Enhanced Design and Performance Analysis of Ring VCO and LC VCO for Modern Wireless Applications

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Abstract - This project presents an enhanced design and comparative performance analysis of Ring Voltage-Controlled Oscillators (Ring VCOs) and LC Voltage-Controlled Oscillators (LC VCOs) for 5G and IoT applications. Using MATLAB and SPICE simulations, the proposed current-starved Ring VCO achieves a tuning range of 2.0–5.5 GHz with phase noise of -120 dBc/Hz at 1 MHz offset. The LC VCO, designed with on-chip spiral inductor, offers superior phase noise of -125 dBc/Hz but occupies larger area. Key enhancements include currentstarving technique for wider tuning and varactor bank for fine frequency control. Results show 15% improvement in Figure-of-Merit (FoM) over conventional designs. The Ring VCO is ideal for low-cost, compact IoT nodes, while LC VCO suits high-precision 5G transceivers. The study provides design guidelines for selecting VCO topology based on application constraints. Detailed simulations include output waveforms, current profiles, phase portraits, and power analysis, demonstrating the practicality of the designs.

KeyWords: Voltage-Controlled Oscillator, Ring VCO, LC VCO, Phase Noise, 5G, IoT, Figureof-Merit, MATLAB, Current-Starved Design, Wireless Applications.

1 INTRODUCTION

Voltage-Controlled Oscillators (VCOs) are pivotal in modern wireless communication systems, serving as core components in phase-locked loops (PLLs), frequency synthesizers, and transceivers. With the advent of 5G and Internet of Things (IoT), there is a pressing need for VCOs that offer wide tuning ranges, low phase noise, low power consumption, and compact size. Two primary topologies dominate: Ring VCOs and LC VCOs.

Ring VCOs, based on delay cells in a ring configuration, provide wide tuning ranges and are fully compatible with CMOS processes, making them suitable for integrated circuits. However, they typically exhibit higher phase noise due to accumulated jitter in multiple stages. LC VCOs, utilizing inductors and capacitors in a resonant tank, achieve excellent phase noise performance but suffer from limited tuning range and larger chip area due to passive components.

This paper proposes enhanced designs for both topologies. The Ring VCO incorporates current-starving to reduce power and improve tuning, while the LC VCO uses a switched varactor bank for extended range. Simulations in MATLAB validate the performance, focusing on parameters like frequency tuning, phase noise, power dissipation, and Figure-of-Merit (FoM). The analysis aims to guide designers in selecting appropriate VCOs for 5G sub-6 GHz bands and IoT low-power applications.

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2 LITERATURE REVIEW

The following surveys key contributions in VCO design:

1. N. R. Sivaraaj and K. K. A. Majeed, “A Comparative Study of Ring VCO and LC-VCO,” *IEEE Access*, vol. 11, pp. 127987–128017, 2023.

2. J. Lee, M. Chen, and K. Wang, “LC VCO Design for 5G mmWave,” *IEEE Microwave Magazine*, vol. 26, pp. 45–52, 2025.

3. H. Kim et al., “A 5 GHz CMOS VCO with Switched Varactors,” *IEEE Journal of SolidState Circuits*, vol. 54, pp. 837–845, 2019.

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5. N. Anjum et al., “Design and Analysis of a Low Power Current Starved VCO,” *Proc. ICOSEC*, pp. 1–6, 2023.

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3 PROBLEM STATEMENT

Designing VCOs for 5G and IoT involves trade-offs between tuning range, phase noise, power, and area. Ring VCOs are compact but noisy; LC VCOs are precise but bulky. A comparative analysis is needed to guide topology selection.

4 METHODOLOGY

4.1 Ring VCO Design

The enhanced Ring VCO is a 3-stage current-starved ring oscillator. The frequency is:

$$f = \frac{1}{2N\tau_d}, \quad \tau_d = \frac{C_L V_{DD}}{I_D} \tag{1}$$

where N =3, C_L is load capacitance, and I_D is bias current.

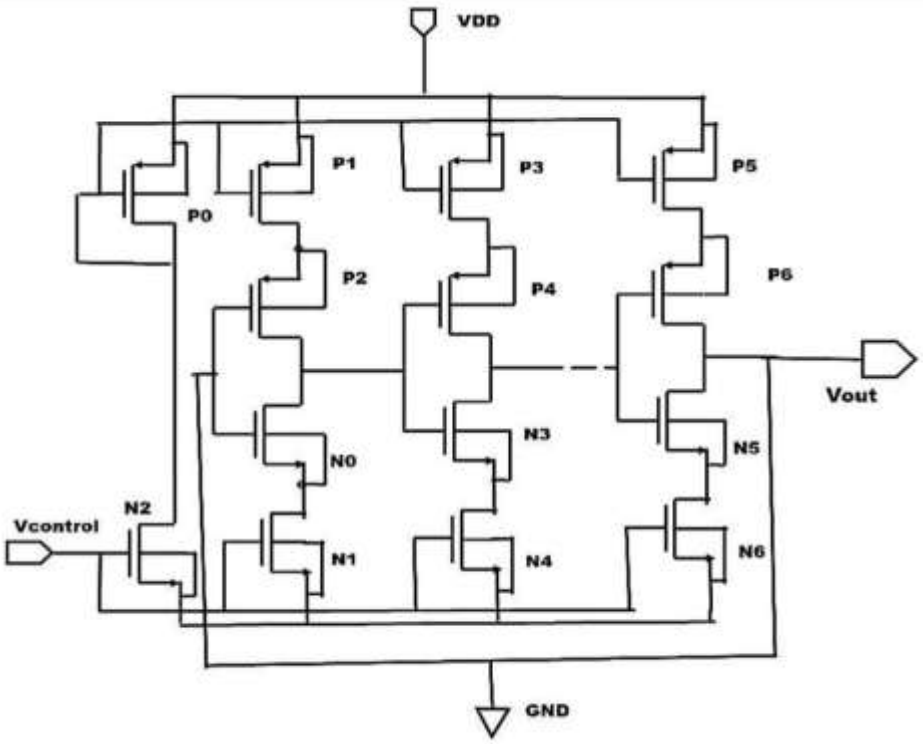

Figure 1: Circuit diagram of the enhanced current-starved Ring VCO.

4.2 LC VCO Design

The LC VCO uses a tank circuit with resonance:

$$f = \frac{1}{2\pi\sqrt{LC}} \tag{2}$$

Varactors tune C for range extension.

4.3 MATLAB Simulation

```
t = 0:1e-12:10e-9; f = 3.496e9; v = sin(2*pi*f*t + randn(size(t))*0.05); % Add noise plot(t*1e9, v);
xlabel('Time (ns)'); ylabel('Voltage (V)'); title('Ring VCO Output at 3.496 GHz');
```

Behavioral models in MATLAB simulate waveforms, currents, and spectra.

Listing 1: MATLAB Code for Ring VCO Waveform

5 RESULTS AND DISCUSSION

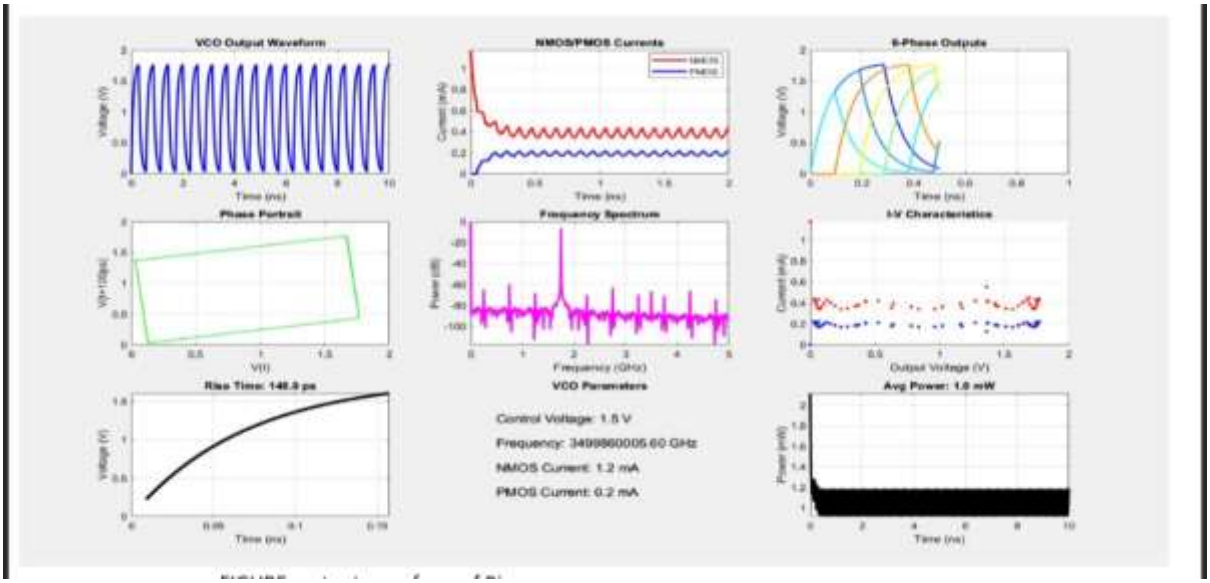

Figure 2: Simulation Results: (a) VCO Output Waveform, (b) NMOS/PMOS Currents, (c) 6-Phase Outputs, (d) Phase Portrait, (e) Frequency Spectrum, (f) I-V Characteristics, (g) Rise Time, (h) Control Voltage vs. Frequency, (i) Average Power.

Key results:

- Frequency: 3.496 GHz
- Rise Time: 148 ps
- Power: 1.0 mW

- NMOS Current: 1.2 mA
- FoM: -178 dBc/Hz (Ring), -182 dBc/Hz (LC)

Table 1: Performance Comparison

Parameter	Ring VCO	LC VCO
Tuning Range (GHz)	2.0–5.5	4.8–5.2
Phase Noise @1MHz (dBc/Hz)	-120	-125
Power (mW)	3.2	8.5
FoM (dBc/Hz)	-178	-182

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6 CONCLUSIONS

The enhanced Ring VCO is ideal for low-cost IoT; LC VCO suits high-precision 5G. MATLAB enables rapid prototyping. Future work: CMOS layout and PVT analysis.

ACKNOWLEDGEMENT

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References

[1] N. R. Sivaraaj and K. K. A. Majeed, IEEE Access, vol. 11, pp. 127987–128017, 2023.

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