Basic LC VCOs

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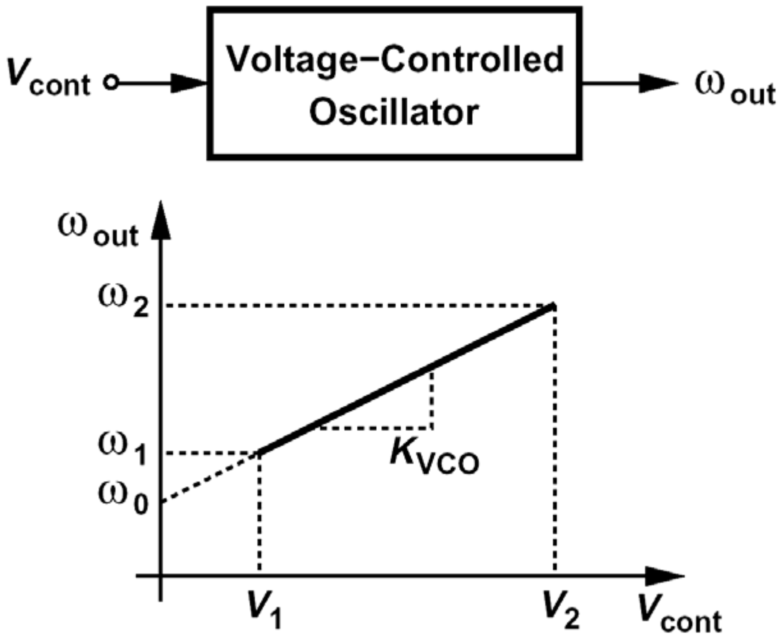
Outline

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

Voltage-Controlled Oscillators

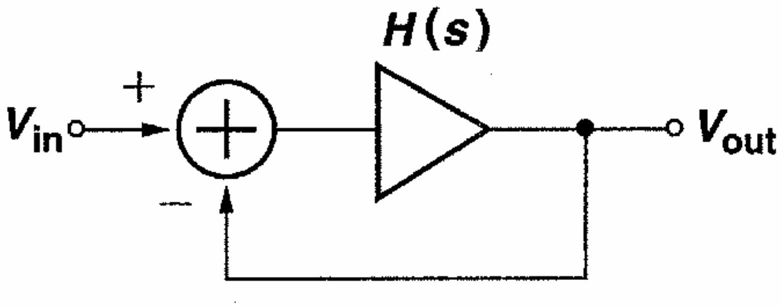


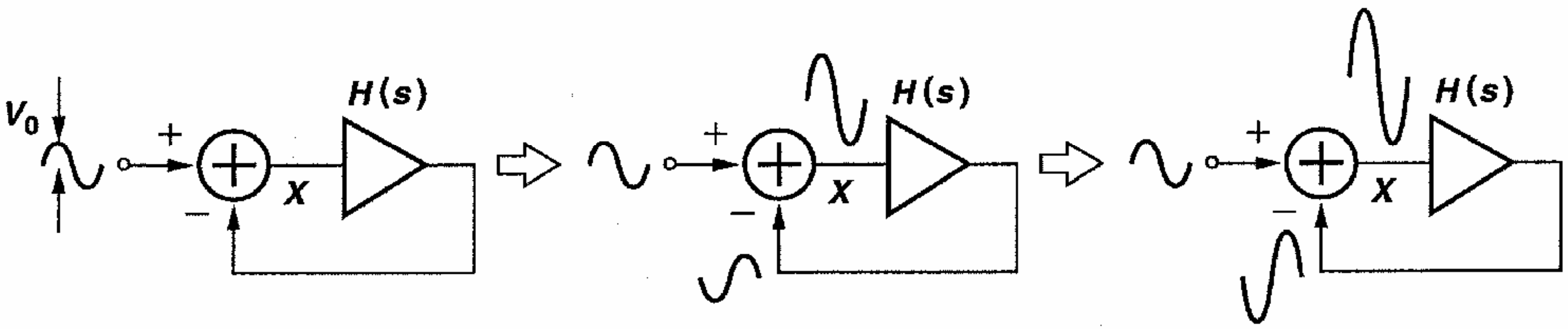
- Center Frequency
- Tuning Range:
  - Band of Interest
  - PVT Variations
- Gain (Sensitivity)

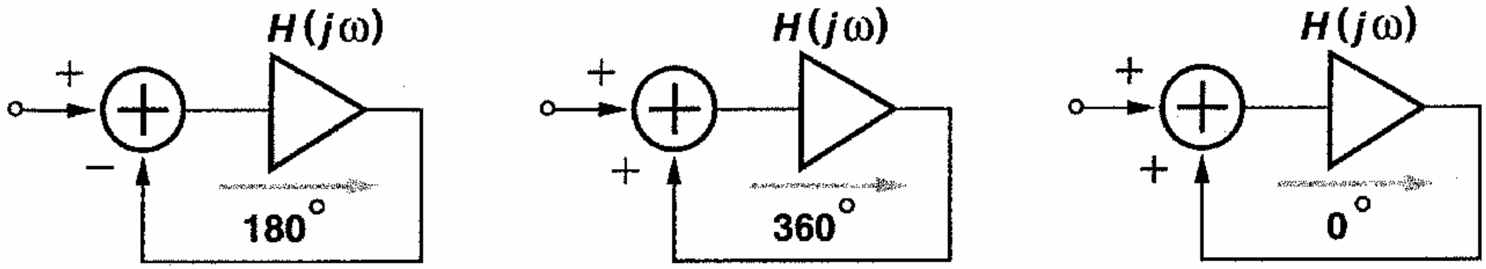
$$K_{VCO} \geq \frac{\omega_2 - \omega_1}{V_2 - V_1}$$

- Supply Rejection
- Tuning Linearity
- Intrinsic Jitter
- Output Amplitude

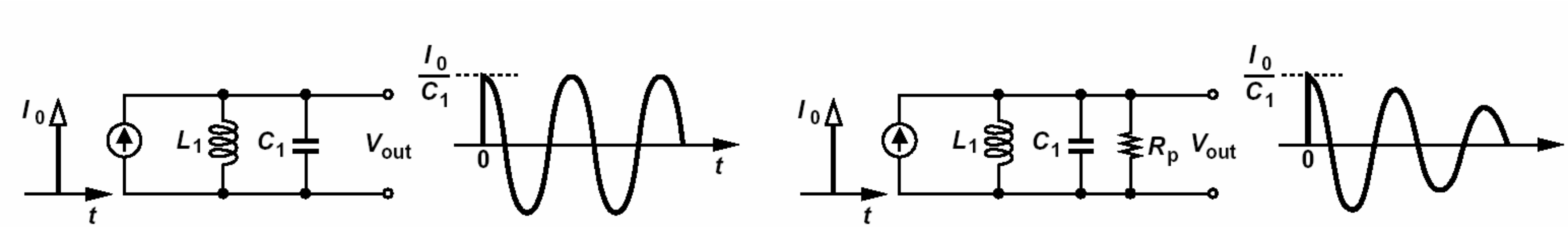
Feedback Oscillator

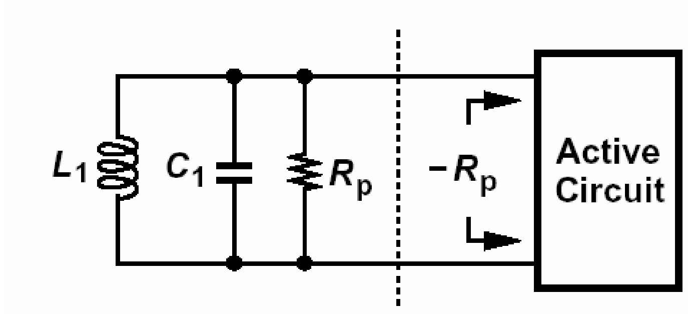




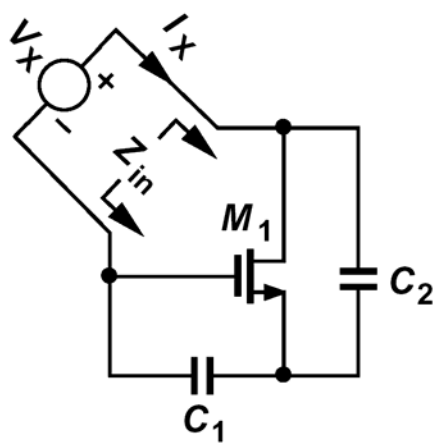


One-Port View





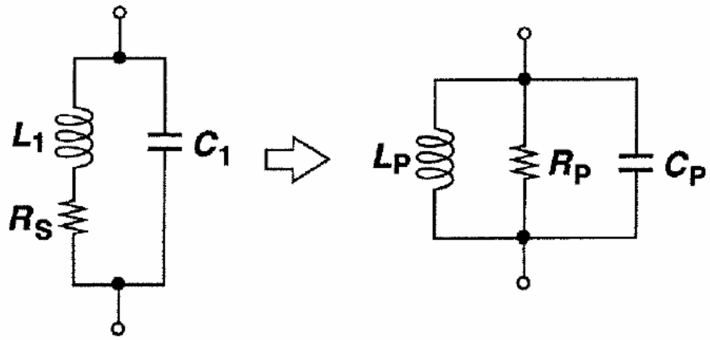
- **Example of negative resistance:**



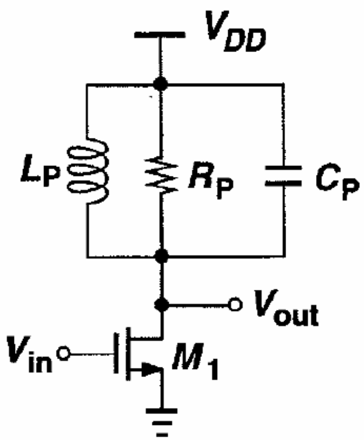
$$\frac{V_X}{I_X}(j\omega) = \frac{1}{jC_1\omega} + \frac{1}{jC_2\omega} - \frac{g_m}{C_1C_2\omega^2}$$

Use of Resonance in Oscillator Design

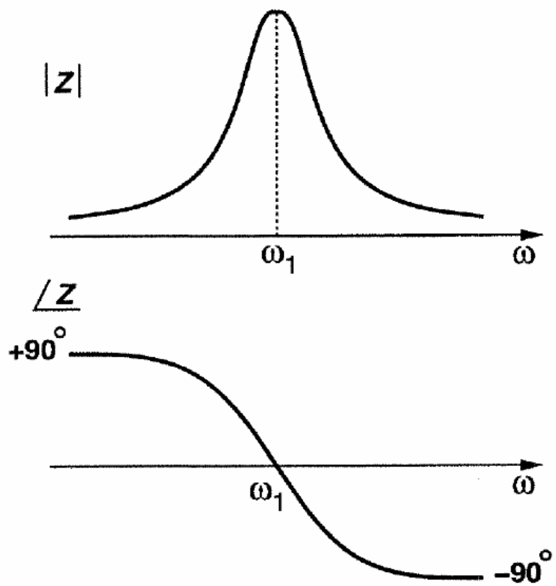
Series-Parallel Transformation



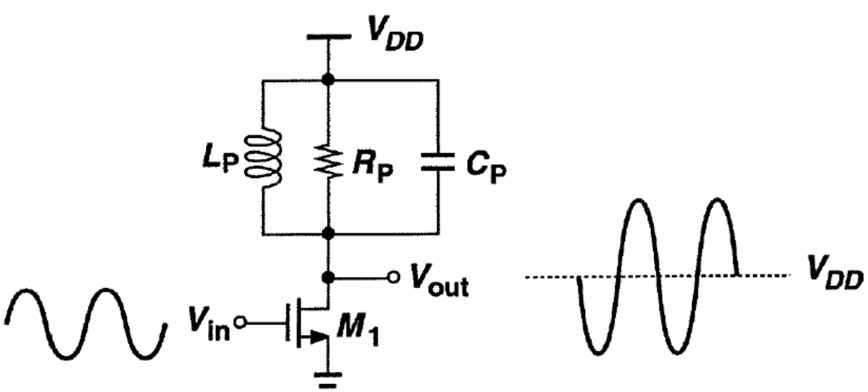
Tuned Amplifier



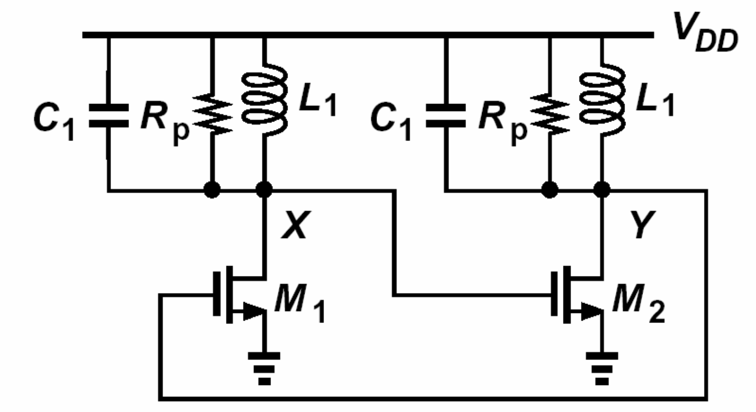
Tank Impedance Characteristics

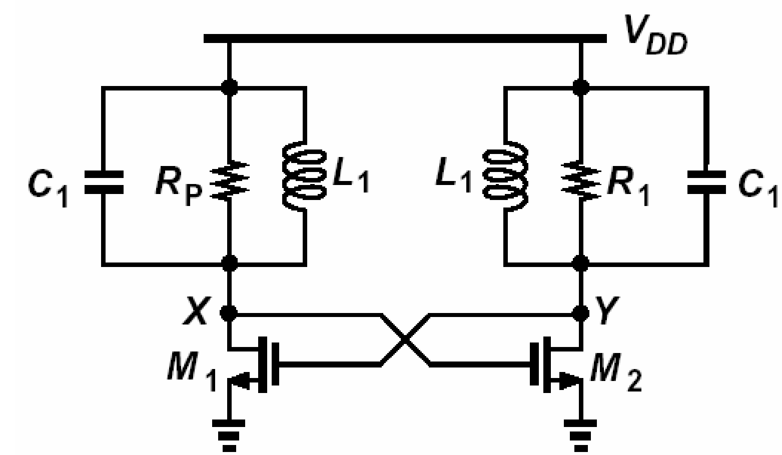


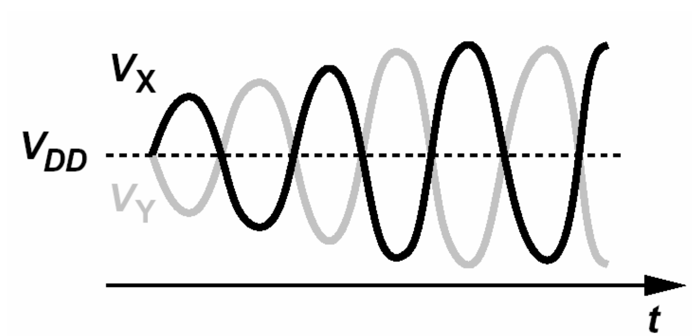
Voltage Swings

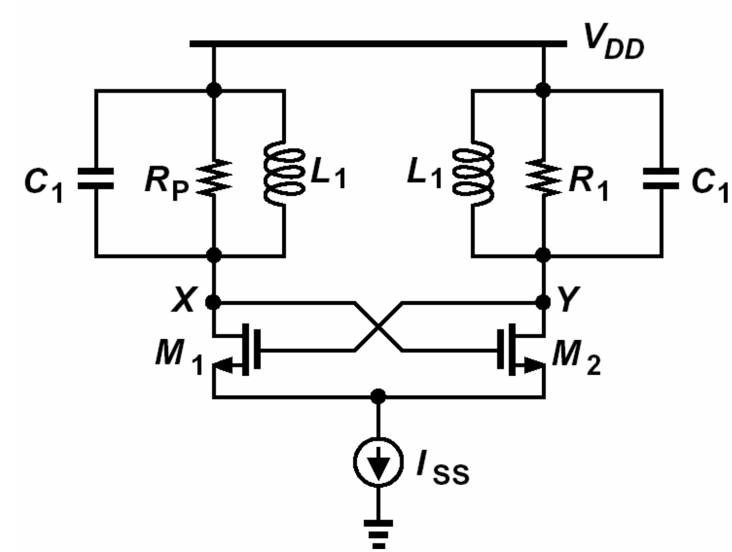


Cross-Coupled Oscillator



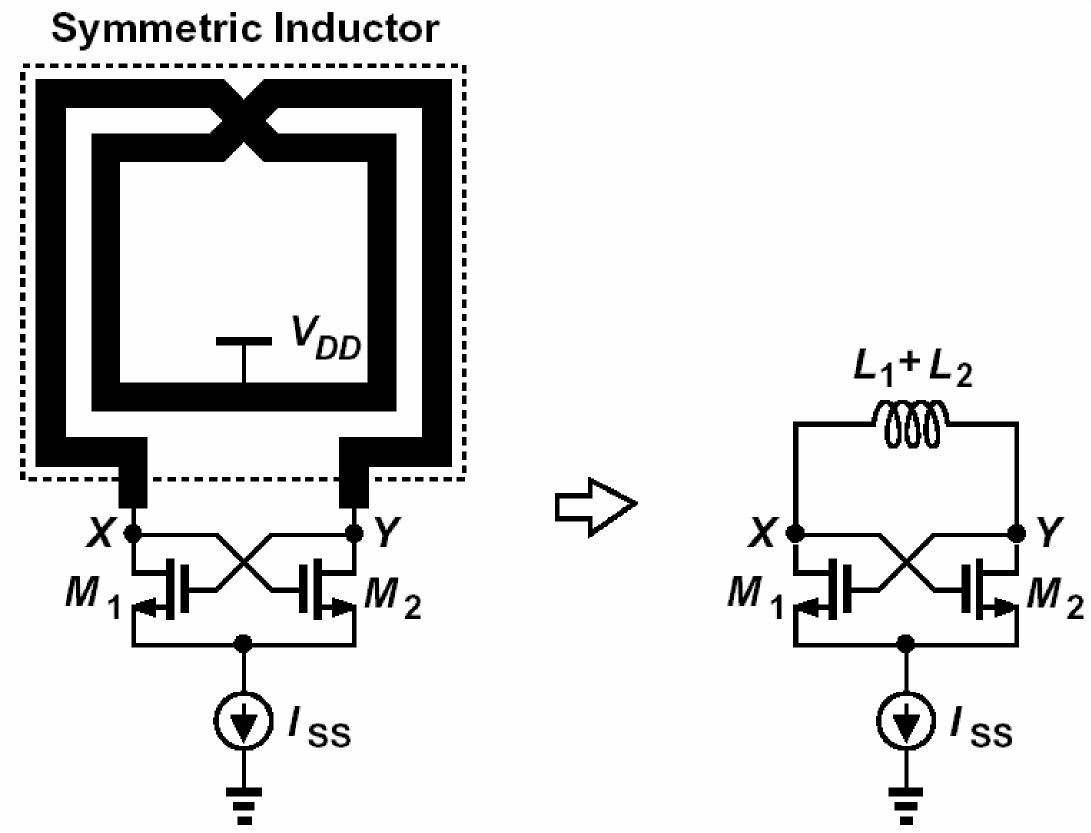






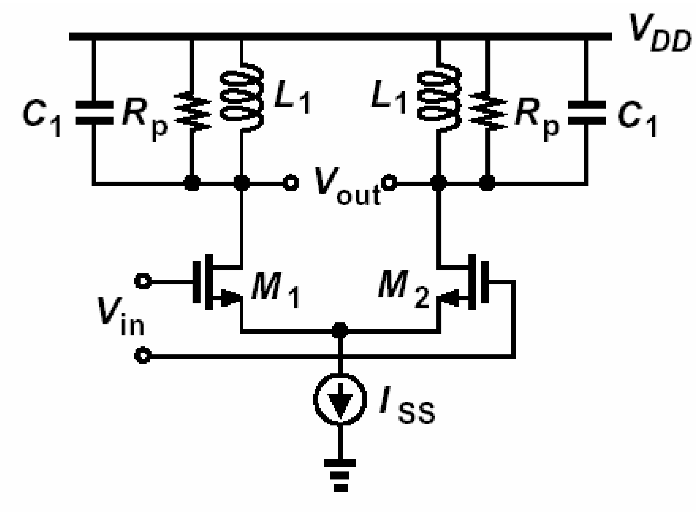
- Looks like a diff pair with positive feedback.
- Oscillation freq is given by:

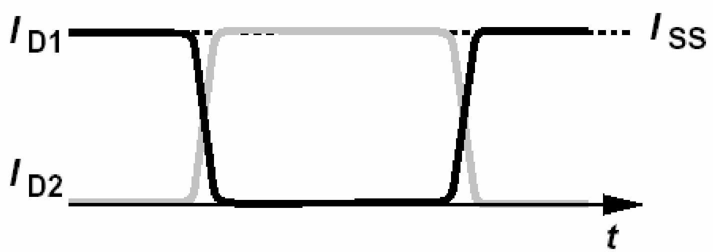
Use of Symmetric Inductor



- **Requires accurate model of inductor.**
  → can't begin design without a useful inductor library.

Output Swing



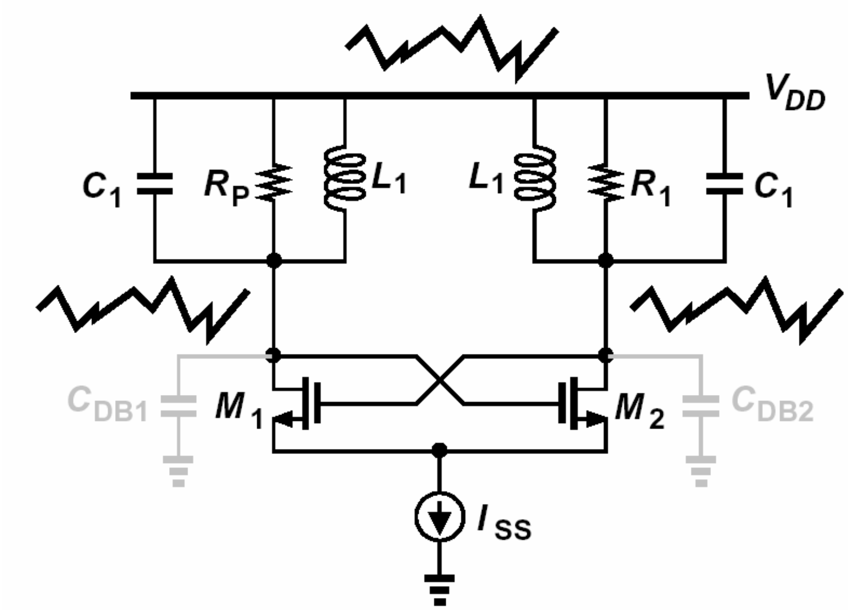


- Peak differential output voltage swing is given by:

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

- How much is the output CM level?

Supply Sensitivity



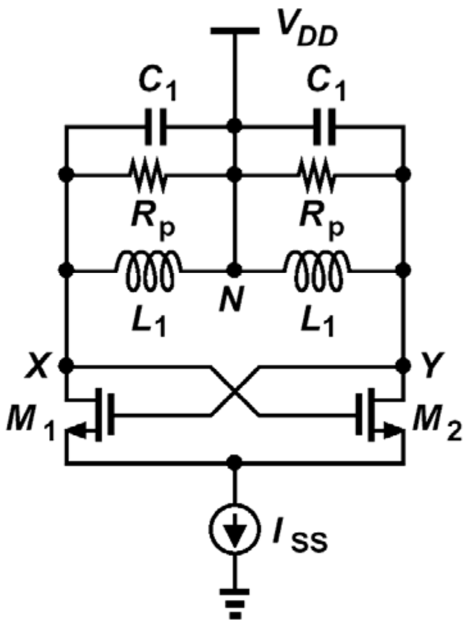
- **Voltage-dependent C_{DB} results in a finite K_{vco} from V_{DD} to output frequency:**

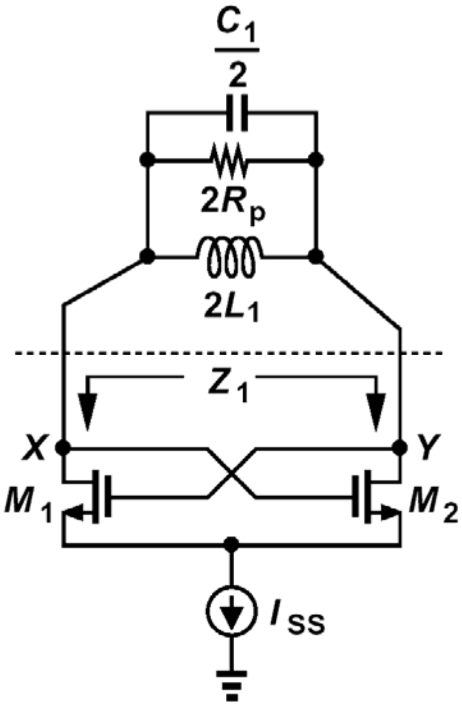
$$\omega_{osc} = \frac{1}{\sqrt{L_1(C_1 + C_{DB})}} \qquad C_{DB} = \frac{C_{DB0}}{\left(1 + \frac{V_{DD}}{\phi_B}\right)^m}$$

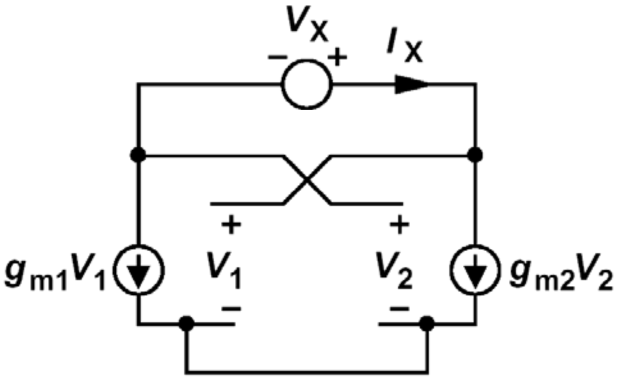
$$K_{VCO} = \frac{\partial \omega_{out}}{\partial V_{DD}} = \frac{\partial \omega_{osc}}{\partial C_{DB}} \cdot \frac{\partial C_{DB}}{\partial V_{DD}}$$

⇨

One-Port View



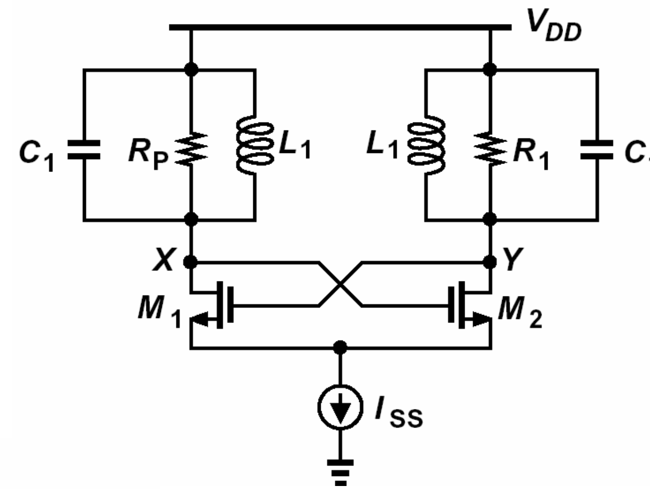




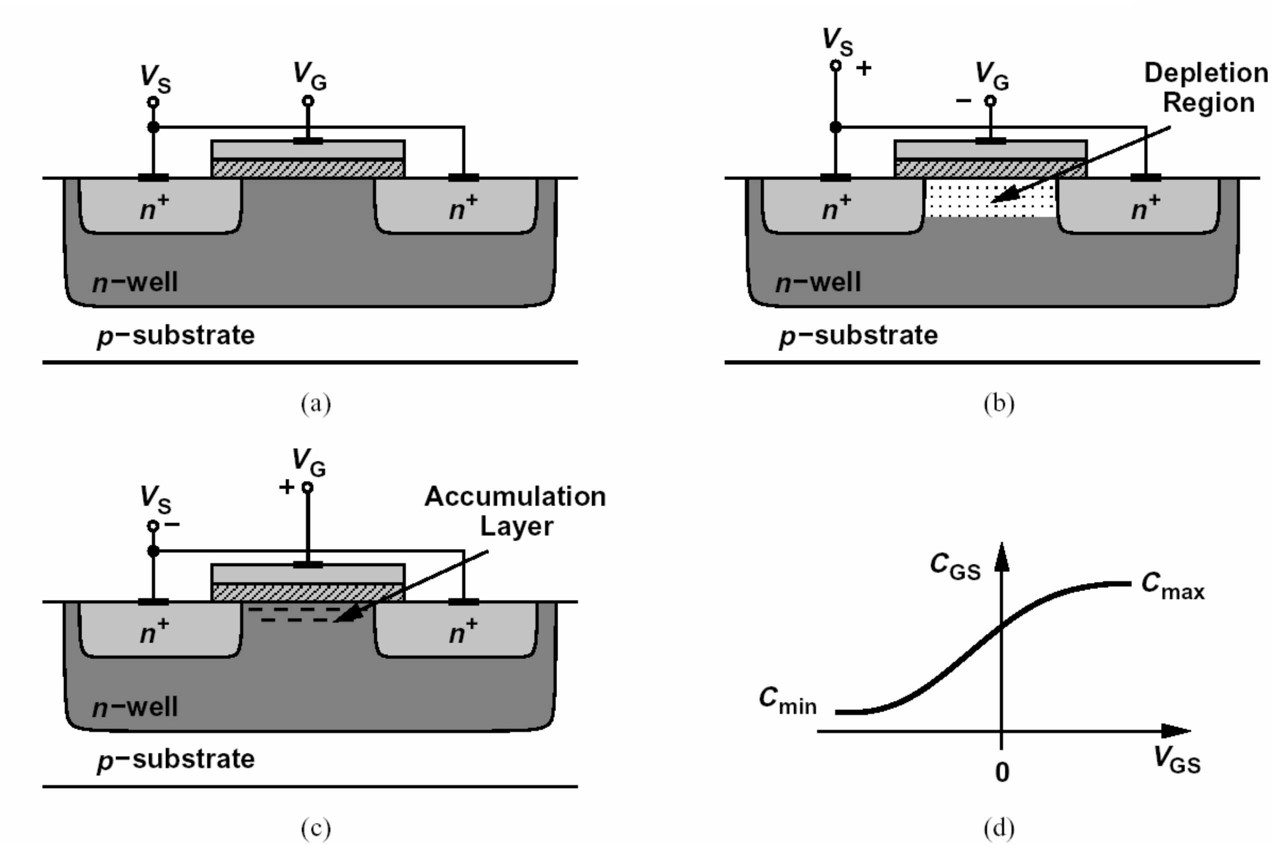
$$\frac{V_X}{I_X} = -\frac{2}{g_m}$$

$$g_m R_P \geq 1$$

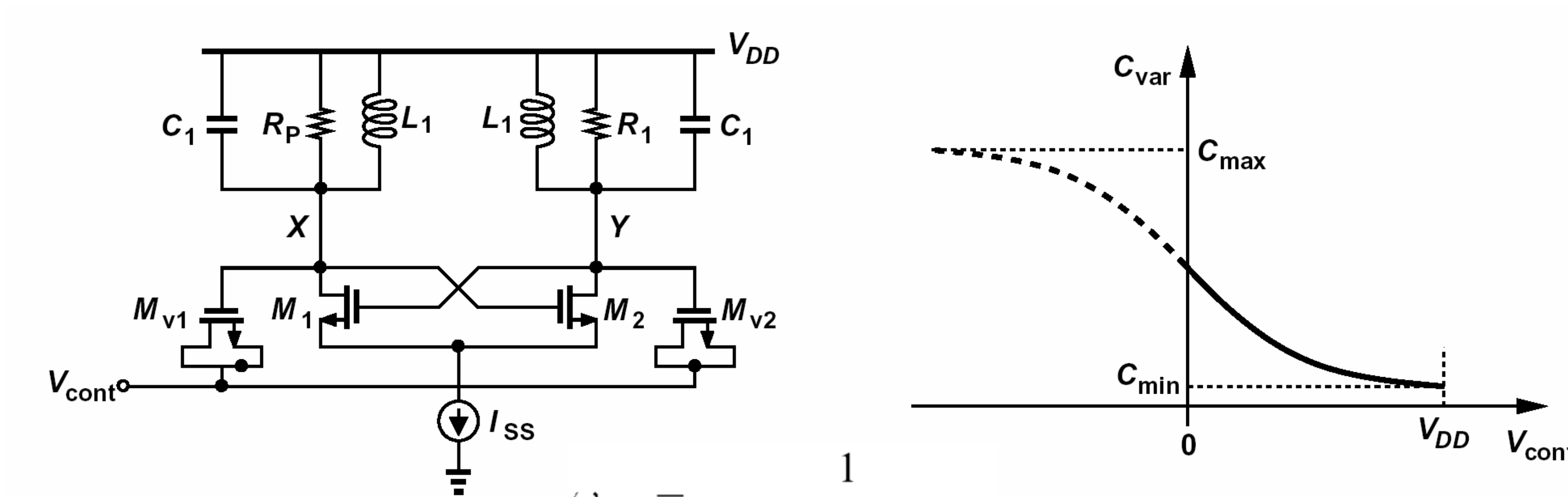
How Do We Vary the Frequeny?



- **Use a MOS varactor.**



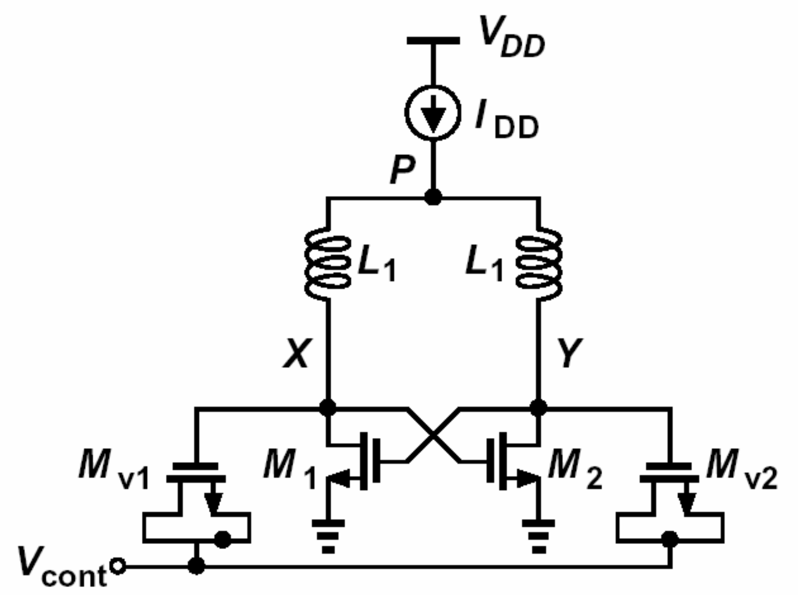
VCO Type I

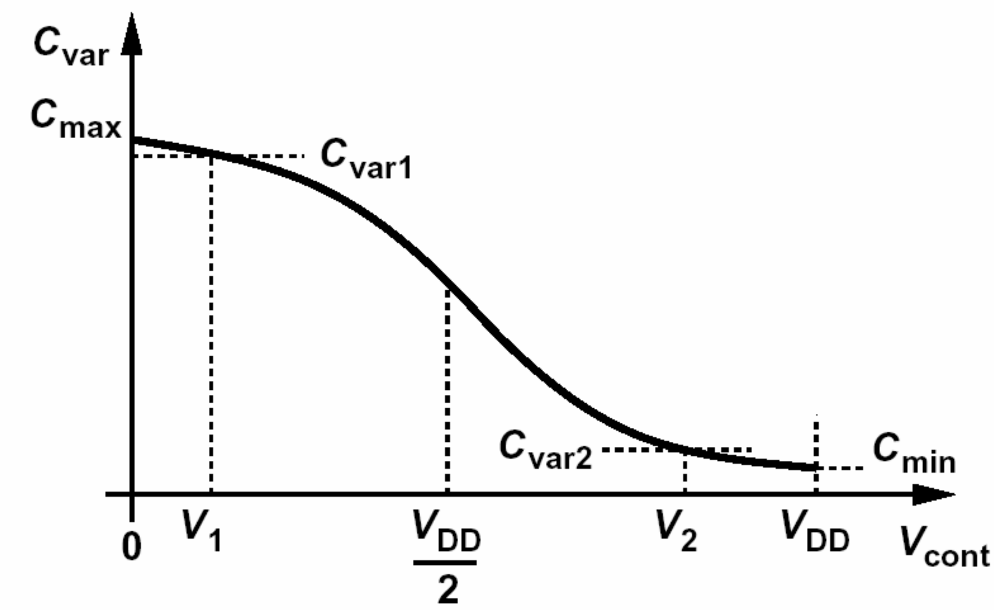


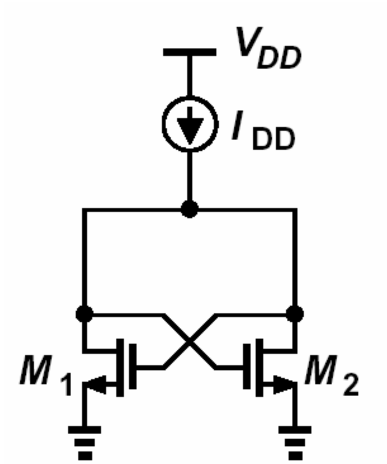
$$\omega_{osc} = \frac{1}{\sqrt{L_1(C_1 + C_{var})}}$$

- To maximize tuning range, we wish to minimize C1.
- But C1 is given by:
  - Caps of M1 and M2 (including 4Cgd)
  - Cap of L1
  - Input cap of next stage
- Tuning range may be limited.

VCO Type II

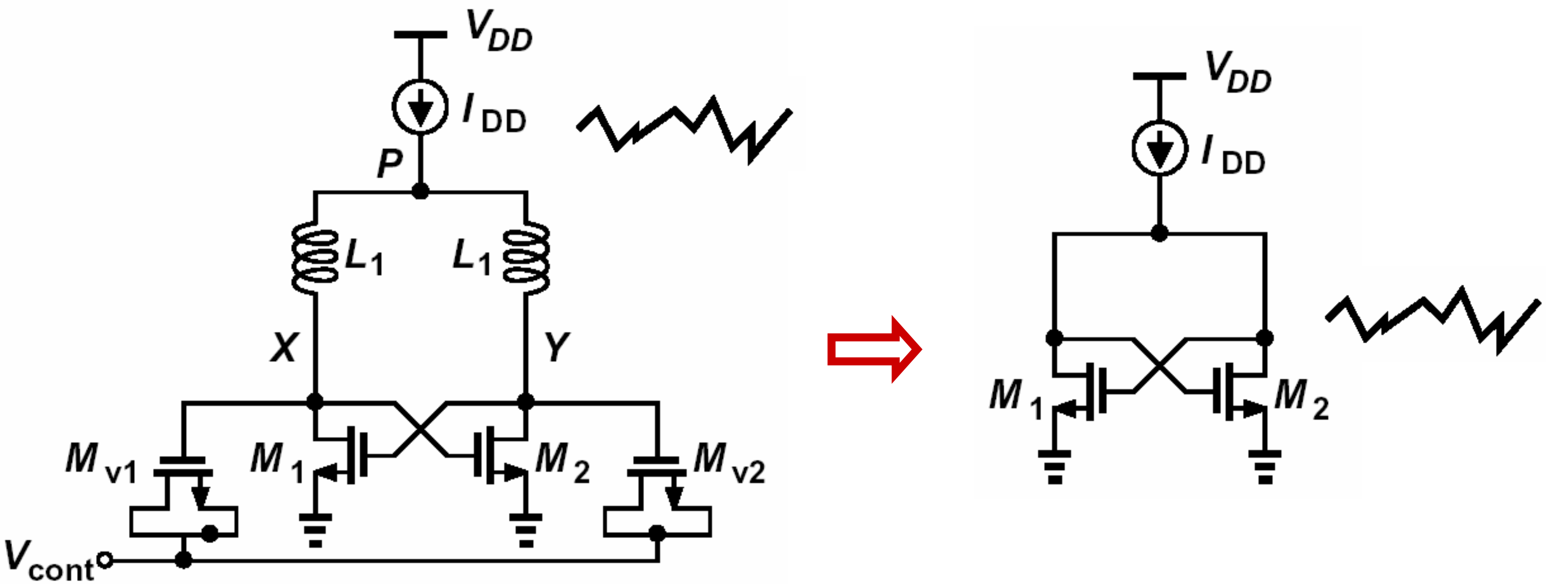






- **Select device dimensions to set the output CM level to about Vdd/2.**

Varactor Modulation by I_{DD}

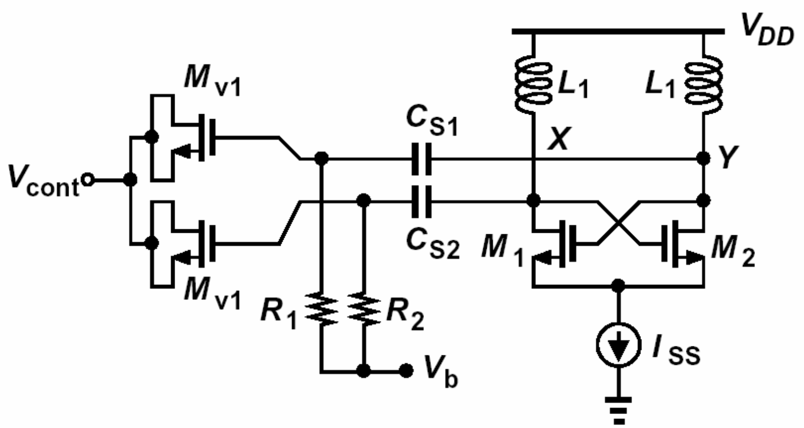


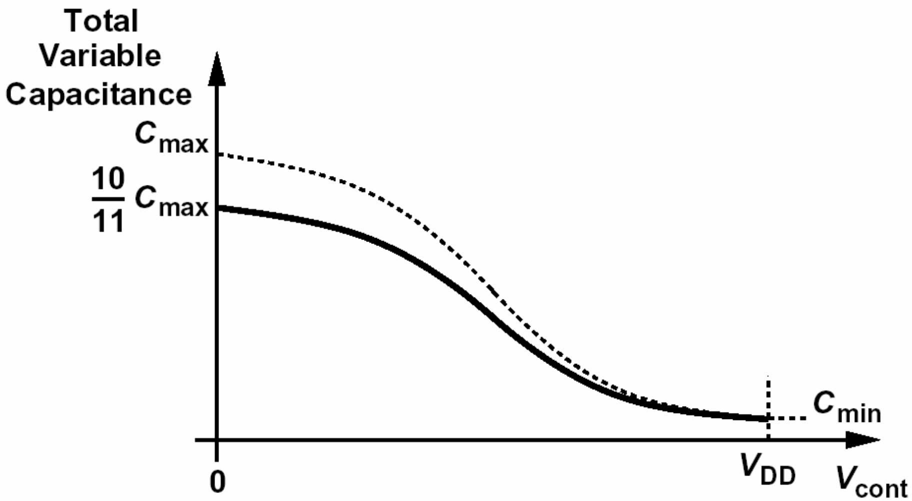
$$\Delta V = \frac{1}{g_m}\frac{i_n(t)}{2} \Rightarrow V_{out}(t) = V_0 \cos\left[\omega_0 t + \int K_{VCO}\frac{i_n(t)}{2g_m}dt\right]$$

$$V_{out}(t) \approx V_0 \cos\omega_0 t - V_0\frac{K_{VCO}}{2g_m}\left[\int i_n(t)dt\right]\sin\omega_0 t \Rightarrow S_{\phi n}(f) = \left(\frac{K_{VCO}}{2g_m}\frac{1}{2\pi f}\right)^2\frac{\alpha}{f}$$

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

VCO Type III





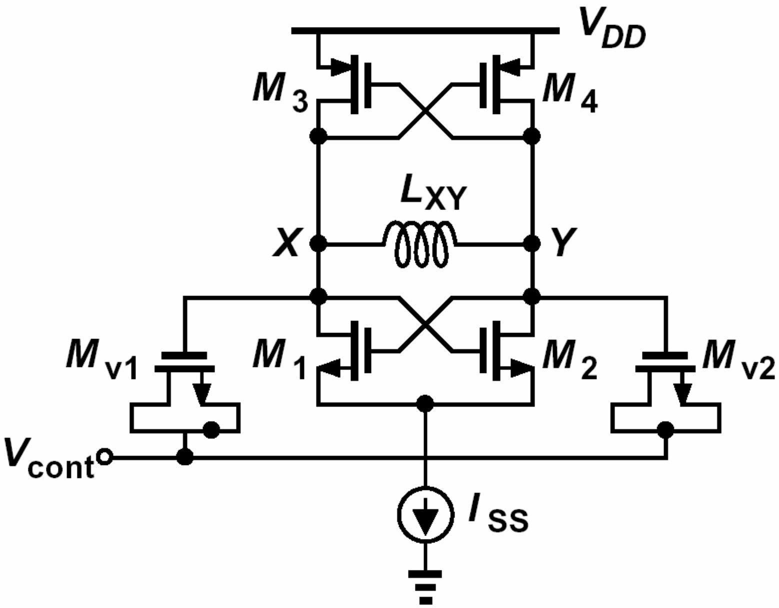
- **Tuning range:**

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

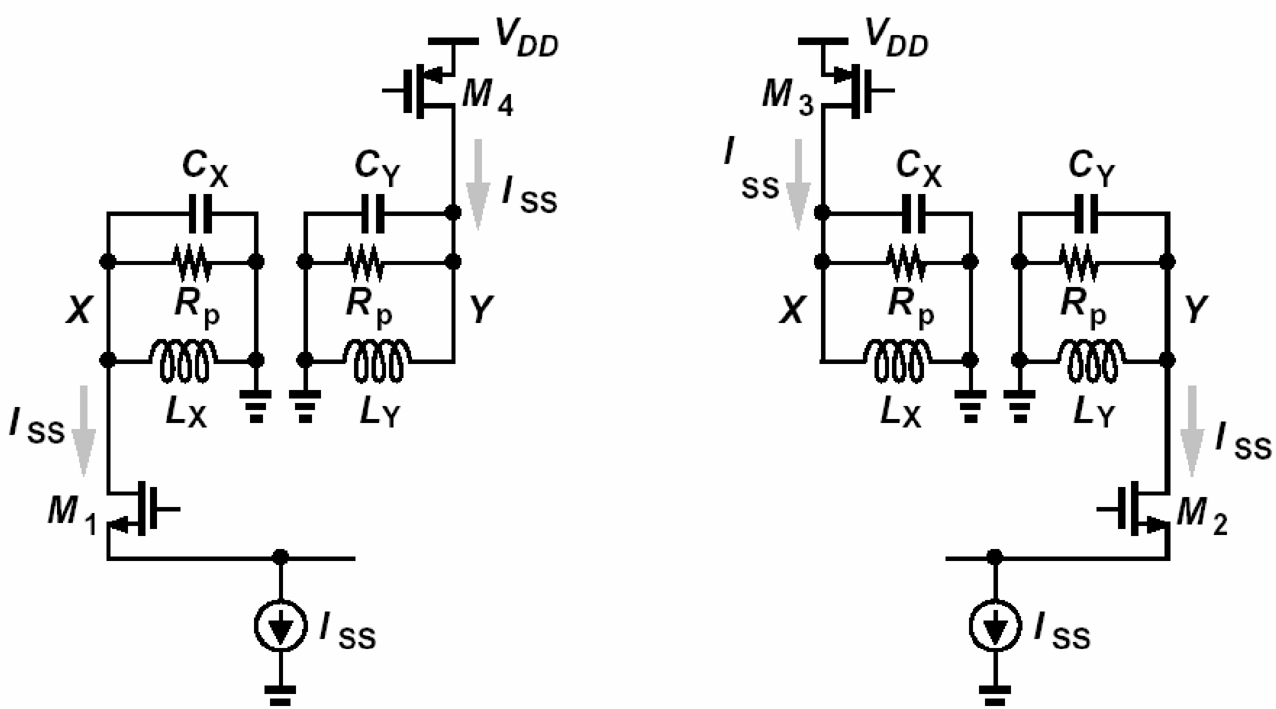
- **With 5% bottom-plate parasitic cap:**

$$\Delta\omega_{osc} \approx \frac{1}{\sqrt{L_1(C_1 + 0.5C_{max})}} \times \frac{0.43C_{max}}{2(C_1 + 0.5C_{max})}$$

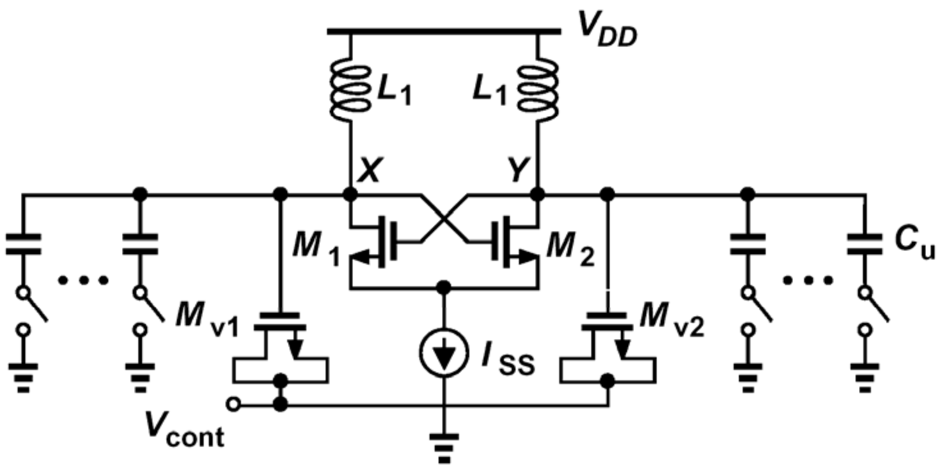
VCO Type IV

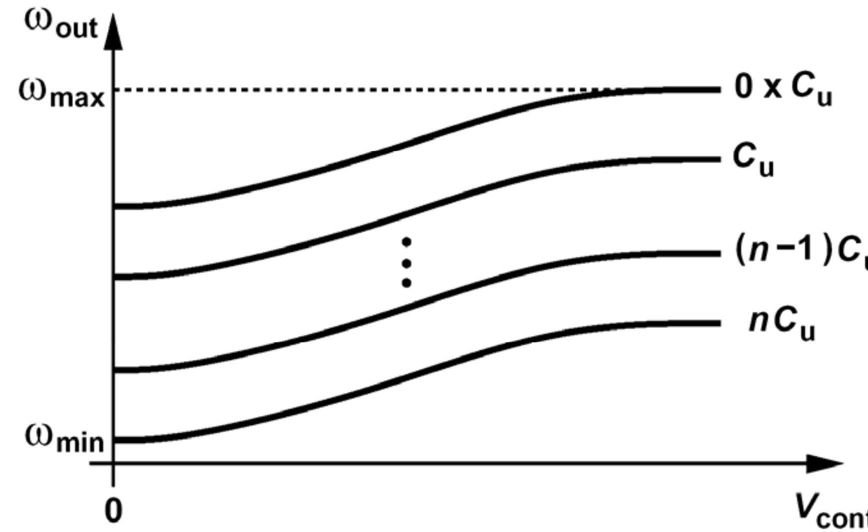


- Select device dimensions to set the output CM level to about Vdd/2.
- Output swing twice that of previous topologies.
- But tail noise modulates varactors.

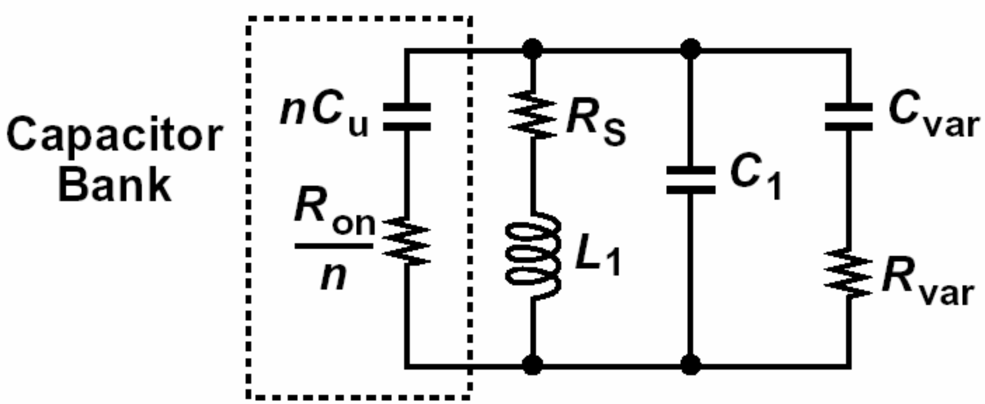


Discrete Tuning





- **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