IDEC Chip Design Contest

Continuous-Time Bandpass ΔΣ Capacitance-to-Digital Converter

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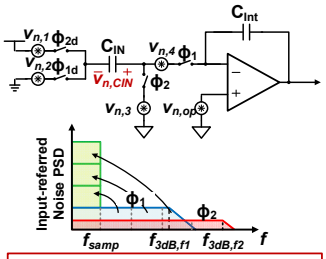
Abstract

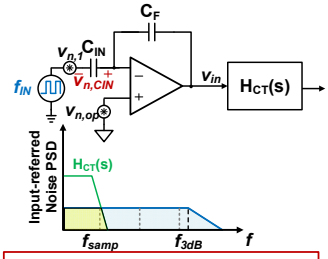
This paper presents an ultra-high-resolution energy-efficient 4th-order continuous-time (CT) bandpass (BP) ΔΣ capacitance-to-digital converter (CDC) where thermal noise folding is avoided by CT operation and power is saved by using a BP ΔΣ architecture. The proposed CDC achieves a resolution of 3.68 aF_{rms} at room temperature while achieving a Schreier figure-of-merit (FoM_S) of 183dB which is more than 2x improvement over the state-of-the-art CDCs.

Introduction

DT-ΔΣ CDC Resolution

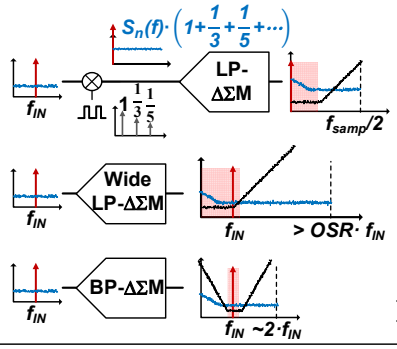


CT-ΔΣ CDC Resolution



- ✓ DT circuits inevitably increases the in-band noise floor due to noise folding
- ✓ CT circuits significantly reduce the minimum capacitor resolution

Energy-Efficient ΔΣM Structure

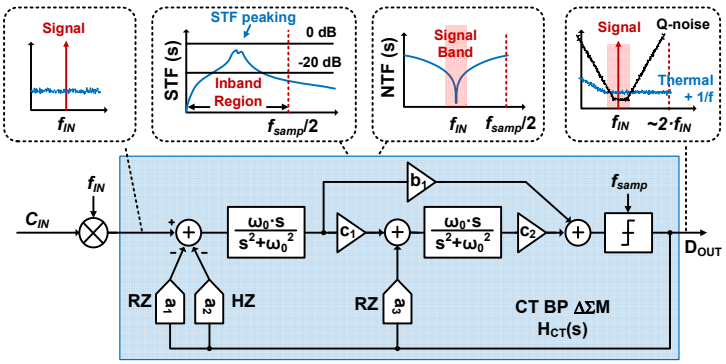


2nd-order noise shaping

Amp. GBW	Loop-filter Power
$(OSR \cdot f_{IN}) \cdot 10$	$2 \cdot \left(\frac{10 \cdot OSR}{10^{2.5}}\right)^2 \cdot P_{BP}$
$f_{IN} \cdot 10^{2.5}$	$4 \cdot P_{BP}$

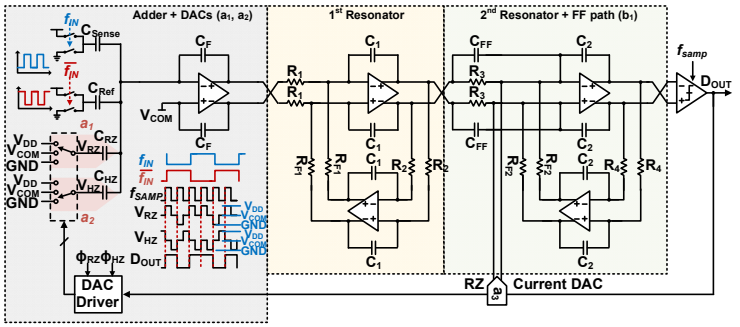
- Gain in the signal band > 50dB
- Gain in $f_{samp}/2$ > 20dB.

Proposed Architecture & Implementation



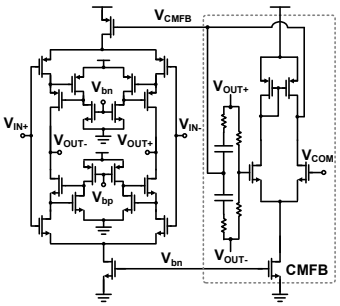
Block Diagram of the Proposed 4th-order CT BP ΔΣ CDC

- ✓ Combination of feedforward and feedback paths



Overall Circuit Schematic of the Proposed CDC

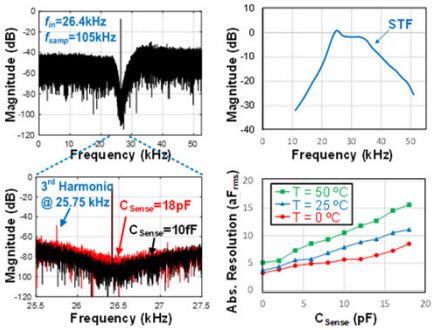
- ✓ Input stage is realized by a capacitive feedback amplifier
- ✓ 2 feedbacks (a_1, a_2) are realized by charge-domain DACs (C_{HZ}/C_{RZ})
- ✓ Active RC resonators are employed as it offers high linearity, parasitic insensitivity, wide input range, and simplicity.



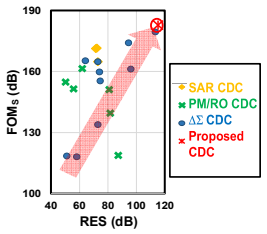
Proposed Inverter-based Amplifier with Gain-boosting

- ✓ Active RC integrator requires a high DC-gain amplifier
- ✓ Achieves high DC gain and low power consumption

Measurement Results & Conclusion

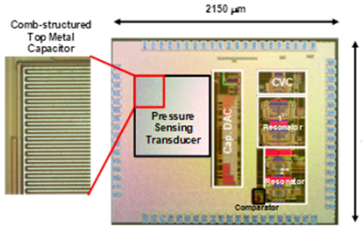


Measured output spectrum, STF and cap. Resolution according to C_{Sense}



Performance of CDCs

- ✓ Cap. Resolution : 115.1dB (C_{Sense} = 18pF)
- ✓ Power : 71.7 μW
- ✓ FoM_W : 0.37 pJ/c.step
- ✓ FoM_S : 183 dB



Die Photograph

	JSSC 19	ISSCC 19	This Work
Abs. Resol. (Meas. Cap)	116aF (40fF)	290aF (N.A)	3.68aF (10fF)
Cap. Range (pF)	0-18.12	0-5	0-18
Power	3μW	6.64μW	71.2μW
FoM_W (fJ/c.step)	660	16	373
FoM_S (dB)	159.9	156.5	182.8

Comparison Table

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