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An Active Time-Constant Variation Tuning Technique for Continuous-Time Delta-Sigma Modulators

Tobias Wolfer, Eckhard Hennig

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Problem Statement

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Continuous-time (CT) loop filter coefficients relate on Time Constants (TC).

$\mathrm{TC} \sim (R * C)$

or $\mathrm{TC} \sim (C/g_m)$

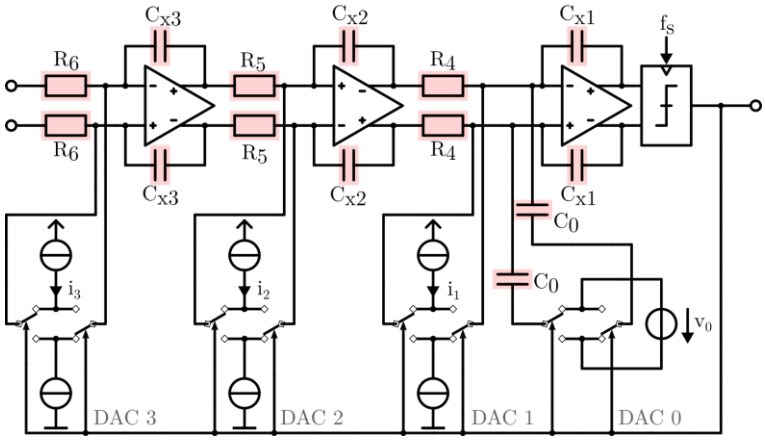
In CMOS technologies: $\Delta TC \cong \pm 30\ \%$

$$TC + \Delta TC = TC \cdot (1 + \delta_{RC})$$

TC variation in CT ΔΣ Modulators:

- Transfer characteristics
  - Signal Transfer Function (STF)
  - Noise Transfer Function (NTF)
- Performance
  - In-Band Noise (IBN)
  - Signal-to-Noise Ratio (SNR)
- Stability
  - Maximum Stable Amplitude (MSA)

Example: 3rd order 1-bit low-pass CT ΔΣ modulator in CIFB structure with current-steering feedback DACs and ELD compensation



Problem Statement

Worst Case: Instability due to Time-Constant Variation

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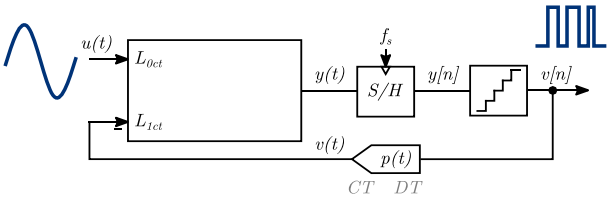

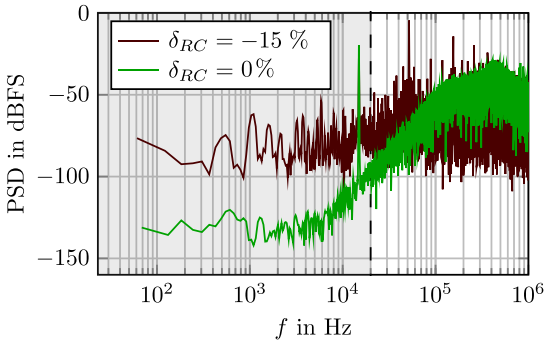

State of the Art

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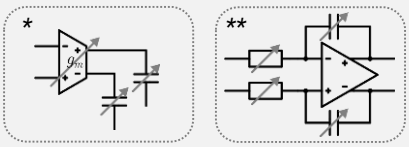
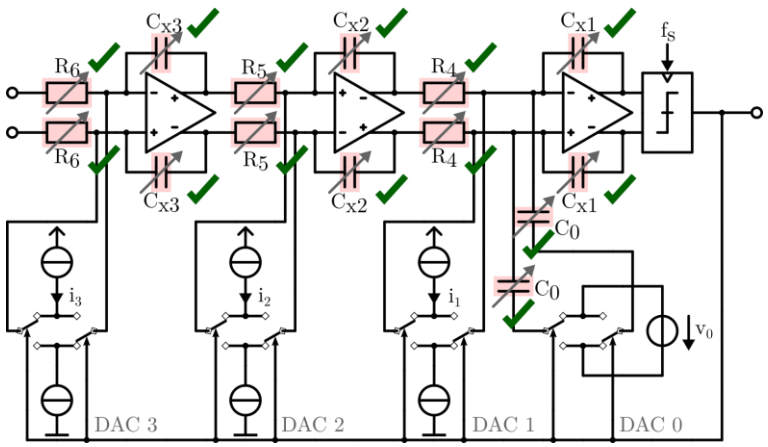
Design Options for CT ΔΣ Modulators:

- No tuning + design margin
  [Gerfers, IEEE Journal of SSC, 2003]
- g_m- C integrators *
  - g_m-tuning
  - C-tuning
  [Xia, IEEE ISCAS, 2002]
- Active R-C-integrators **
  - R-tuning
  - C-tuning
  [Billa, IEEE JSSC, 2020]





Proposed Tuning Technique

TC Variation Compensation Factors on System Level

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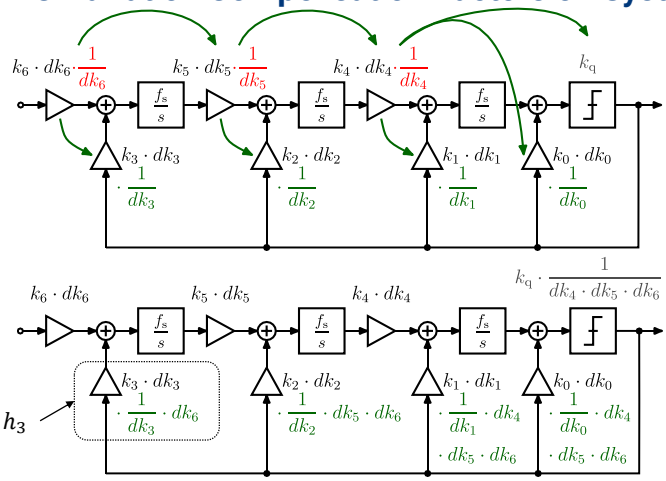

Ref.: [T. Wolfer and E. Hennig, IEEE APCCAS, 2021]
[T. Wolfer and E. Hennig, IEEE SMACD, 2022]

h_i : Effective modulator coefficients
k_i : Nominal modulator coefficients
dk_i : Individual influence of TC variation
$\{\dots\}$: Compensation factors to be implemented

$$h_6 = k_6 \cdot dk_6$$
$$h_5 = k_5 \cdot dk_5$$
$$h_4 = k_4 \cdot dk_4$$
$$h_3 = k_3 \cdot dk_3 \cdot \left\{\frac{1}{dk_3} \cdot dk_6\right\}$$
$$h_2 = k_2 \cdot dk_2 \cdot \left\{\frac{1}{dk_2} \cdot dk_5 \cdot dk_6\right\}$$
$$h_1 = k_1 \cdot dk_1 \cdot \left\{\frac{1}{dk_1} \cdot dk_4 \cdot dk_5 \cdot dk_6\right\}$$
$$h_0 = k_0 \cdot dk_0 \cdot \left\{\frac{1}{dk_0} \cdot dk_4 \cdot dk_5 \cdot dk_6\right\}$$
$$h_q = k_q \cdot \frac{1}{dk_4 \cdot dk_5 \cdot dk_6}$$

Proposed Tuning Technique

Reference Tuning Scheme on Circuit Level

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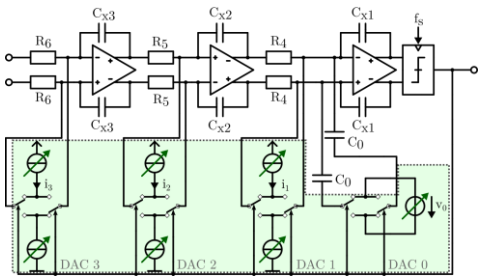
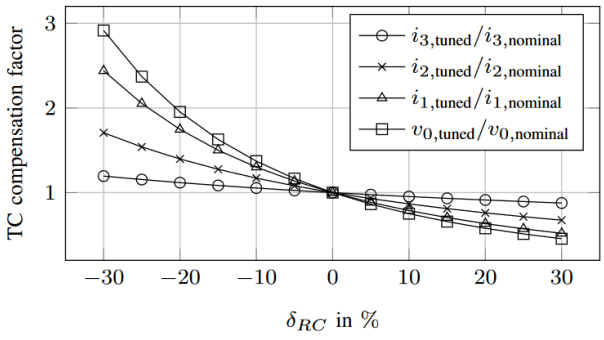


DAC 3: $i_3 = i_{3,\text{nominal}} \cdot \left\{\frac{1}{dk_3} \cdot dk_6\right\}$
DAC 2: $i_2 = i_{2,\text{nominal}} \cdot \left\{\frac{1}{dk_3} \cdot dk_5 \cdot dk_6\right\}$
DAC 1: $i_1 = i_{1,\text{nominal}} \cdot \left\{\frac{1}{dk_1} \cdot dk_4 \cdot dk_5 \cdot dk_6\right\}$
DAC 0: $v_0 = v_{0,\text{nominal}} \cdot \left\{\frac{1}{dk_0} \cdot dk_4 \cdot dk_5 \cdot dk_6\right\}$

Relative Time-Constant (TC) Variation:

$$\delta_{RC} = \frac{1}{(1+\Delta R) \cdot (1+\Delta C)}$$



Example: $dk_3 = \frac{1}{(1+\Delta R_6) \cdot (1+\Delta C_{x3})}$

Test Chip and Measurement Setup

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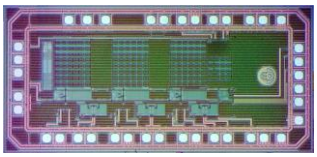
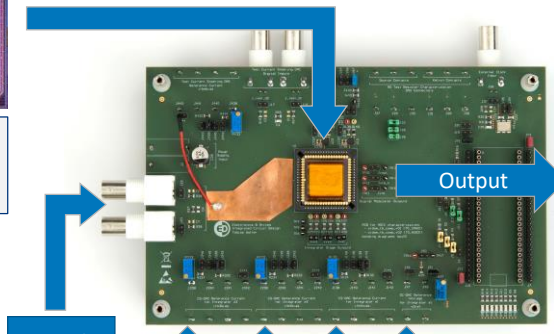


Fabricated CT ΔΣ modulators test-chip samples



Measurement: Spectrum vs. TC Variation

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TC Errors Compensated for all Parameter Variations