Basic LC VCOs

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Outline

• Operation of Oscillators
• One-Port View
• Cross-Coupled Oscillator
• VCO Techniques
• Discrete Tuning
Voltage-Controlled Oscillators

- Center Frequency
- Tuning Range:
  - Band of Interest
  - PVT Variations
- Gain (Sensitivity)
  \[ K_{VCO} \geq \frac{\omega_2 - \omega_1}{V_2 - V_1} \]
- Supply Rejection
- Tuning Linearity
- Intrinsic Jitter
- Output Amplitude
Feedback Oscillator
One-Port View

Example of negative resistance:

\[
\frac{V_X}{I_X}(j\omega) = \frac{1}{jC_1\omega} + \frac{1}{jC_2\omega} - \frac{g_m}{C_1C_2\omega^2}
\]
Use of Resonance in Oscillator Design

Series-Parallel Transformation

Tank Impedance Characteristics

Tuned Amplifier

Voltage Swings
Cross-Coupled Oscillator

- Looks like a diff pair with positive feedback.
- Oscillation freq is given by:
Use of Symmetric Inductor

- Requires accurate model of inductor.
  → can’t begin design without a useful inductor library.
Output Swing

- Peak differential output voltage swing is given by:

\[ V_{out,P} = \frac{4}{\pi} I_{SS} R_P \]

- How much is the output CM level?
Supply Sensitivity

- Voltage-dependent $C_{DB}$ results in a finite $K_{vco}$ from $V_{DD}$ to output frequency:

$$\omega_{osc} = \frac{1}{\sqrt{L_1(C_1 + C_{DB})}}$$

$$C_{DB} = \frac{C_{DB0}}{(1 + \frac{V_{DD}}{\phi_B})^m}$$

$$K_{VCO} = \frac{\partial \omega_{out}}{\partial V_{DD}}$$

$$= \frac{\partial \omega_{osc}}{\partial C_{DB}} \cdot \frac{\partial C_{DB}}{\partial V_{DD}}$$
One-Port View

\[
g_m R_P \geq 1
\]

\[
\frac{V_X}{I_X} = -\frac{2}{g_m}
\]
How Do We Vary the Frequency?

- Use a MOS varactor.
VCO Type I

To maximize tuning range, we wish to minimize $C_1$.

But $C_1$ is given by:
- Caps of M1 and M2 (including $4C_{gd}$)
- Cap of L1
- Input cap of next stage

Tuning range may be limited.

$$\omega_{osc} = \frac{1}{\sqrt{L_1(C_1 + C_{var})}}$$
VCO Type II

Select device dimensions to set the output CM level to about Vdd/2.
Varactor Modulation by $I_{DD}$

- Noise of current mirror becomes the dominant source.
- Does this effect exist in Type I VCO?
VCO Type III

- Tuning range:

\[
\Delta \omega_{osc} \approx \frac{1}{\sqrt{L_1 C_1}} \cdot \frac{1}{2C_1} \cdot \frac{C_S^2(C_{var2} - C_{var1})}{(C_S + C_{var2})(C_S + C_{var1})}
\]

- With 5% bottom-plate parasitic cap:

\[
\Delta \omega_{osc} \approx \frac{1}{\sqrt{L_1(C_1 + 0.5C_{max})}} \times \frac{0.43C_{max}}{2(C_1 + 0.5C_{max})}
\]
VCO Type IV

- Select device dimensions to set the output CM level to about Vdd/2.
- Output swing twice that of previous topologies.
- But tail noise modulates varactors.
Discrete Tuning

- But on-resistance of switches lowers tank Q:

\[
\frac{1}{Q_{tot}} = \frac{1}{Q_L} + \frac{1}{Q_{var}} + \frac{1}{Q_{caps}} = \frac{R_S}{L_1\omega} + R_{var}C_{var}\omega + R_{on}C_u\omega
\]
Use of “Floating” Switch