4A-1

An Ultra-Low-Noise Differential Relaxation Oscillator based on a Swing-Boosting Scheme

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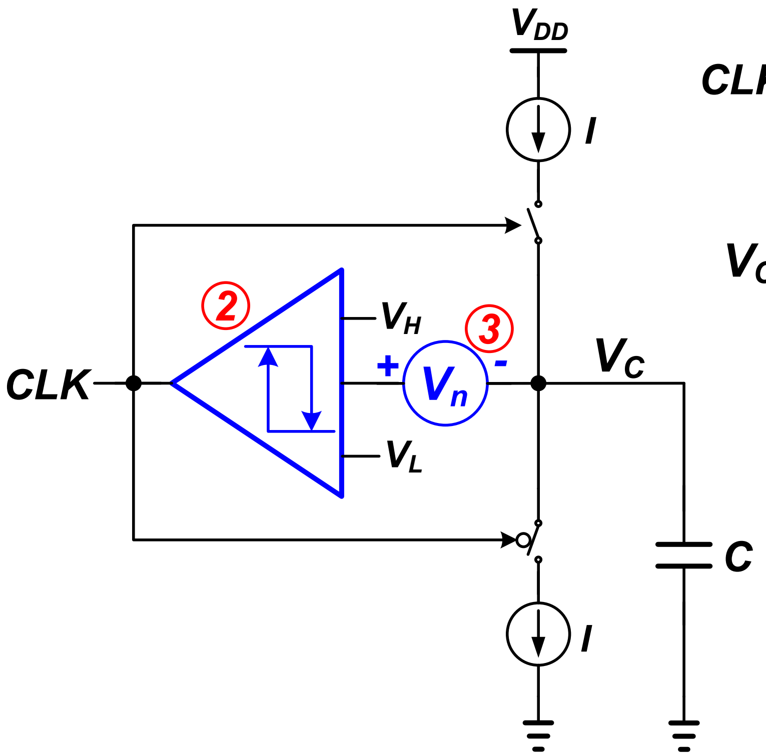
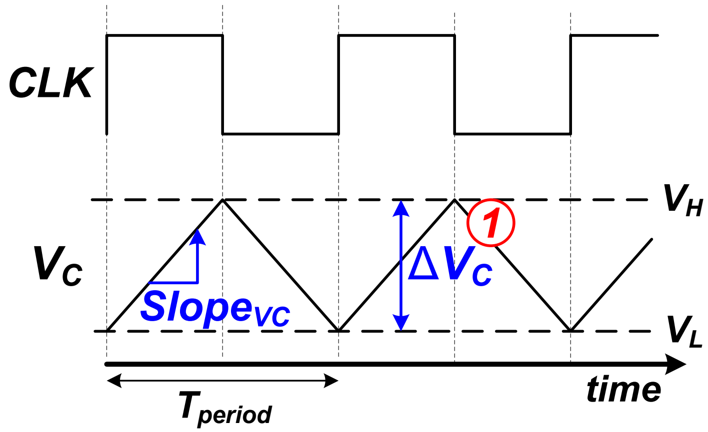
Relaxation Oscillators

- Relaxation OSC: Low-power CLK ref, sensor front-ends for IoT
- Low FOM (~152.6dB). Fundamental limit is 169.1dBc/Hz.
- Low-noise Design Considerations:



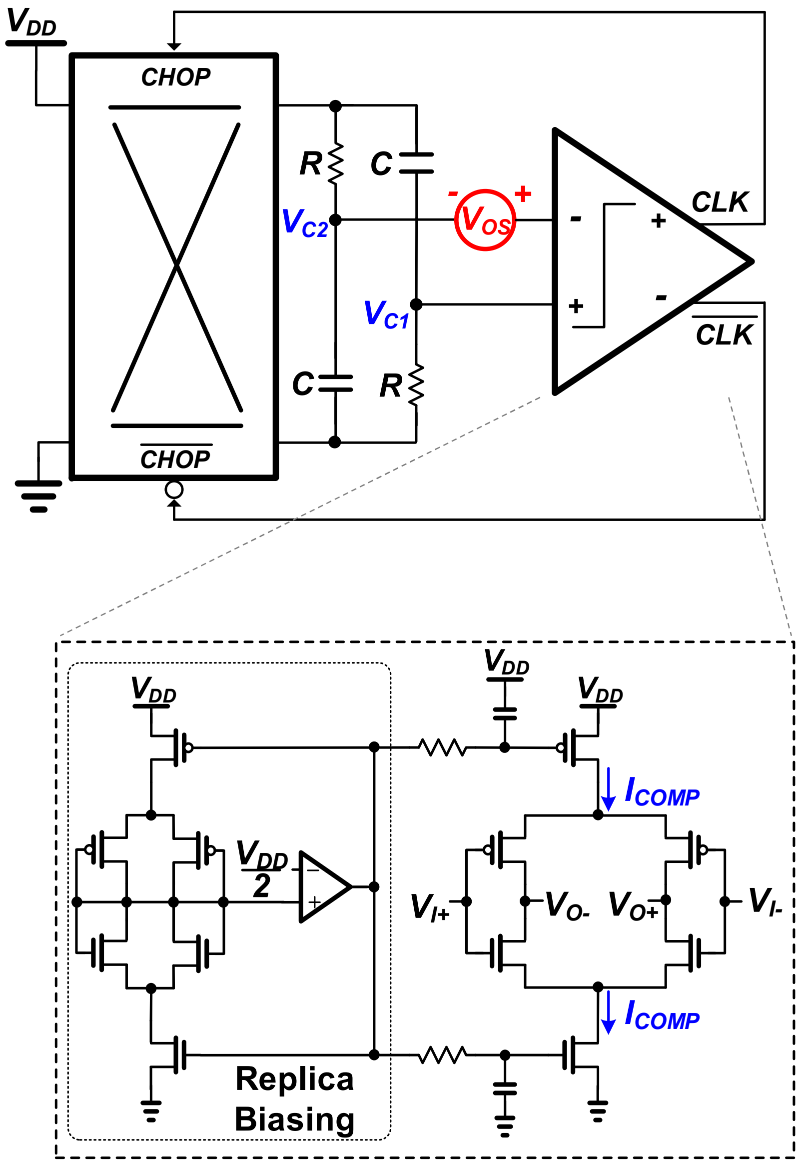


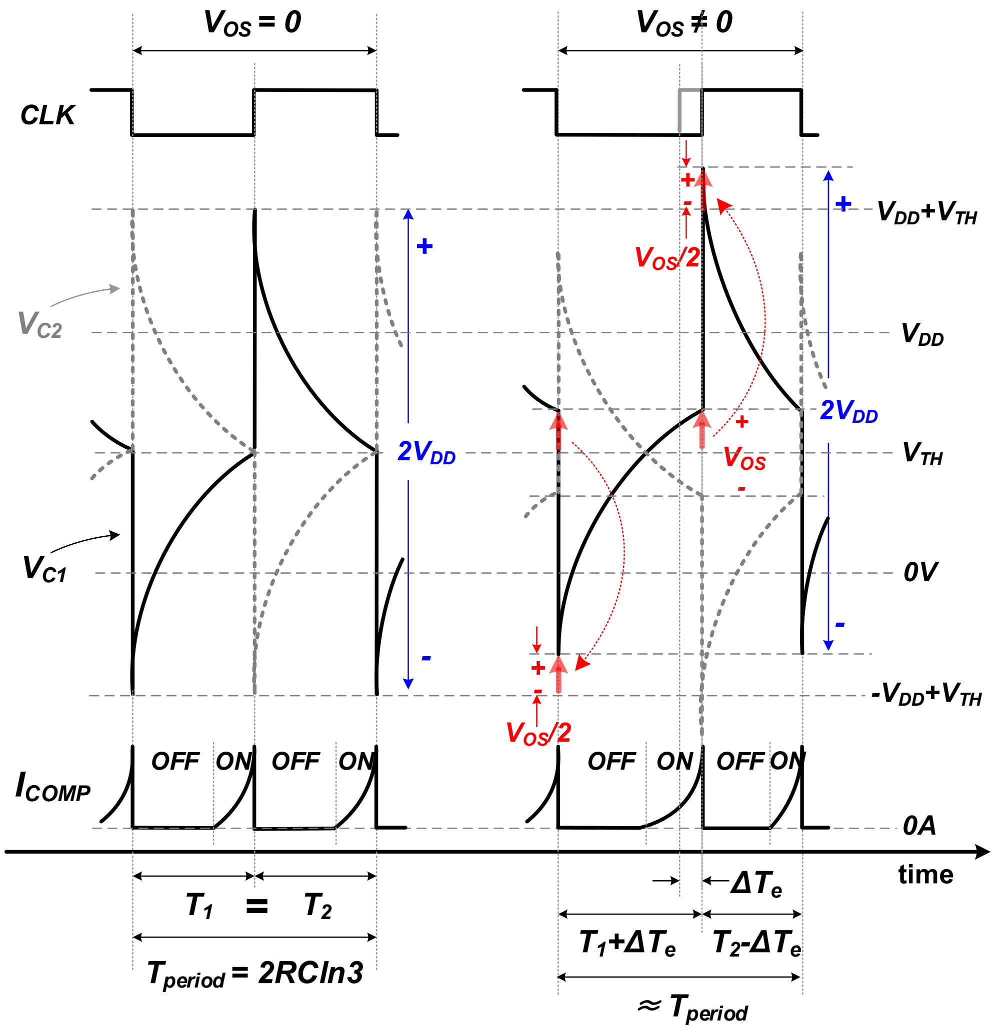
$$\sigma_{\Delta t}^{2} \propto \frac{\sigma_{V_n}^{2}}{Slope_{VC}}$$

[JSSC82]

① Large voltage swing
② Low-noise & low-power comparator
③ Offset cancellation

Swing-boosted Differential Oscillator

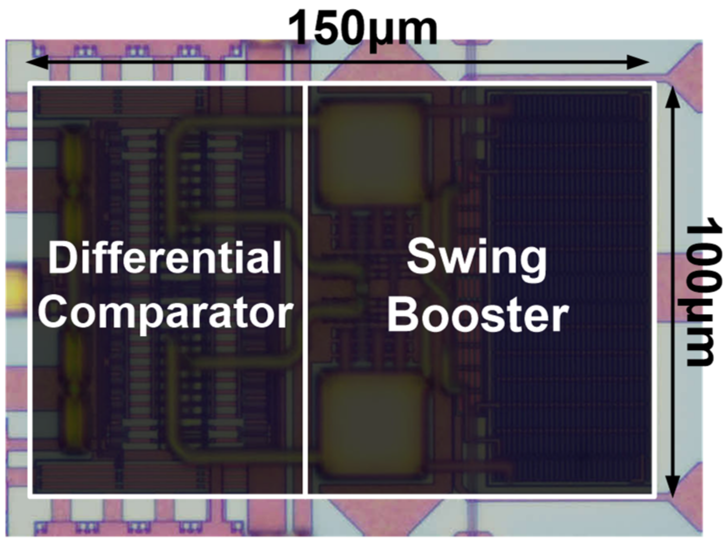




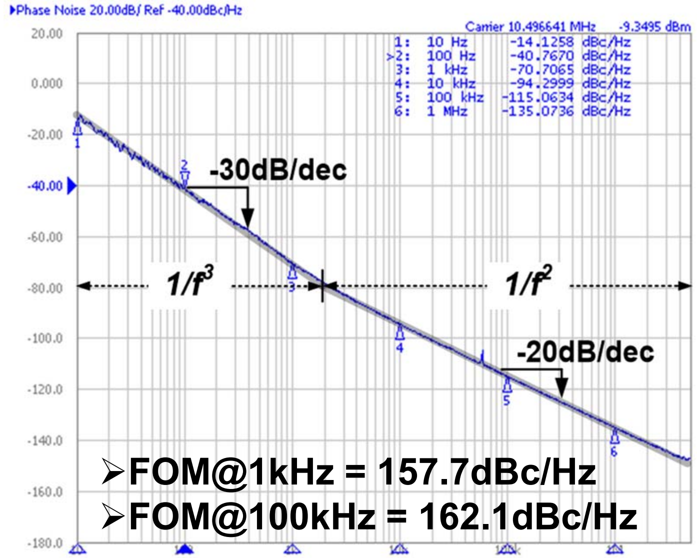
➔ **Swing = $4V_{DD}$**

- **Inherently resilient to offset and consumes dynamic power**

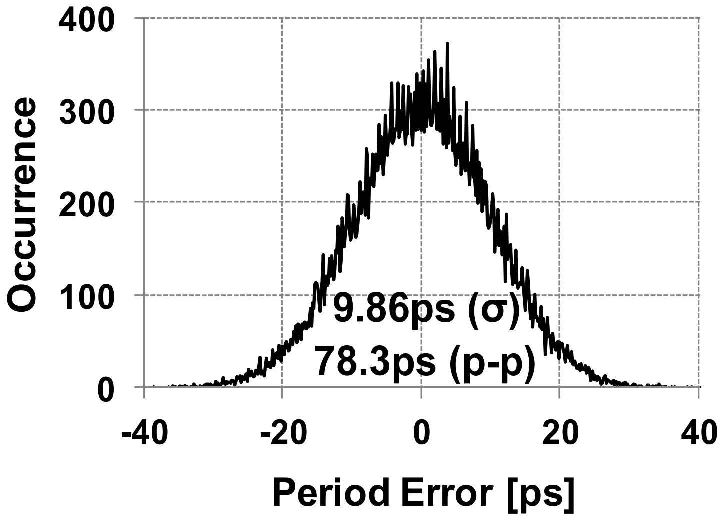
Measurement Results



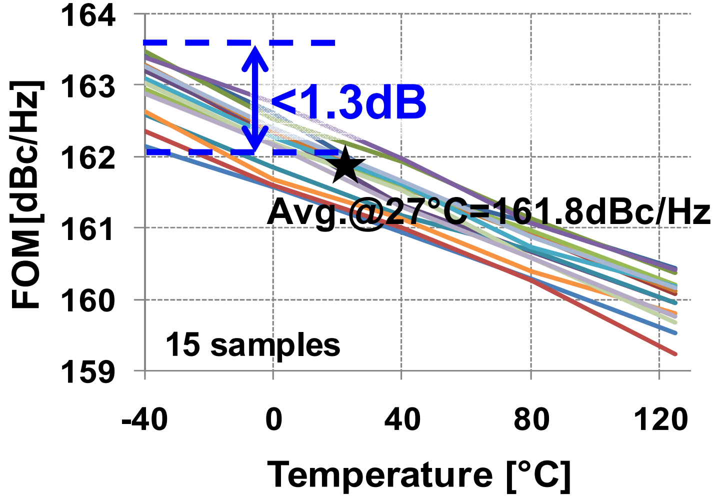
<Chip Micrograph>



<Phase-noise Measurement>



<Jitter Measurement>



<Robustness of Performance>

Performance Summary & Conclusion

Parameters	ISSCC 08	ISSCC 09	VLSI 10	ISSCC 13	This Work
Technology [nm CMOS]	65	130	65	65	180
Approach	Anti-jitter technique	Autozeroing	Chopping-FLL	Chopping-FLL + Integrated error feedback	Differential swing boosting
Freq. [MHz]	12.5	3.2	6	12.6	10.5
Area [mm^2]	0.03	0.073	0.02	0.01	0.015
Min. V_{DD} [V]	1.3	1.4	1.15	1.1	1.4
Power [μW]	91[1] / ~3600[2]	38	100	98.4	219.8
Period Jitter	N.A.	$455ps_{rms}$ (0.146%)	$88ps_{rms}$ (0.053%)	~$55ps_{rms}$ (0.07%)	$9.86ps_{rms}$ (0.01%)
FOM	162 @ 100kHz[1] 148 @ 100kHz[2]	132 @ 10kHz	137.6 @ 1kHz	154.1 @ 1kHz 152.6 @ 100kHz	157.7 @ 1kHz 162.1 @ 100kHz
Supply Var. [%/0.1V]	N.A.	0.4 @1.4 to 1.6V	0.26 @1.15 to1.35V	0.0175 @1.1 to 1.5V	0.44 (Worst-case) @1.4 to 2V
Temp. Var. [ppm/°C]	N.A.	125[3] @ 20 to 60°C	24[4] @-40 to 125°C	205[3] @0 to 80°C	137[3] (Worst-case) @-40 to 125°C
Samples	1	1	1	1	15

[1]Excludes power of anti-jitter comparator
[2]Includes power of anti-jitter comparator
[3] w/o temperature calibration, [4] w/ temperature calibration

- **Simple, small-area architecture achieving the highest FOM**
- **Easily extended to various low-power sensors**