National Aeronautics and Space Administration

FY24 Strategic University Research Partnership (SURP)

Monolithic W-Band Frequency Synthesizer

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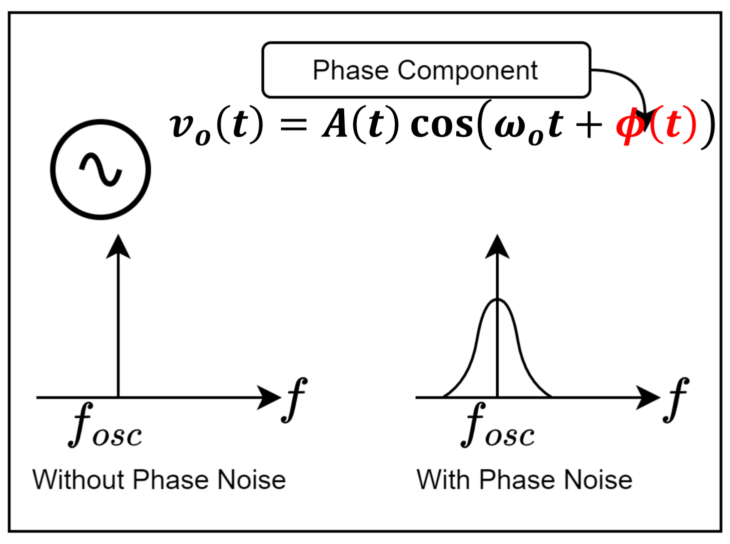
Objectives

Analysis, design, tape-out, and measurements of low-phase-noise millimeter-wave voltage-controlled oscillators in a commercial foundry SiGe HBT process.

Phase Noise



$$\mathcal{L}(\Delta f) = 10\log\left(\frac{k\,T\,F}{2\,Q_L^2\,P_{res}}\left(\frac{f_o}{\Delta f}\right)^2\right)$$

$\mathcal{L}(\Delta f)$: Phase Noise at Δf offset of carrier f_o

T : Absolute Temperature

F : Excess Noise Number

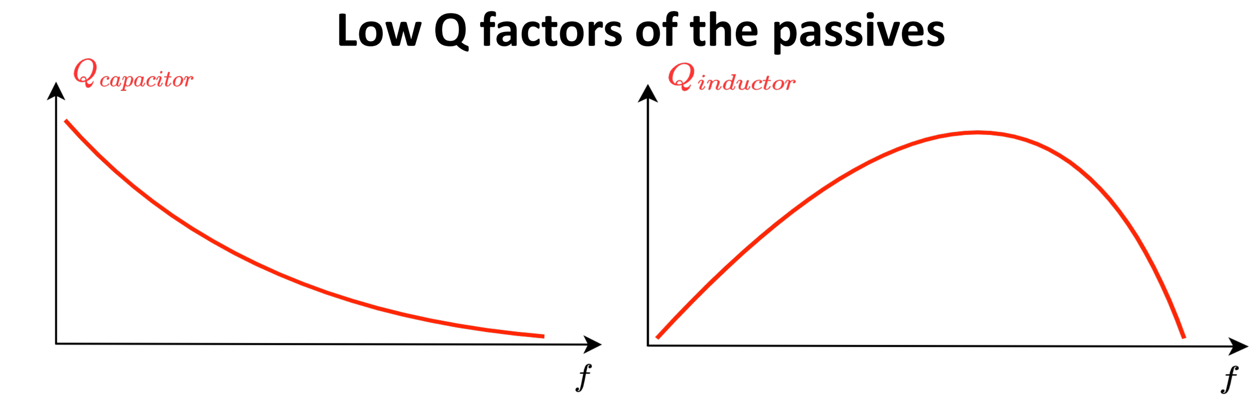
k : Boltzmann Constant

Q_L: Loaded quality-factor of the Resonator

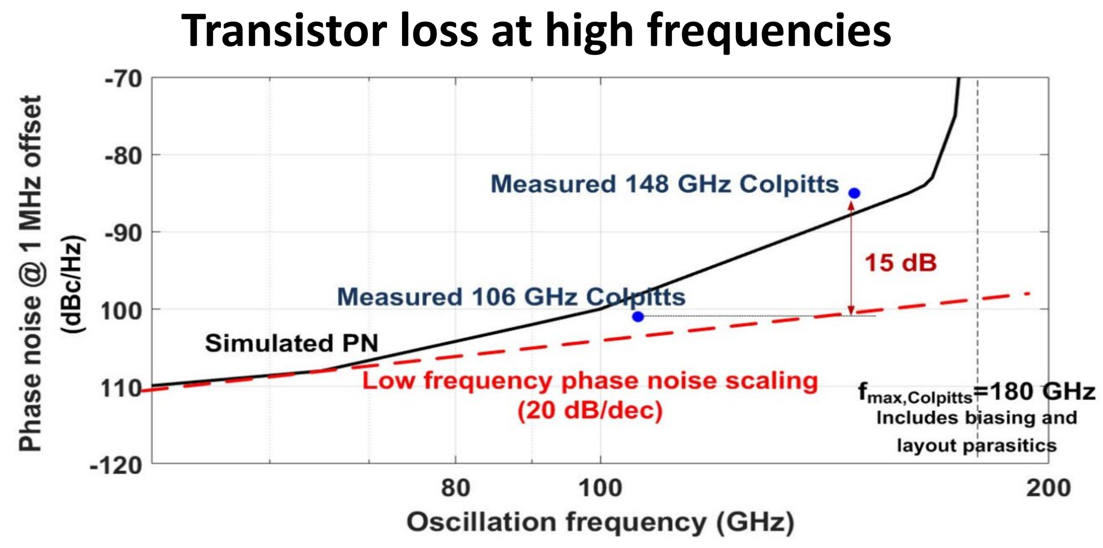
P_{res}: Power Dissipated at the Resonator

Challenges

Low Q factors of the passives

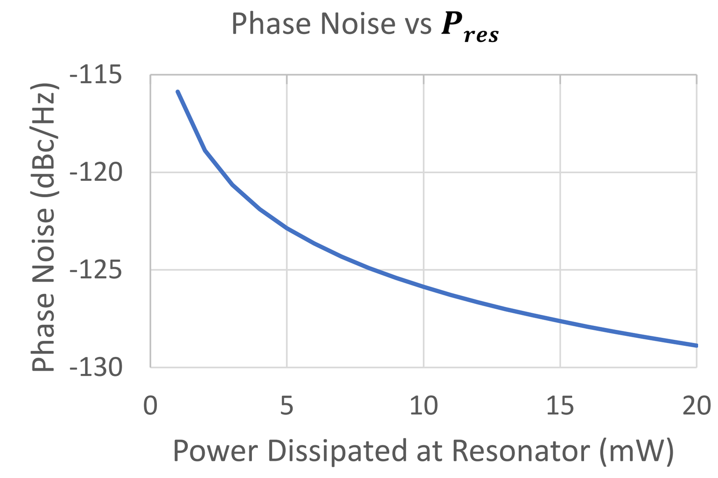


Transistor loss at high frequencies

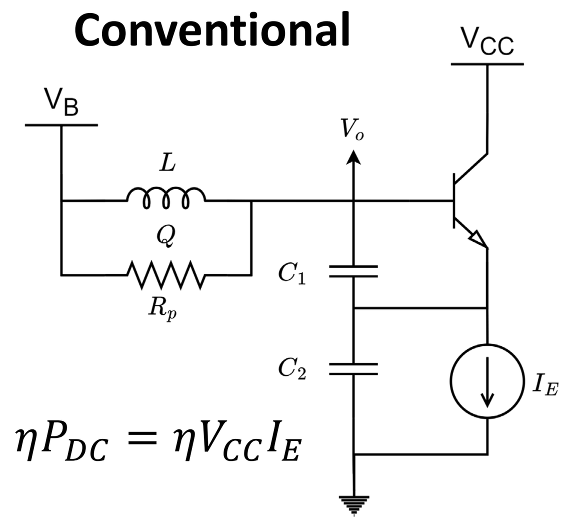


A. Imani and H. Hashemi, "Frequency and Power Scaling in mm-Wave Colpitts Oscillators," in IEEE Journal of Solid-State Circuits, vol. 53, no. 5, pp. 1338-1347, May 2018.

Improving Phase Noise by Increasing Power

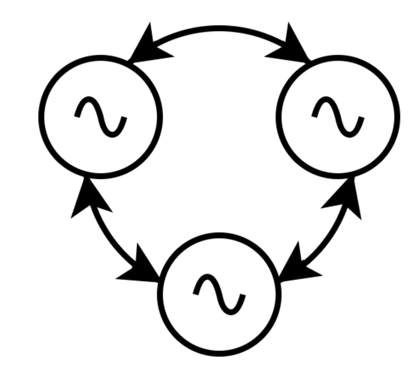


Conventional



$$P_{res} = \eta P_{DC} = \eta V_{CC} I_E$$

Coupled Oscillators



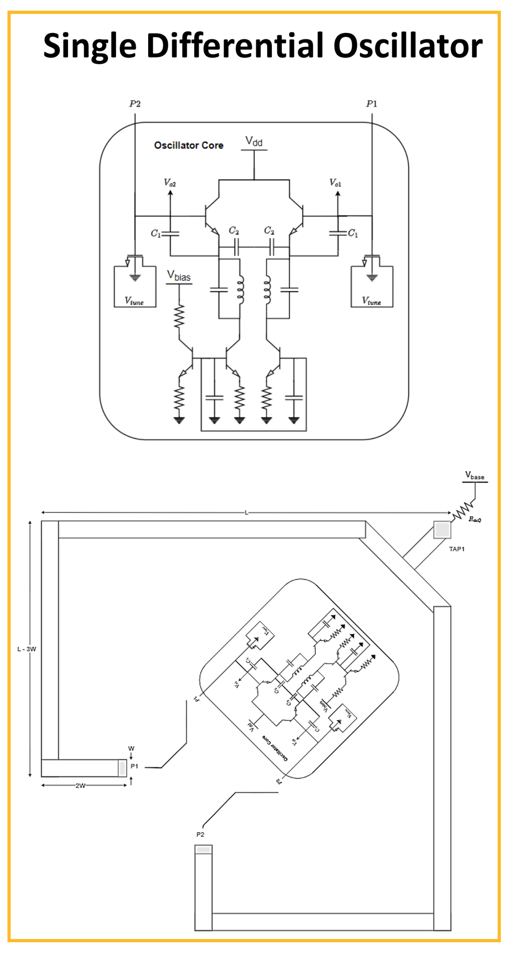
$$f_{osc}\Big|_{system} = \frac{1}{N}\sum_{i=1}^{N} f_{osc,i}$$

$$P\Big|_{system} = N\,P_{single}$$

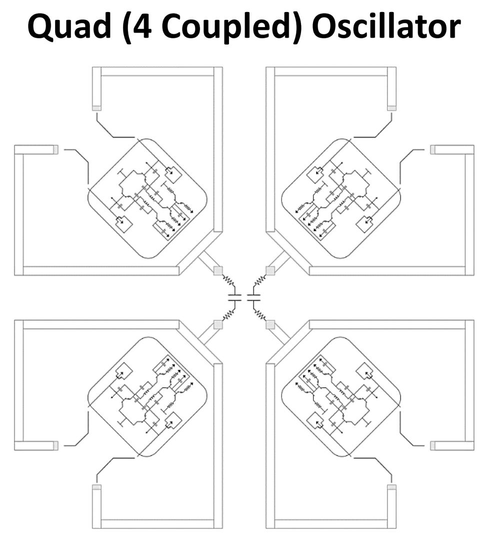
$$\mathcal{L}(\Delta f)\Big|_{system} = \frac{1}{N}\mathcal{L}(\Delta f)\Big|_{single}$$

Scalable Coupled Oscillator Design

Single Differential Oscillator

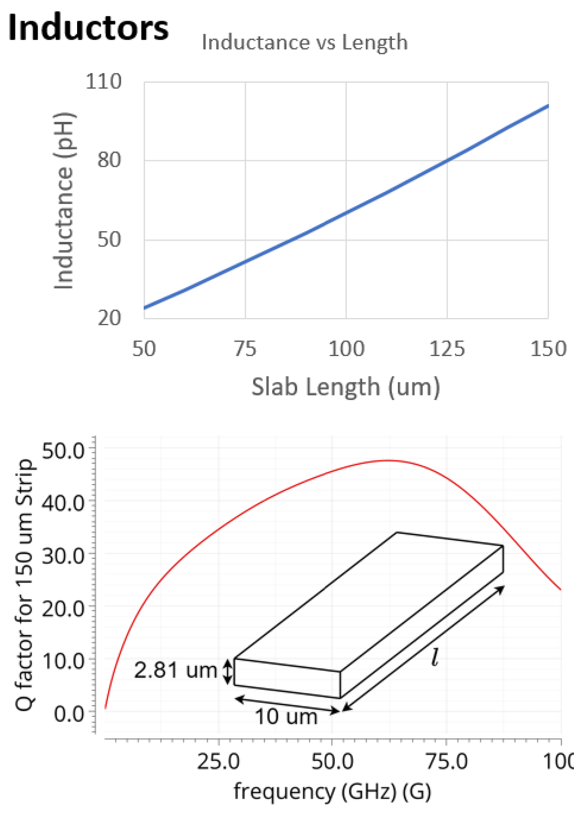


Quad (4 Coupled) Oscillator



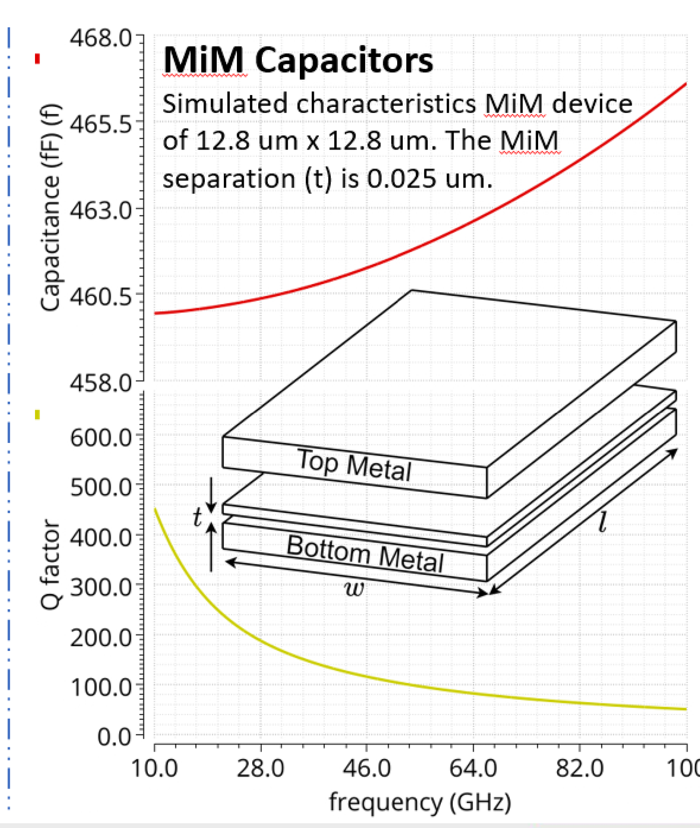
A above unit quad cell can be scaled in 2D with magnetic coupling.

Inductors

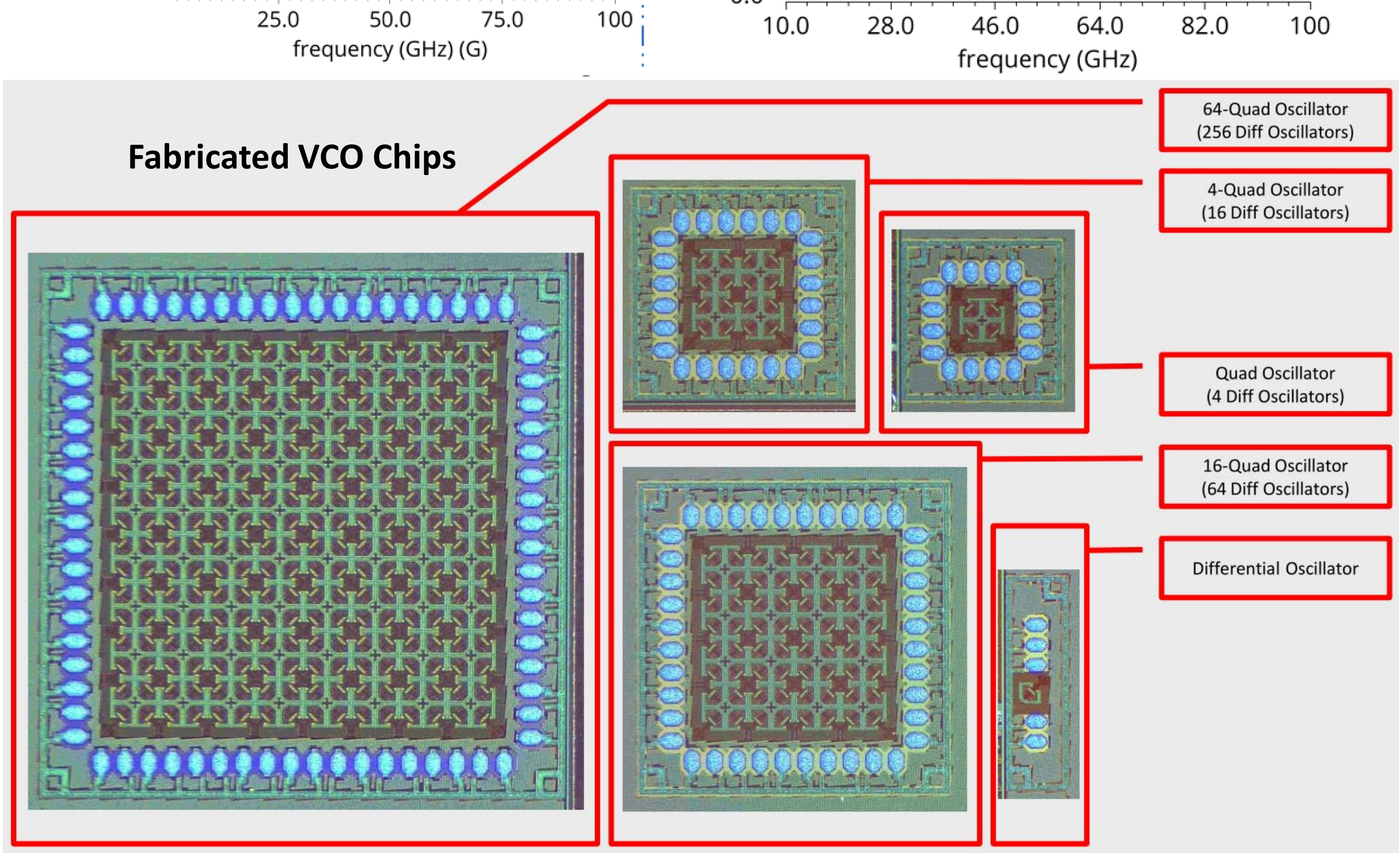


MiM Capacitors

Simulated characteristics MiM device of 12.8 um x 12.8 um. The MiM separation (t) is 0.025 um.

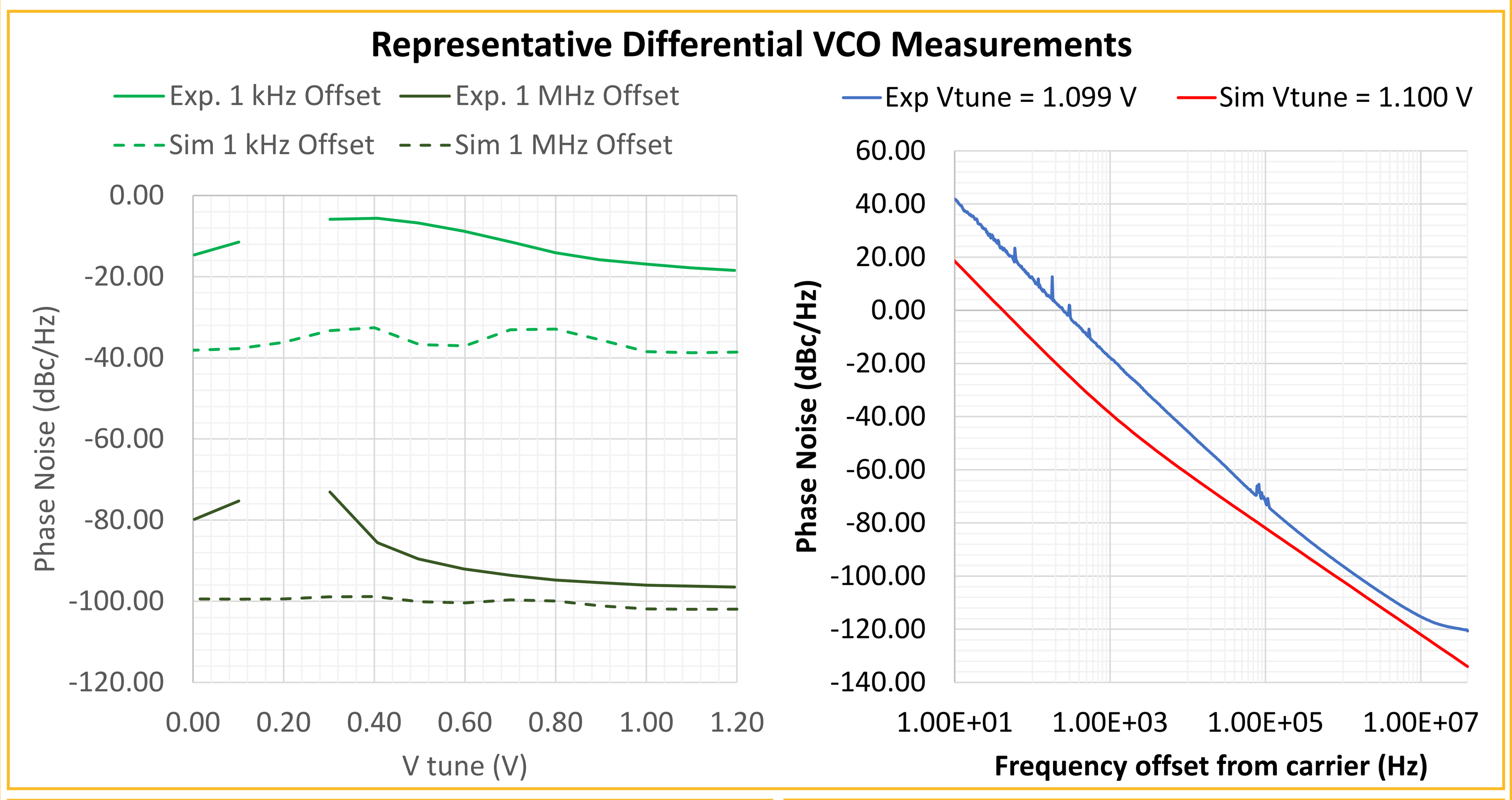


Fabricated VCO Chips

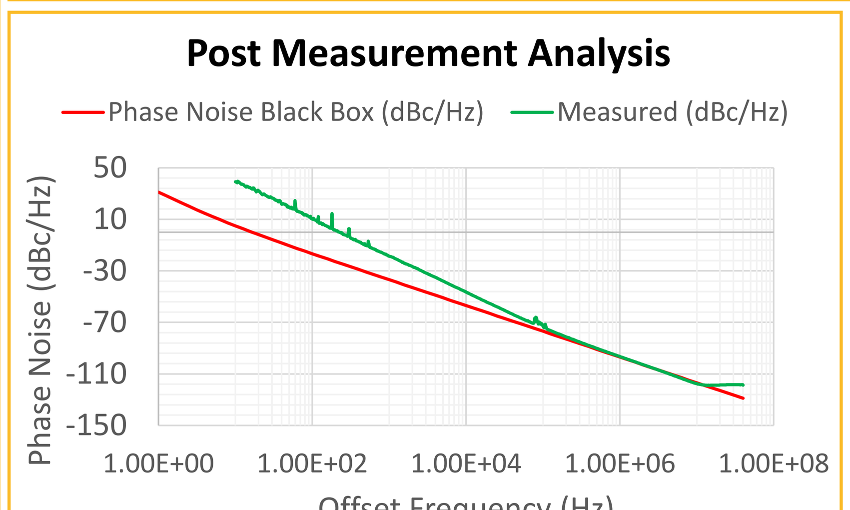


Experimental Results, Analysis, and Future Work

Representative Differential VCO Measurements



Post Measurement Analysis



- Post-measurement EM simulation of the entire VCO layout brings the results closer to measurements.
- The $1/f^3$ region of measured phase noise is still considerably higher compared with simulation.

Future Directions

- Invent magnetic coupling layout schemes which will have minimum effects from the layout of the oscillator core.
- Utilization of different resonator architectures
  - Resonance mode
    - Parallel resonance and coupled
    - Series resonance
    - Series resonance and coupled
  - Different Waveforms with different ISFs such as class F.
- Invent different oscillator topologies which not only depends on magnetic coupling when creating coupled oscillator arrays.

Publication and Experimental Results Summary

Design/ Author		VCC (V)	Current	Phase Noise*	Max. Frequency	Tuning Range	FoM_1 *	FoM_T *	No of Cores	Technology
This Work	Design 1	1.5 V	5.5 mA (max)	-96.5 dBc/Hz	37.3 GHz	3.2 GHz (9.0 %)	-179.2 dB	-179.2 dB	1	180 nm SiGe
	Design 2	1.5 V	22 mA (max)	-102.3 dBc/Hz	35.1 GHz	2.0 GHz (5.5 %)	-178.0 dB	-173.4 dB	4	180 nm SiGe
	Design 3	1.5 V	88 mA (max)	-106.9 dBc/Hz	34.7 GHz	3.1 GHz (8.7 %)	-176.5 dB	-175.9 dB	16	180 nm SiGe
	Design 4	1.5 V	352 mA (max)	Oscillators did not lock into a single frequency.					64	180 nm SiGe
	Design 5	1.5 V	1408 mA (max)	Oscillators did not lock into a single frequency.					256	180 nm SiGe

$$\mathrm{FoM}_1 = PN\Big|_{dB} - 20\log\left(\frac{f}{\Delta f}\right) + 10\log\left(\frac{P_{DC}}{1mW}\right)$$

$$\mathrm{FoM}_T = PN\Big|_{dB} - 20\log\left(\left(\frac{f_{osc}}{\Delta f}\right)*\left(\frac{TR\%}{10}\right)\right) + 10\log\left(\frac{P_{DC}}{1\text{ mW}}\right)$$

* Phase noise, FoM, FoM_T and are considered with 1 MHz offset from carrier frequency.

Significance/Benefits to JPL and NASA: The long-term goal of this collaboration is to develop a compact W-band transceiver for application in W-band radars in upcoming missions. The development of this compact radar has several significant building blocks that require innovations in mm-wave circuit design and development to produce a compact system. One of which is a very low phase noise oscillator that results in a high-performance LO for RF and a high-performance clock for digital subsystems of the radar. Hence resulting in high performance radar that allows optimization of velocity and range ambiguities for radar landers and precise measurements in minuscule fragments of molecules and particles of space and earth atmospheric environment.

Publications:
NA

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