Quadrature Generation Techniques in CMOS Relaxation Oscillators

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Outline

- Introduction & Motivation
- Quadrature Relaxation Oscillators (QRXO)
  - Shunt-coupled QRXO
  - Series-coupled QRXO
- Design and Simulation Results
- Summary

Introduction

- RF oscillator: key block in wireless & wireline communication systems [1,2]
- LC VCOs are commonly used
  - Low phase noise (high-Q)
  - Large area (spiral inductors)
  - Tuning range limited by device parasitics
- Quadrature LO signals
  - Recovery of IQ signal
  - Image-rejection

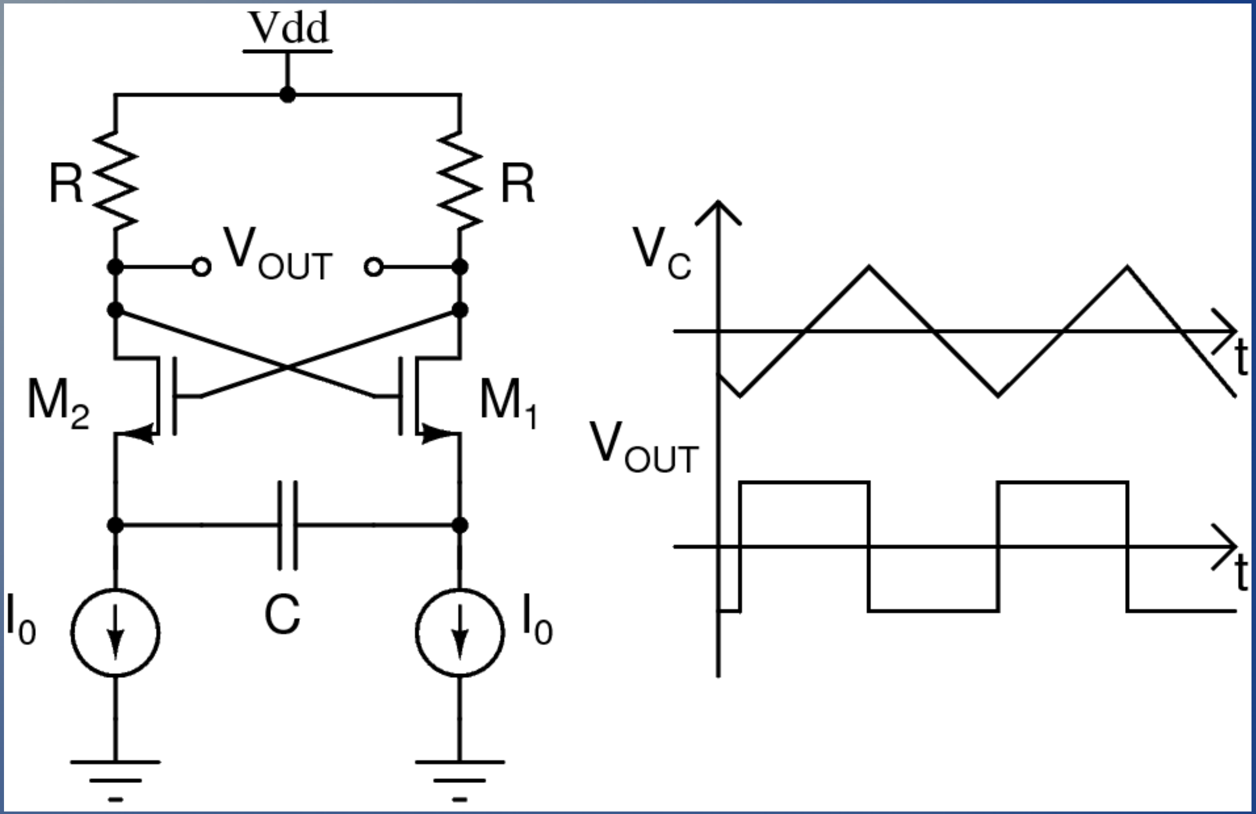
IQ LO Generation – 1

- VCO (f_0) + polyphase filter
  - High frequencies: capacitive parasitics become comparable to filter C
  - Buffers required to drive low impedances = high power consumption
  - Quadrature error ⇐ R & C matching
- VCO ($2f_0$) + Divide-by-2
  - LC oscillator potentially has higher Q at $2f_0$
  - Divider power becomes significant
  - Quadrature error ⇐ device matching

IQ LO Generation – 2

- Four-stage ring oscillator (f_0)
  - Tuning range set by stage delays
  - Quadrature error ⇐ delay matching
- Quadrature VCO (f_0) [1,3,4]
  - Power efficient at higher frequencies
  - Quadrature error ⇐ coupling strength

Relaxation Oscillator

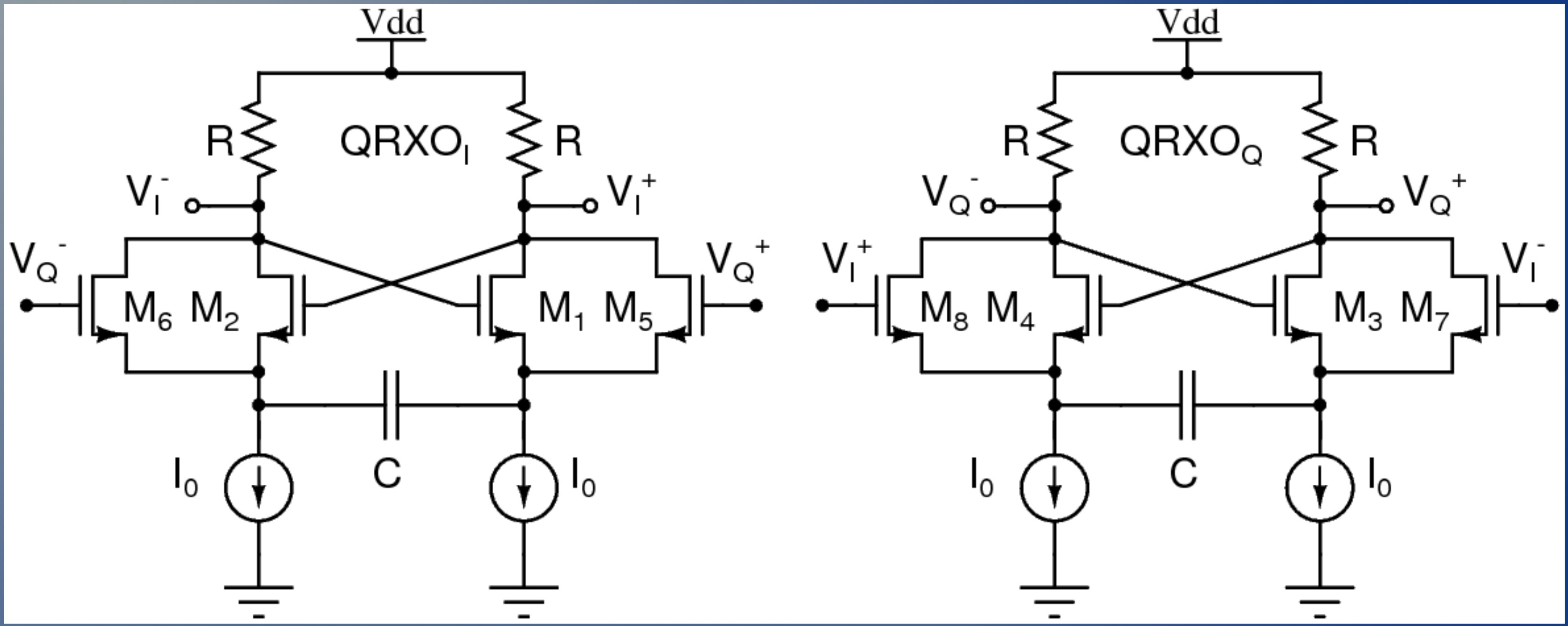


- Schmitt Trigger: Cross-coupled NMOS + R loads
- Integrator: Capacitor C
- Tune frequency using I_0

Quadrature Generation

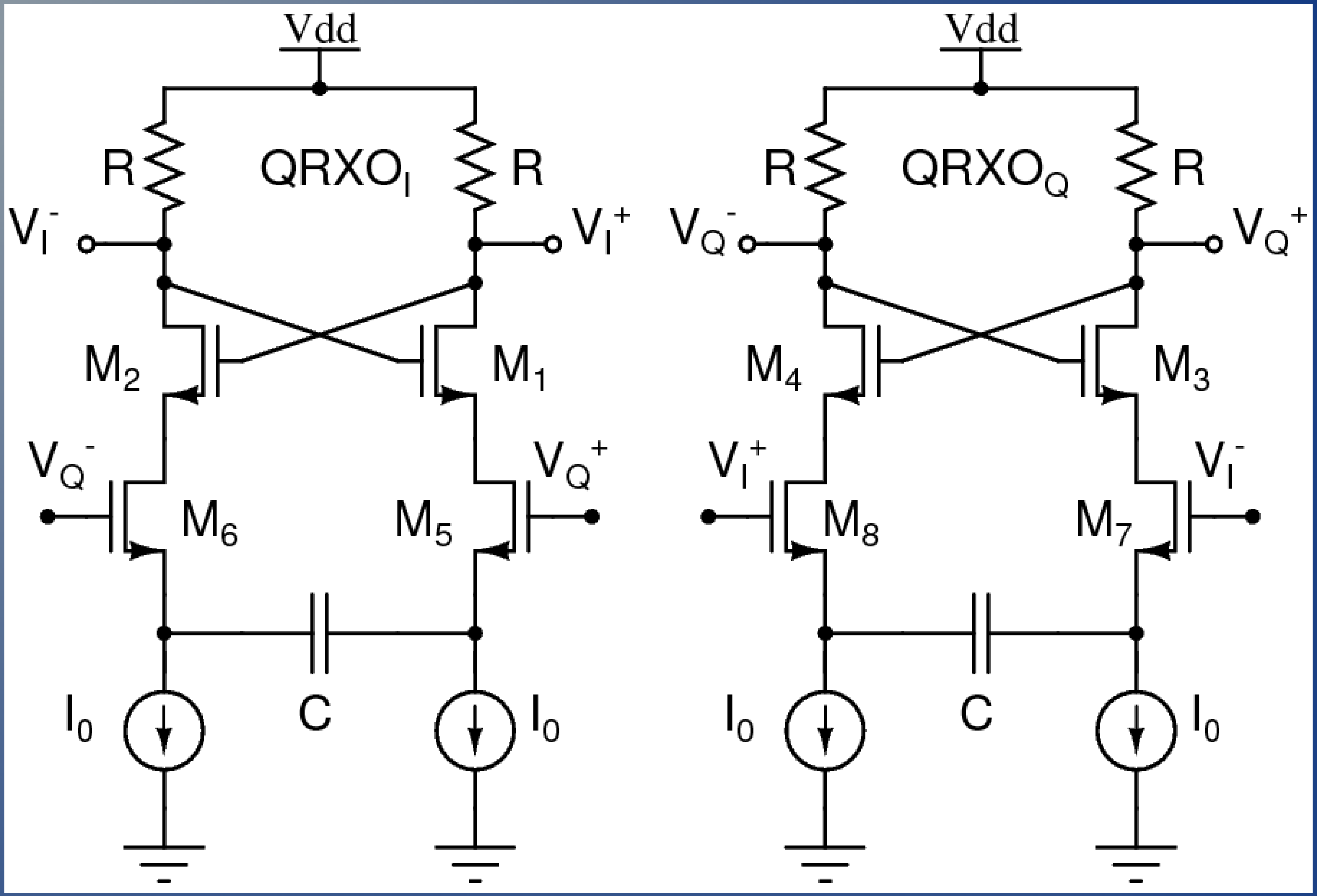
- Quadrature Relaxation Oscillator [5,6]
  - V_C and V_{OUT} are 90° out of phase
  - Integrator of each oscillator triggers the other
- Quadrature LC VCO
  - Inhibit negative resistance generation for 0° or 180° modes
  - Shunt & series injection
- Quadrature Relaxation Oscillator (this work)
  - Suppress Schmitt-trigger operation for 0°/180°
  - Shunt & Series coupling

Shunt Coupled QRXO



- I=Q (in-phase) ⇒ $M_{5\text{-}6}$ oppose $M_{1\text{-}2}$
  - $QRXO_I$ dies out ⇒ $QRXO_Q$ too ceases to oscillate
- I=$\overline{Q}$ (out-of-phase) ⇒ $M_{7\text{-}8}$ oppose $M_{3\text{-}4}$
  - $QRXO_Q$ dies out ⇒ $QRXO_I$ too ceases to oscillate

Series Coupled QRXO



- Series injection through $M_{5\text{-}8}$
- Coupling devices in triode region

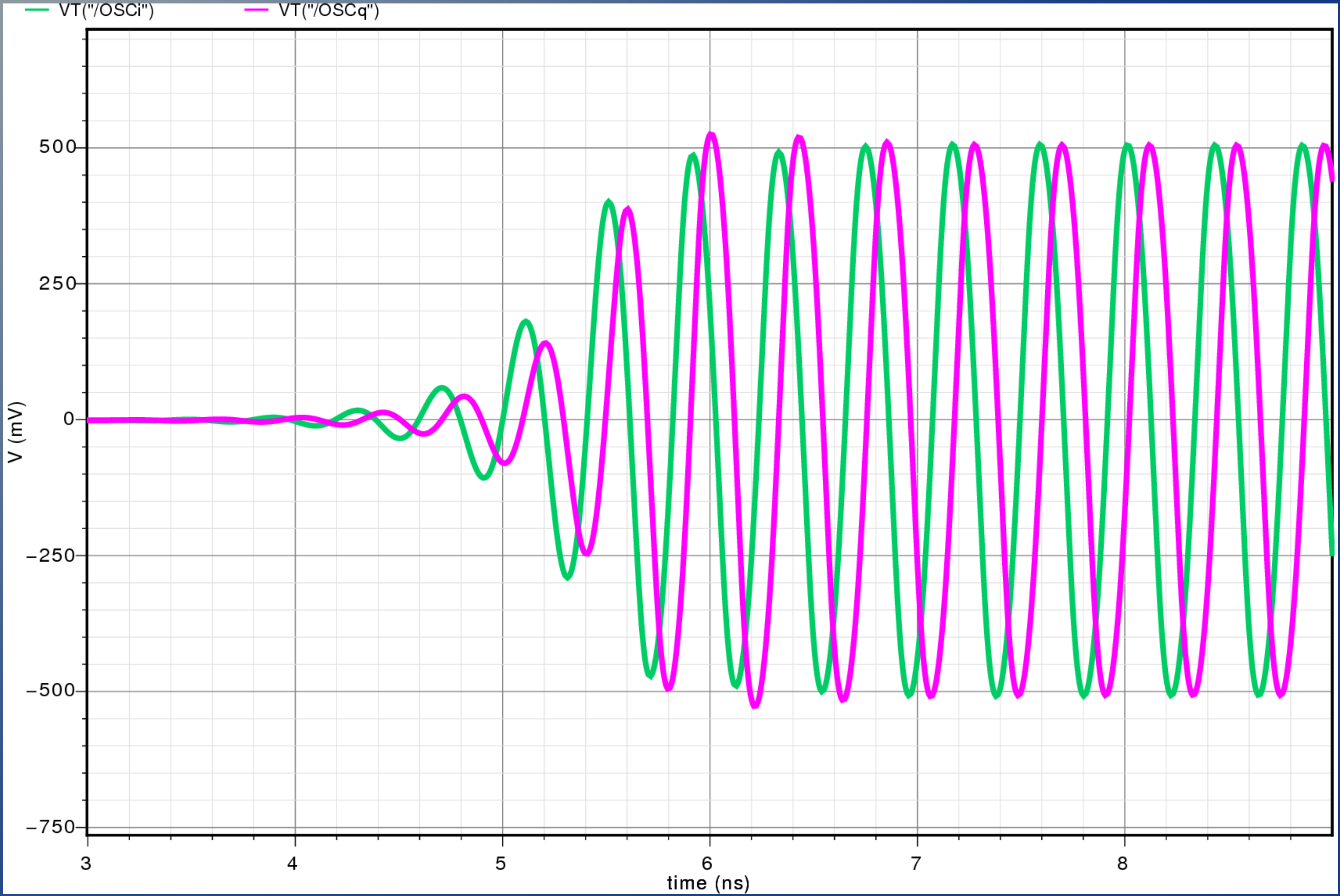
Circuit Design & Simulation

- Quadrature relaxation oscillators designed and simulated using Spectre (Cadence)
  - f_0 = 2.4GHz
  - UMC 0.18µm CMOS process (V_{DD} = 1.8V)
- Reference 2.4GHz relaxation oscillator
  - Total bias current = 6mA
  - $M_{1\text{-}2}$ = 100µm X 0.25µm
  - Load resistance R = 100Ω
  - Integrator capacitance C = 460fF

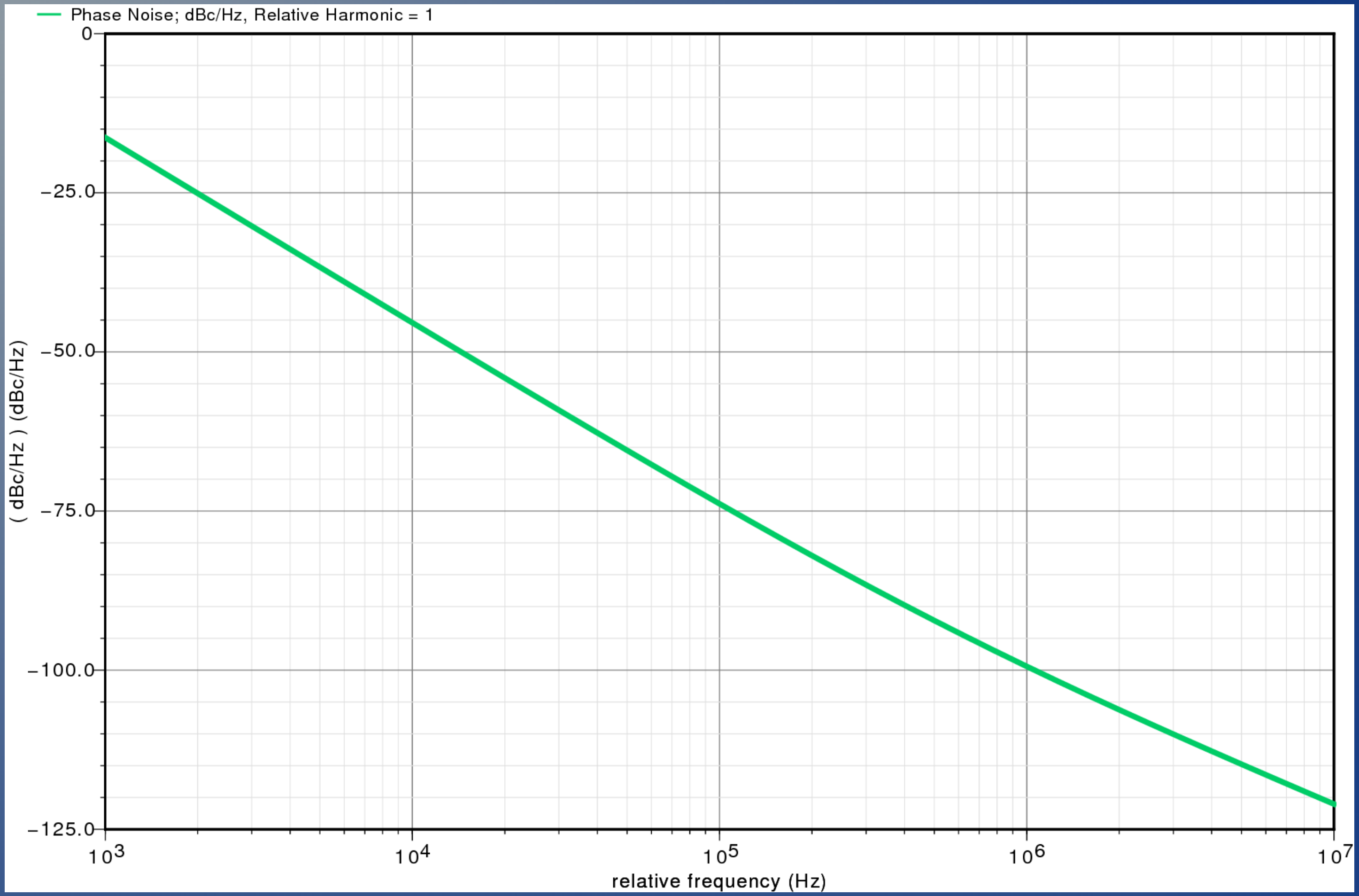
Shunt-coupled QRXO

- Quadrature coupling validated in simulation
- Primary design parameter: size of quadrature coupling devices
  - Large W/L ⇒ strong coupling, larger parasitics
  - Small W/L ⇒ weak coupling, more flicker noise
  - Larger L ⇒ less flicker noise, more parasitics
  - $M_{5\text{-}8}$ = 36μm X 0.65μm
- Total QRXO current = 12mA
- 1% I-Q mismatch ⇒ 0.25° quadrature error

Shunt QRXO – Startup

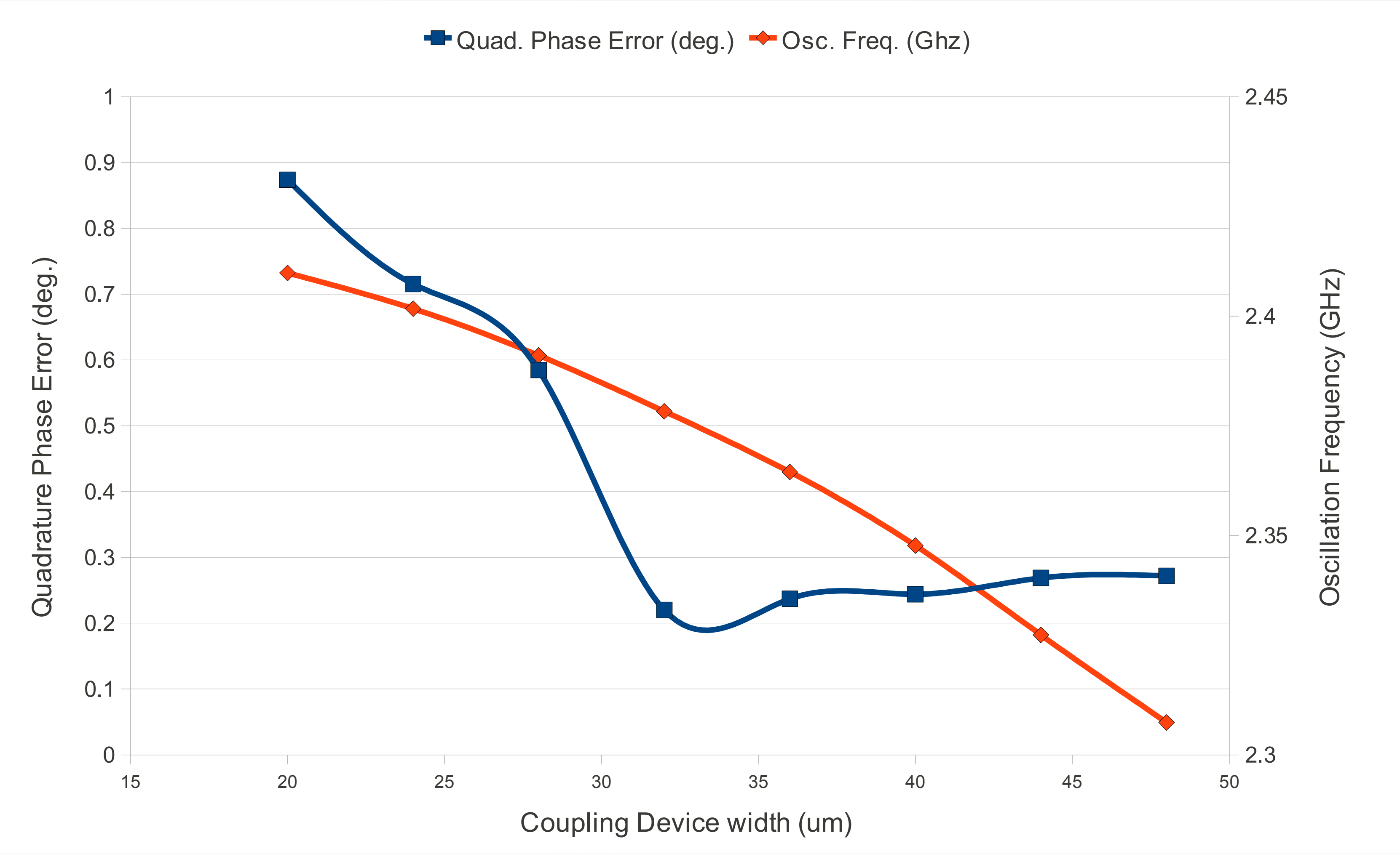


Shunt QRXO – Phase Noise



- -99.4dBc/Hz @ 1MHz offset
- R = 24%; $M_{5\text{-}8}$ (flicker) = 21%; $M_{1\text{-}4}$ (thermal) = 18%

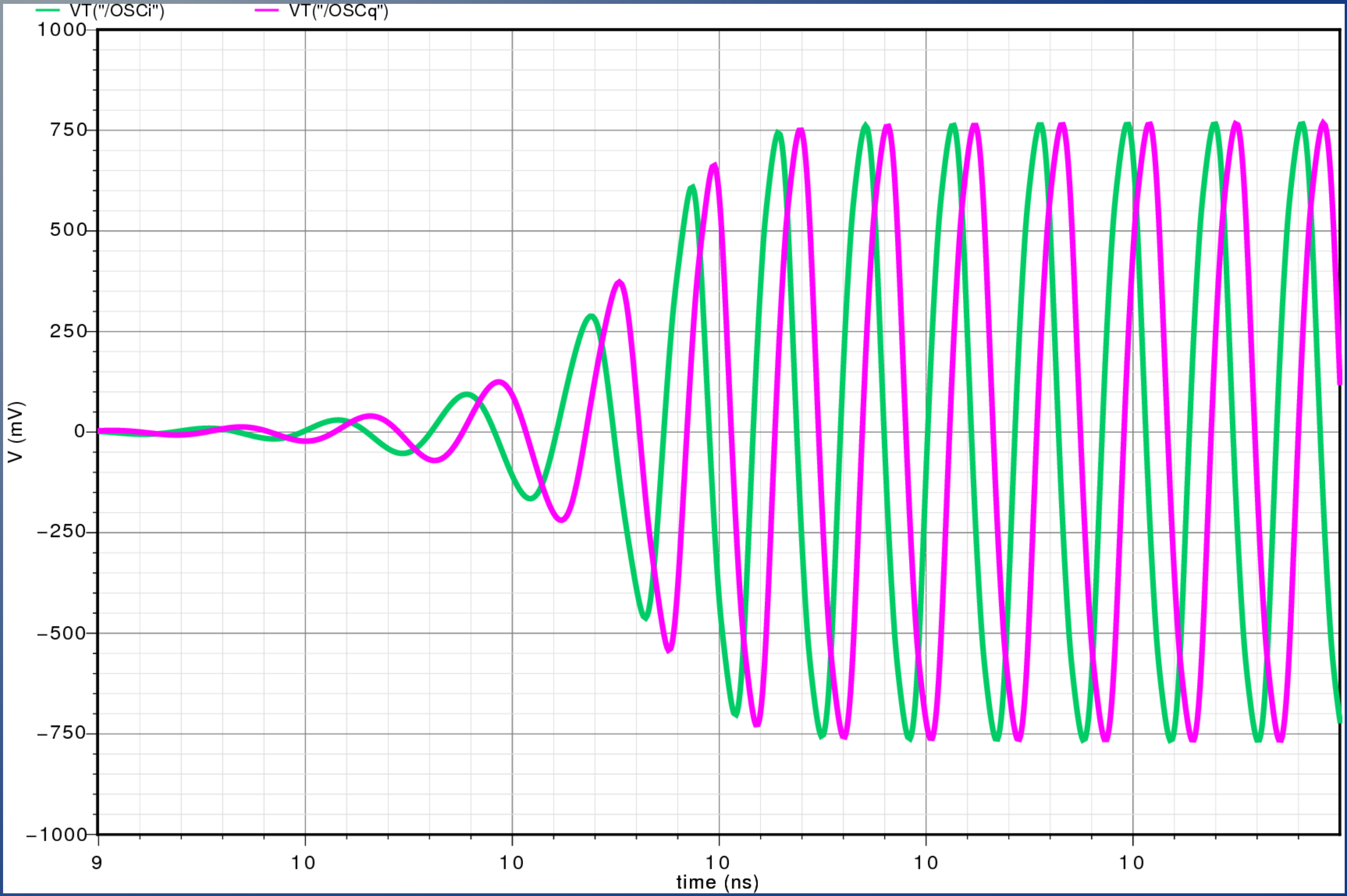
Shunt QRXO – Phase Error



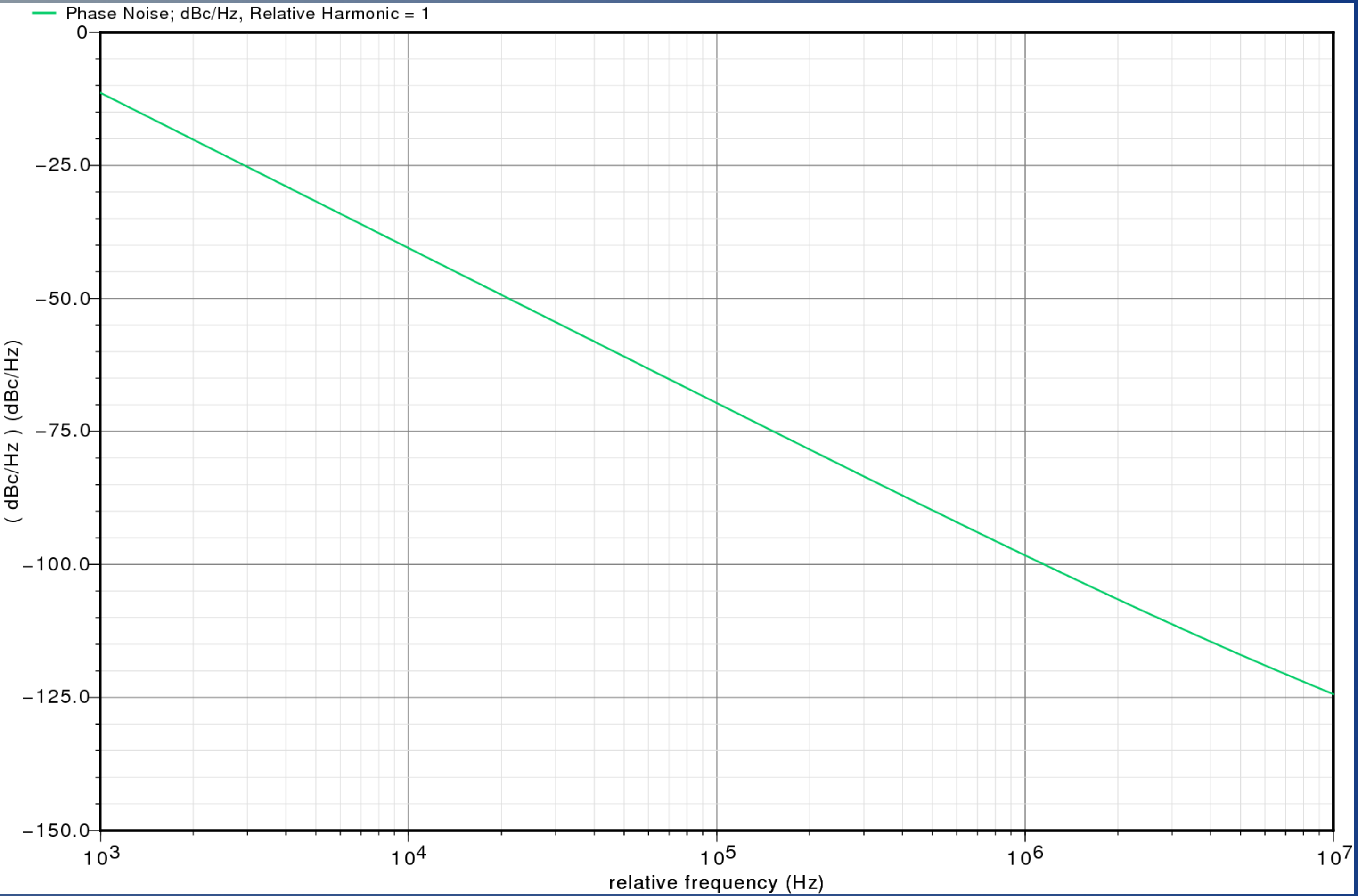
Series-coupled QRXO

- Quadrature coupling validated in simulation
- Coupling devices
  - Operate in triode region
  - Weaken cross-coupled NMOS operation (degeneration)
  - Large W/L ($M_{5\text{-}8}$ = 200µm X 0.18µm)
  - Flicker noise less of a concern
- Total QRXO current = 16mA
- 1% I-Q mismatch $\Rightarrow$ 0.1° quadrature error

Series QRXO – Startup

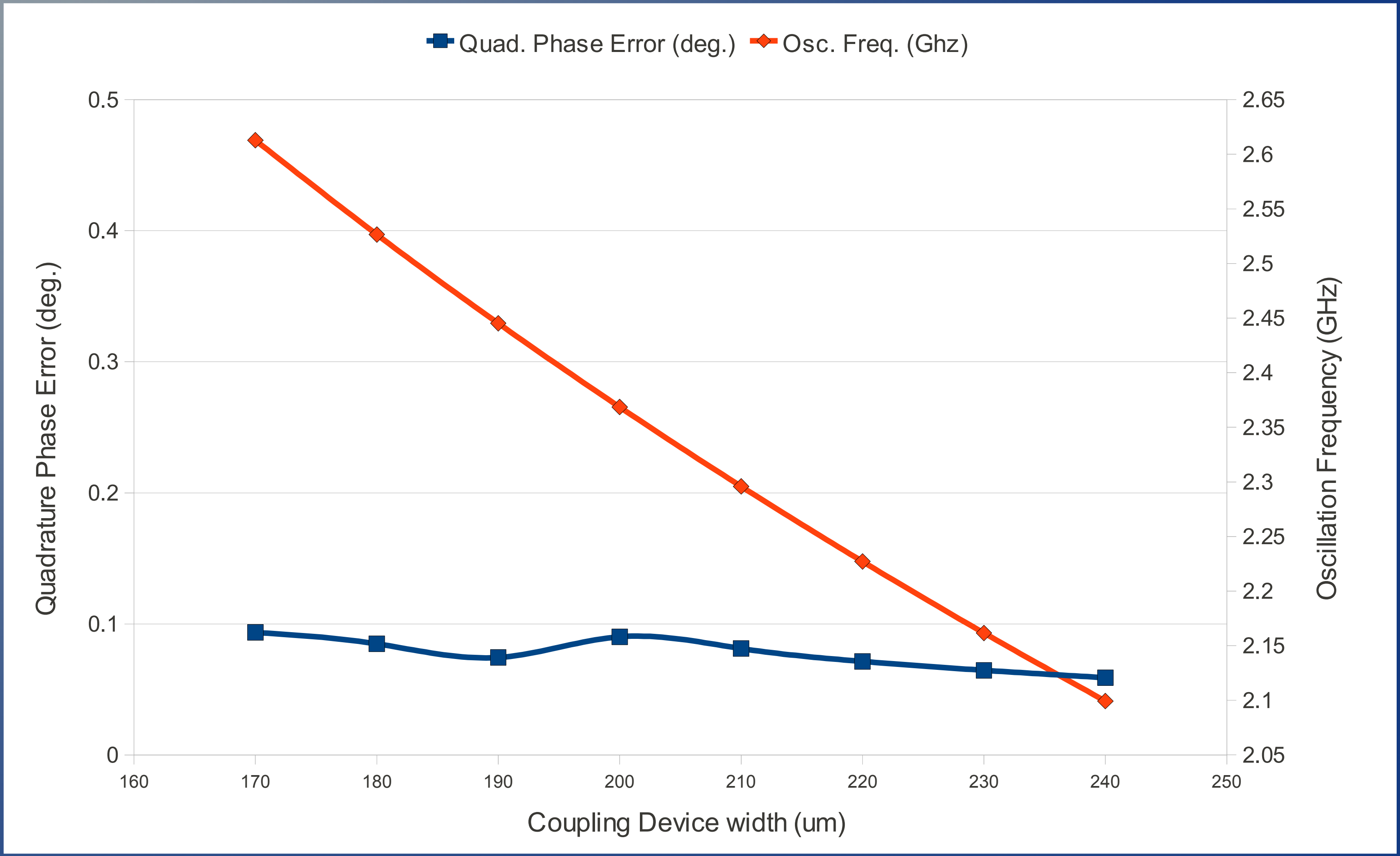


Series QRXO – Phase Noise



- -98.3 dBc/Hz @ 1MHz offset
- $M_{1\text{-}4}$ (flicker) = 70%

Series QRXO – Phase Error



Comparison

	Shunt coupled QRXO	Series coupled QRXO
Coupling Devices	Saturation (smaller)	Triode (larger)
Quadrature Error	×	✓
Phase Noise	✓	×
Current Consumption	✓	×

Summary

- Two topologies for quadrature coupling of relaxation oscillators were presented
- 2.4GHz quadrature oscillators were designed and simulated in a UMC 0.18µm CMOS process
  - Shunt-coupled $\Rightarrow$ lower current, larger quadrature error
  - Series-coupled $\Rightarrow$ larger current, lower quadrature error

References

[1] K. W. Cheng, K. Natarajan, and D. J. Allstot, “A Current Reuse Quadrature GPS Receiver in 0.13 μm CMOS ,” IEEE Journal of Solid-State Circuits, vol. 45, No.3, pp. 510–523, March 2010.

[2] B. G. Perumana, R. Mukhopadhyay, S. Chakarborty, C. H. Lee, and J. Laskar, “A Low-Power Fully Monolithic Subthreshold CMOS Receiver With Integrated LO Generation for 2.4 GHz Wireless PAN Applications ,” IEEE Journal of Solid-State Circuits, vol. 43, No.10, pp. 2229–2238, October 2008.

[3] A. Rofougaran, J. Rael, M. Rofougaran, and A. Abidi, “A 900MHz CMOS LC-Oscillator with Quadrature Outputs,” IEEE International Solid-State Circuits Conference, Digest of Technical Papers, 1996.

[4] P. Andreani, “A 2 GHz, 17% Tuning Range Quadrature CMOS VCO with High Figure-of-Merit and 0.6° Phase Error,” Proceedings of the 28th European Solid-State Circuits Conference, 2002.

[5] C. J. M. Verhoeven, “A High-Frequency Electronically Tunable Quadrature Oscillator ,” IEEE Journal of Solid-State Circuits, vol. 27, No.7, pp. 1097–1100, July 1992.

[6] B. Zhou, W. Rhee, and Z. Wang, “Relaxation oscillator with quadrature triangular and square waveform generation ,” Electronics Letters, vol. 47, No.13, 23rd June 2011.

[7] J. R. Fernandes, M. H. L. Kouwenhoven, C. van den Bos, L. B. Oliveira, and C. J. M. Verhoeven, “The Effect of Mismatches and Delay on the Quadrature Error of a Cross-Coupled Relaxation Oscillator,” IEEE Transactions on Circuits and Systems-I: Regular Papers, vol. 54, No.12, pp. 2592–2598, December 2007.

Thank you