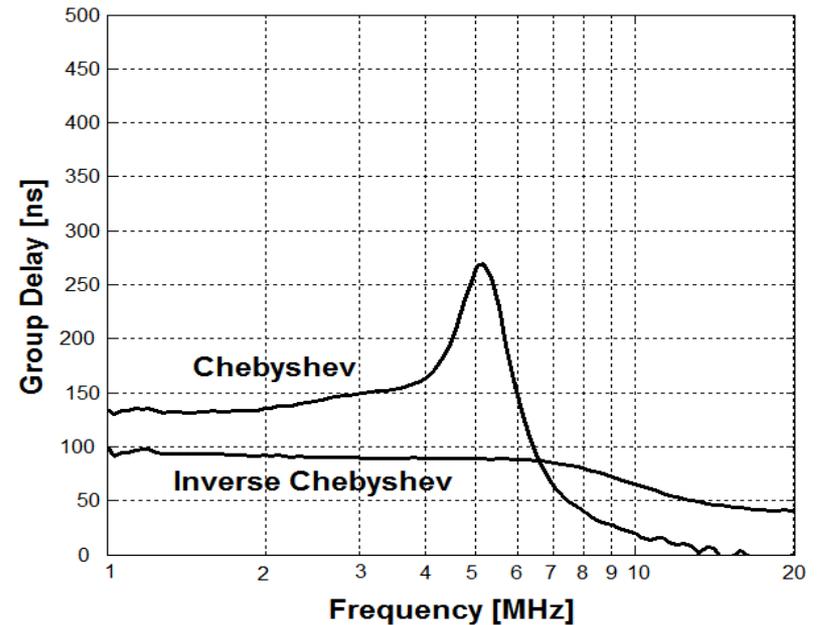
Continuous Freq. Tuning: Dashed line

Filter Type selection

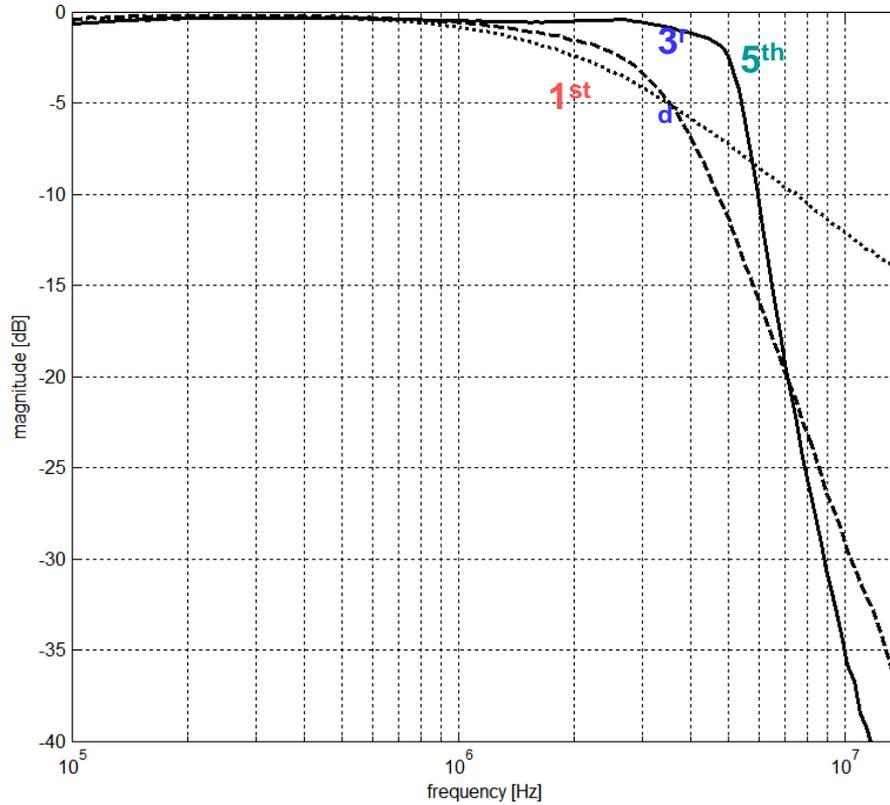
Magnitude Response



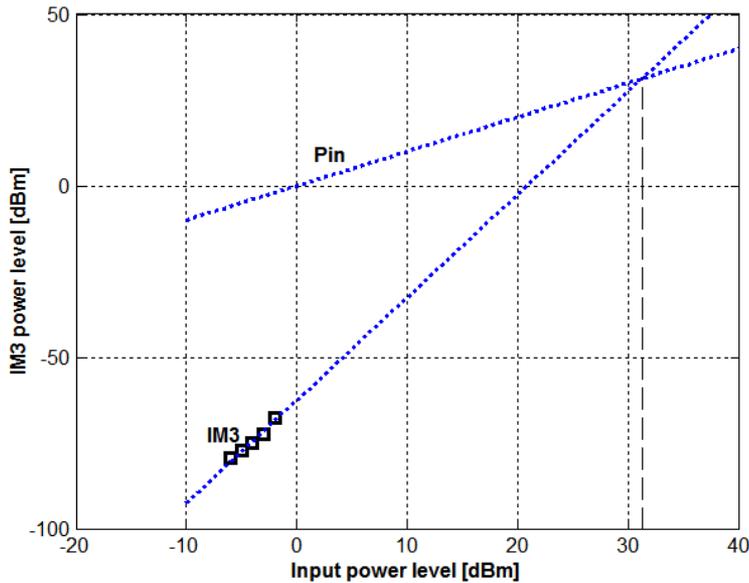
Group Delay



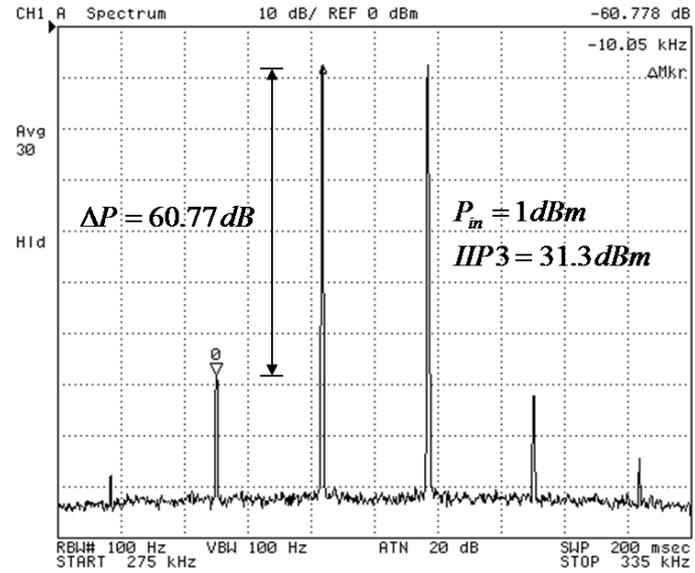
Order Selection



In-band Linearity

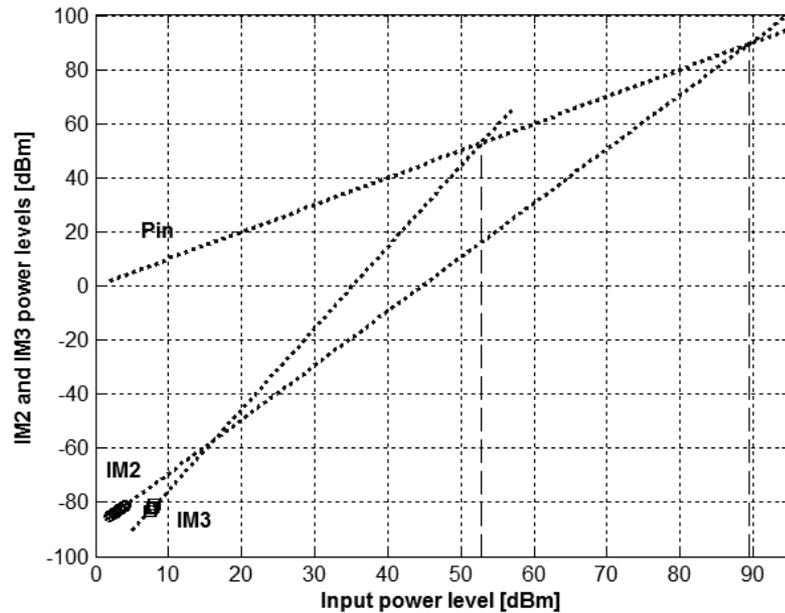


- IIP3=31.3 dBm



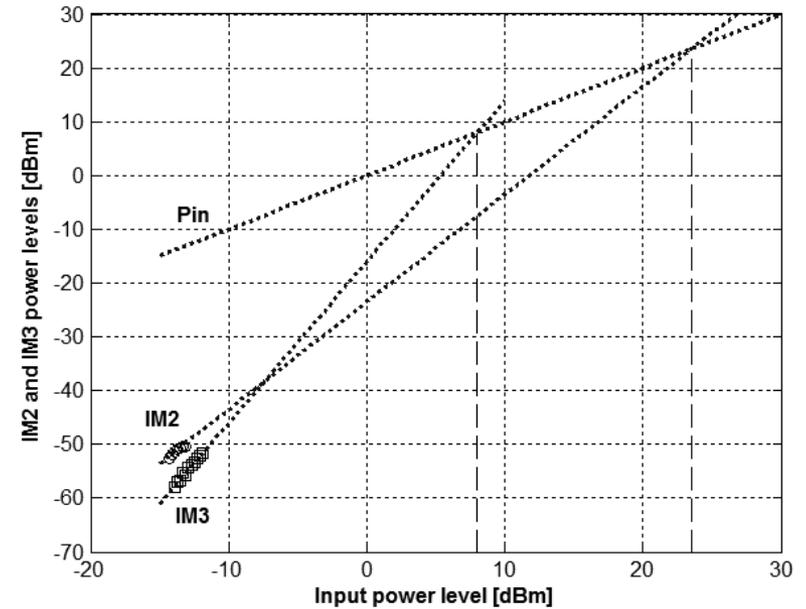
- Two-tone test

Out of band linearity



LF mode :

- IIP2=89.5 dBm
- IIP3=52.8 dBm



HF mode :

- IIP2=23.5 dBm
- IIP3=8 dBm

Comparison

COMPARISON TO RECENTLY PUBLISHED WORKS

	Topology	Order	Type [*]	Power [mW]	Power/pole [mW/pole]	V_{DD} [V]	f_c Range [MHz]	Continuous Tuning?	Noise [nV/\sqrt{Hz}]	DR [dB]	IIP3 [dBm]
[D'Amico'06]	Source Follower	4	-	4.1	1.02	1.8	6-14	No	7.5	79	17.5
[Kousai'07]	Active-RC	5	C	11.25	2.25	1.5	19.7	No	30	69	18.3
[Vasilopoulos'06]	Active-RC	5(C)/3(E)	C/E	4.6	0.92	1.2	5, 10	No	85, 143	73	18.8-21.3
[Giannini'06]	Active- G_m -RC	4	-	3.4 14.2	0.85 3.55	1.2	1.45-3.6 5.87-19.44	No	24.8	81	21
[Chamla'05]	$G_m C$	3	B	2.5-3.1 6.5-7.3	0.83-1.03 2.16-2.43	2.5	0.05-0.35 0.25-2.2	Yes	35-700	-	22, 28
[Lo'07]	$G_m C$	3	B	1.57-1.92	0.52-0.64	1.0	0.135-2.2	Yes	65	-	16.3-20.1
This Work	Active-RC	1/3/5	C/I	3.0-7.5	0.6-1.5	1.0	1-20	Yes	85, 52	71.4	31.3, 26

*B-Butterworth, C-Chebyshev, I-Inverse Chebyshev, E-Elliptic

All the implementations are realized in $0.13\mu m$ CMOS technology except for **[Chamla'05] which is fabricated in $0.25\mu m$ SiGe BiCMOS and **[Lo'07]** which is fabricated in $0.18\mu m$ CMOS