

**TUNABLE CCII-MOSFET-C FILTER BIQUADS
FOR VIDEO FREQUENCIES**

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BUILDING HIGH-FREQUENCY FILTER BIQUADS

USING A NEW BALANCED CURRENT CONVEYOR

ECCTD '97, BUDAPEST SEPTEMBER 1, 1997

ECCTD '97

Tunable CCII-MOSFET-C Filter Biquads, September 1, 1997

Good Morning,

the subject of my talk is “Tunable CCII-MOSFET-C Filter Biquads for Video Frequencies”.

The main points of the talk are

- showing you how to apply the idea behind the Banu-Tsividis integrator to single-amplifier biquads
- presenting a new balanced current conveyor and
- showing how it possible to build low-power high-frequency filters with this CCII.

Introduction: Integrated filters

- Video frequency filter (4.5 MHz), tunable, low power (0.5 mW per MHz and pole pair)
- Single-amplifier biquads (e.g. Sallen-Key filters): only one amplifier per pole pair, pole frequency and pole Q tunable independently
- voltage-mode
high-gain amplifier with feedback
op-amp with feedback
- current-mode
low-gain open-loop amplifier
current mirror
- New differential-input balanced-output current conveyor, MOSFET resistors, capacitors

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- e.g. Sallen-Key filters
Moschytz: filter classification
- high-gain/low-gain
opamp/current mirror
voltage-mode/current-mode
- cascadable filter biquads

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Banu-Tsividis Integrator, Single-Amplifier Biquads

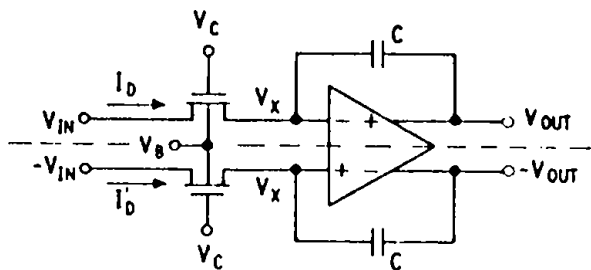
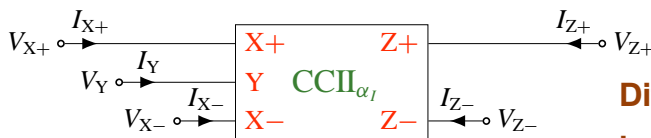
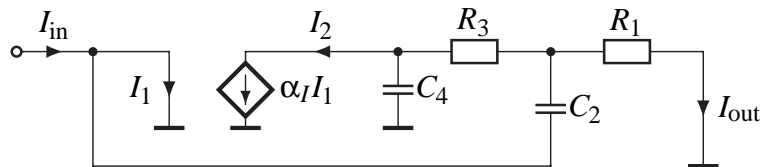


Fig. 2(c), M. Banu and Y. Tsividis, "Fully integrated active RC filters in MOS technology", *IEEE J. Solid-State Circuits*, vol. 18, no. 6, p. 646, dec. 1983

Banu-Tsividis integrator

Current-mode Sallen-Key lowpass filter biquad



Differential-input balanced-output CCII

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Banu-Tsividis integrator: Mihai Banu, Yannis Tsividis, 1983

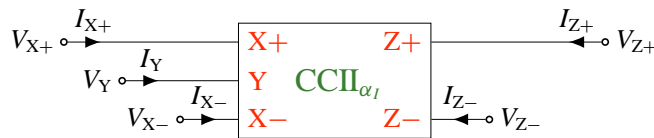
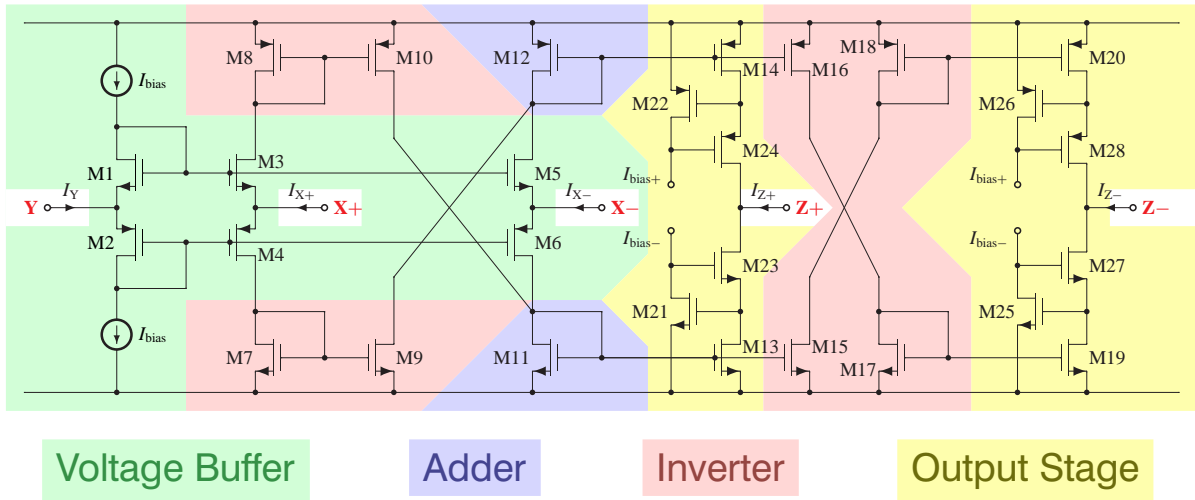
- tunable time constant
- even-order harmonic distortion
- integrator-based filters
- apply to single-amplifier biquads

Sallen-Key lowpass filter: transposed voltage-mode filter

- CCCS with low gain
- negative gain, positive feedback
- duality of CCCS and VCVS
- parasitic zeros and input resistance

CCII: Differential-input balanced output CCII with a non-unity gain and with its Y-terminal grounded.

Balanced CMOS Current Conveyor (CCII)



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- Double-output complementary class AB voltage buffer
- current mirrors
- function
- path symmetry
- output stage

Balanced class AB CMOS CCII, 3 V supply

Voltage buffer: supply current $50\mu\text{A}$, gain ≈ 0.98

Current buffer: gain ≈ 1.6 , pole-zero cluster at above 50 MHz,
5 degrees phase lag at 1.2 MHz

Y input resistance: several $100\text{ k}\Omega$

X input resistance: $540\ \Omega$, resistive up to several 10 MHz

Z output resistance: very high DC value (regulated cascode),
capacitive in the frequency region of interest ($\ll 1\text{ pF}$)

(Simulations: Transient analysis with $50\mu\text{A}$ current step, BSIM 3v3)

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Voltage buffer: not important

Current buffer:

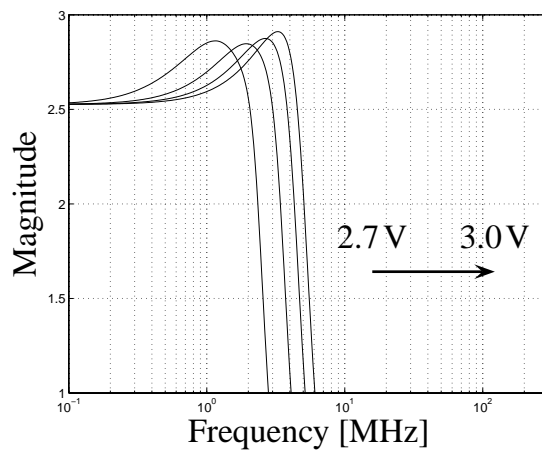
Y input resistance: depends on the output resistance of
the supply current sources only
not important

X input resistance: parasitic zero in lowpass filter
transfer function

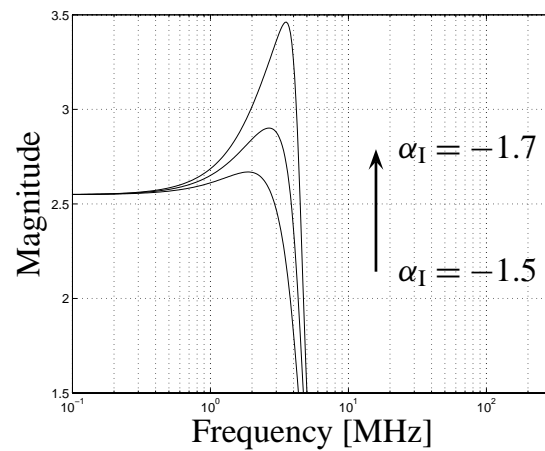
Z output resistance: voltage swing

design equations: see paper

4th-order Chebychev filter, passband edge frequency tunable from 2 MHz to 4.5 MHz



Tuning the **Passband edge frequency** by changing the common gate voltage of the MOSFET resistors



Tuning the **pole Qs** of both biquad sections by varying the gain of the CCIs

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Passband edge frequency: Precision depends on operation mode:

Off-line tuning: precision depends on tuning strategy only

On-line tuning: master-slave
precision depends on matching

Pole Q: can be tuned in steps to within 5%.

pole Q tuning curves are scaled!

Properties of the filter example

	H. P. Schmid simulation	Q. Huang [1] measurement
Supply voltage	3 V	5 V
Passband edge	2 ... 4.5 MHz	560 kHz
Power consumption per pole pair	2 mW 0.5 mW/MHz	2.5 mW 4.5 mW/MHz
Dynamic range	60 dB	60 dB
THD	1 %	1 %
Components	MOSFETs, Capacitors	MOSFET only

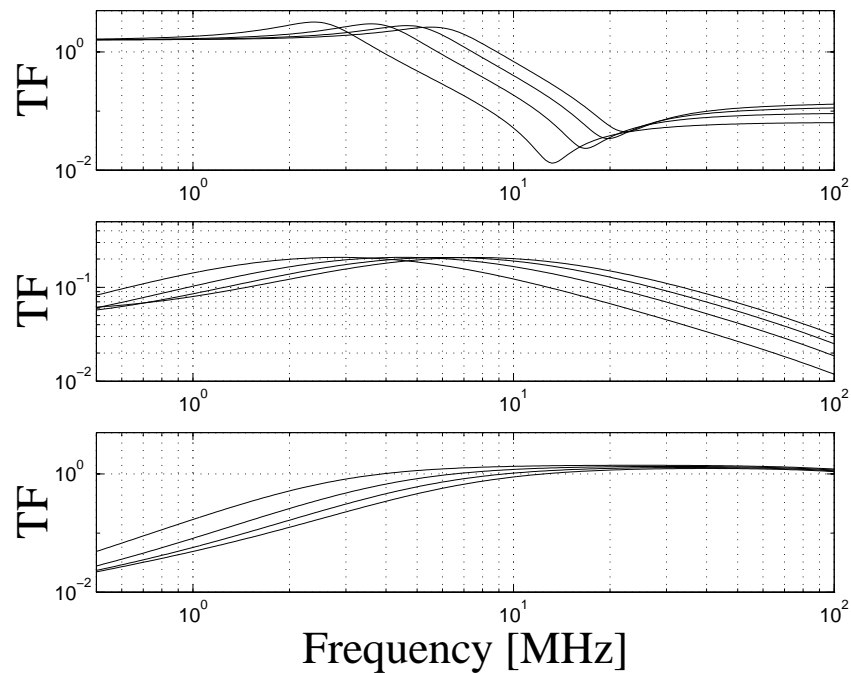
[1] Qiuting Huang, "A MOSFET-only continuous-time bandpass filter", *IEEE Journal of Solid-State Circuits*, vol. 32, no. 2, pp. 147-158, Feb. 1997.

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- IEEE Journal of Solid-State circuits
- Simulations vs. measurements!
- less power, lower supply voltage
- same THD
- dynamic range calculated according to Bruun
- MOSFET only filters vs. MOSFET-C filters
- precision

Lowpass, bandpass and highpass filters



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- parasitic zeros
- stopband attenuation is 45 dB
- highpass: exchange C and R
- bandpass
- other design-equations!

Conclusion

- New differential-input balanced-output CCII with symmetrical forward paths
- Application of the idea behind the Banu-Tsividis integrator to single-amplifier biquads
- Parasitic zeros in Sallen-Key filters built with non-ideal amplifiers
- Example: video frequency filter with tunable passband edge frequency, stepwise tunable pole Q and low power consumption at a supply voltage of 3 V

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Thank you for your attention.