High-Speed Serial Interface Circuits and Systems

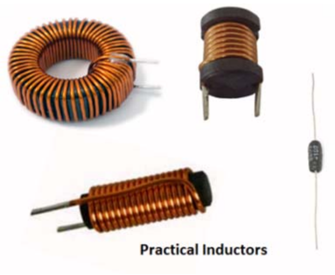
Lect. 3 – LC Oscillators

(From Chap. 6 and 7 of Razavi)

Inductors

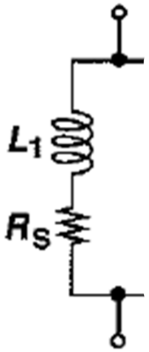
- What is an inductor?

- How to make inductors?

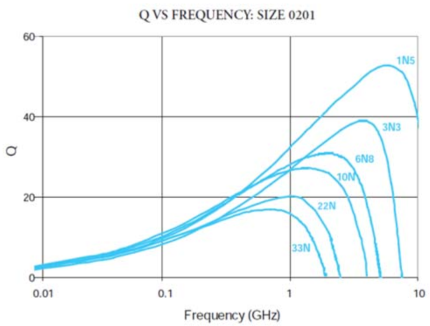


$$L = \frac{\mu N^2 A}{l}$$

- Non-ideality: Series resistance



Rs:
- Finite conductivity
- Skin effect: Surface currents induced by the magnetic field (eddy current) are concentrated near surface and effectively increases the resistance. More pronounced in higher frequency.
- Core loss: Dielectric loss
- Radiation loss

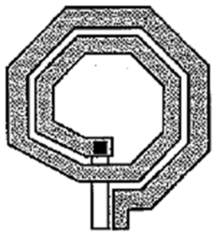


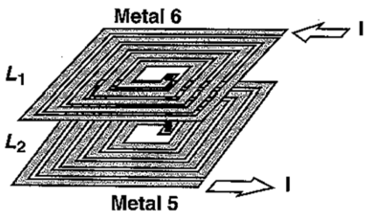
- Quality factor for an inductor: Q = ωL/R (X/R)

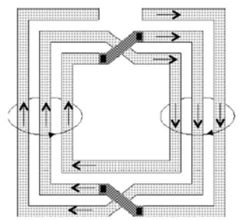
- How does Q change with frequency?

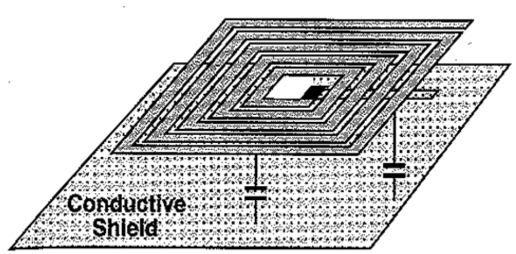
On-Chip Inductors

- How to realize on-chip inductors?





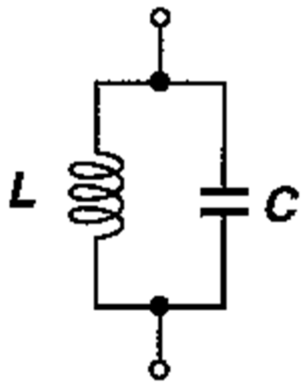




- On-chip inductors are typically lossy and large

- Recently, on-chip inductors are widely used since the required inductance is becoming smaller and processing technology is getting better

LC Tank



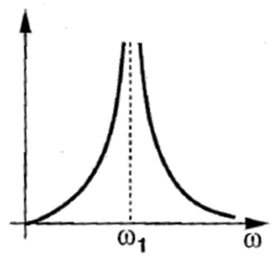
In s-domain

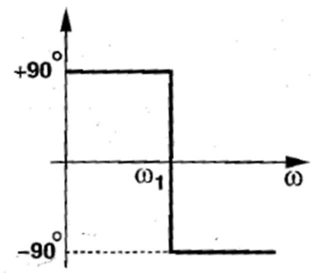
$$Z(s) = sL \parallel \frac{1}{sC} = \frac{sL}{s^2LC+1}$$

Poles at $s = \pm j\frac{1}{\sqrt{LC}}$

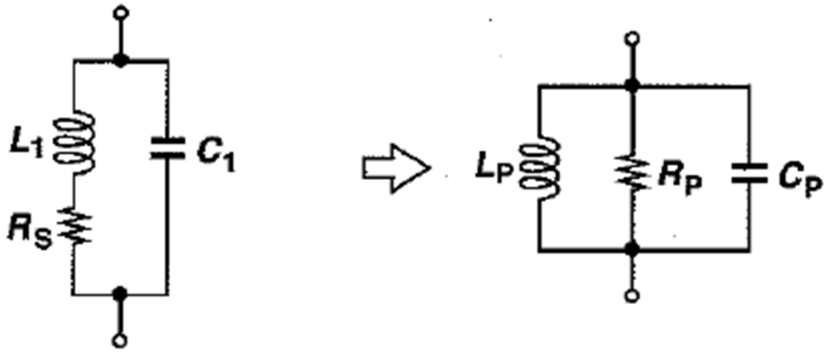
In steady-state $s = j\omega$ $\quad Z(j\omega) = \frac{j\omega L}{1-\omega^2 LC}$

$$|Z(j\omega)| = \frac{\omega L}{|1-\omega^2 LC|} \qquad \angle Z(j\omega) = \frac{\pi}{2} \text{ or } -\frac{\pi}{2}$$





RLC



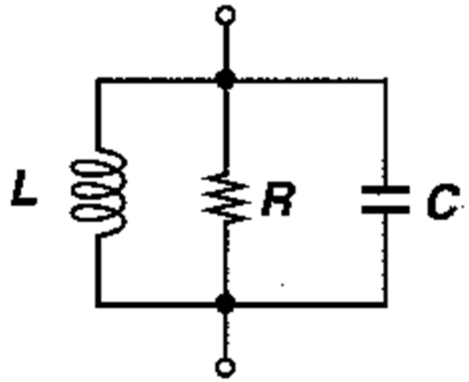
$C_p = C_1$ $\qquad R_s + L_1 s = R_p L_p s \,/\, (R_p + L_p s)$

$$L_P = L_1\left(1 + \frac{R_S^2}{L_1^2 \omega^2}\right)$$

If Q (= $L_1\omega/R_s$) is large $\quad L_P \approx L_1$

$R_p \sim L_1^2\omega^2/R_s \sim Q^2 R_s$

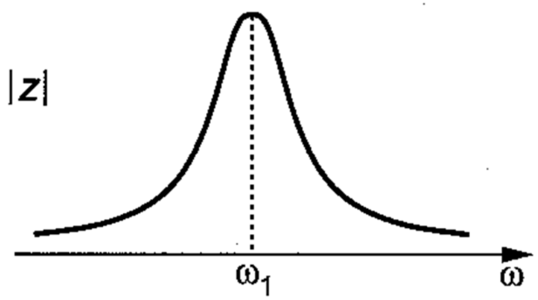
RLC

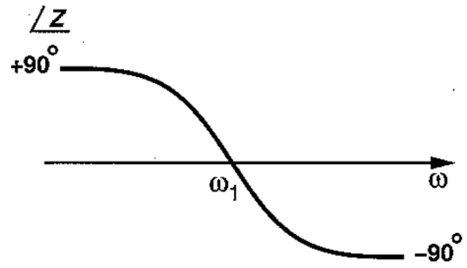


$$Z(s) = sL \,\|\, \frac{1}{sC} \,\|\, R = \frac{RLs}{RLCs^2 + Ls + R} = \frac{s/C}{s^2 + \frac{1}{RC}s + \frac{1}{LC}}$$

Poles at $$s = \frac{-\frac{1}{RC} \pm \sqrt{\left(\frac{1}{RC}\right)^2 - \frac{4}{LC}}}{2}$$

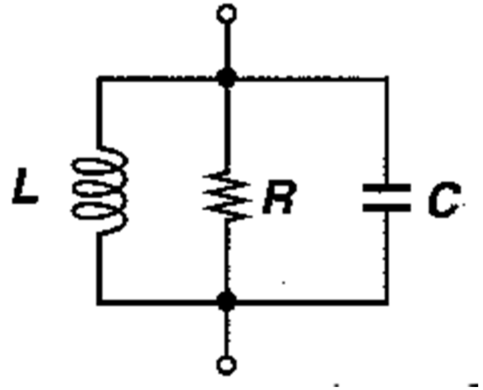
Two complex conjugate poles if $\left(\frac{1}{RC}\right)^2 < \frac{4}{LC}$ ➔ Under-damping

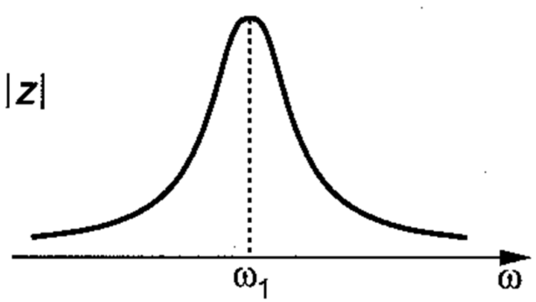




Magnitude peak and zero phase at $\omega = \frac{1}{\sqrt{LC}}$

RLC





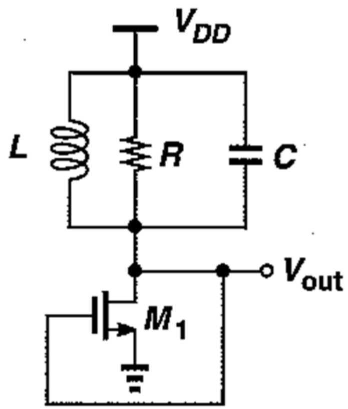
Q-factor: 2π x (Energy Stored / Energy dissipated per cycle)

Q = $R\sqrt{\dfrac{C}{L}}$

For large Q, 3-dB bandwidth: $\dfrac{1}{\sqrt{LC}Q}$

LC Oscillator

Oscillation?

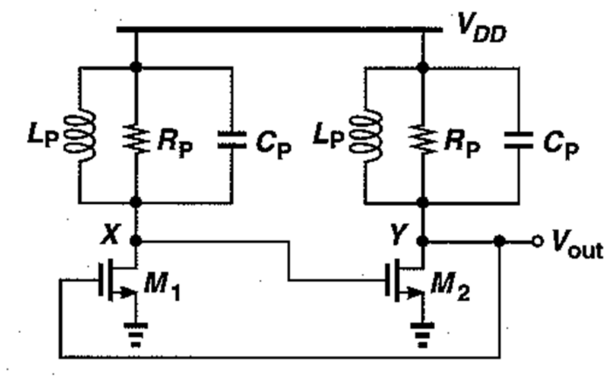


Assume M_1 has no capacitive component

At low frequency

At high frequency

At resonance frequency

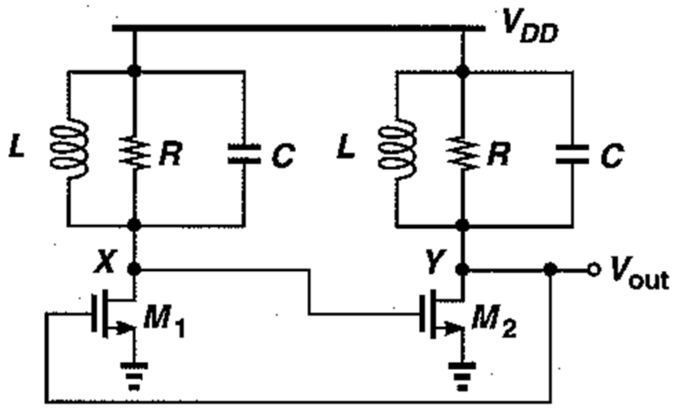


Oscillation!

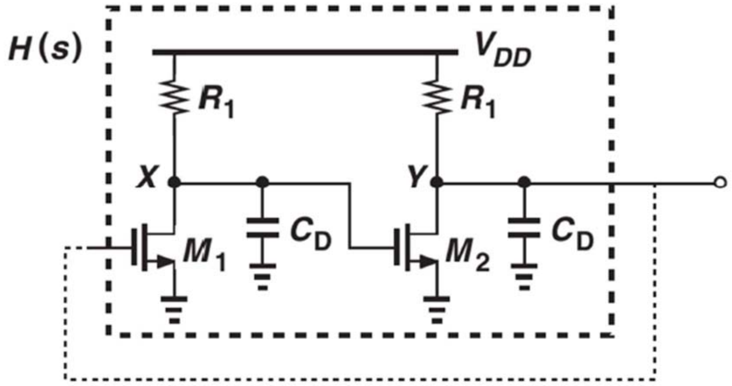
$$\omega = \frac{1}{\sqrt{LC}}$$

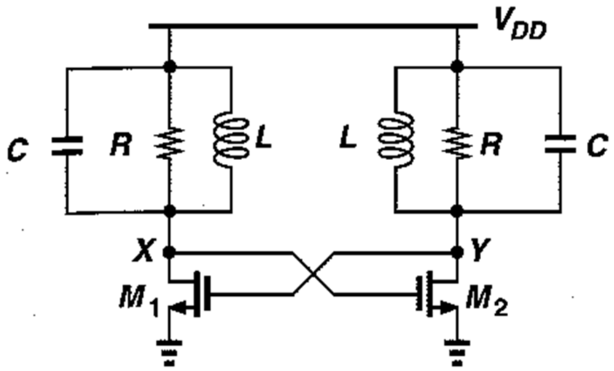
$$g_m R_p = 1$$

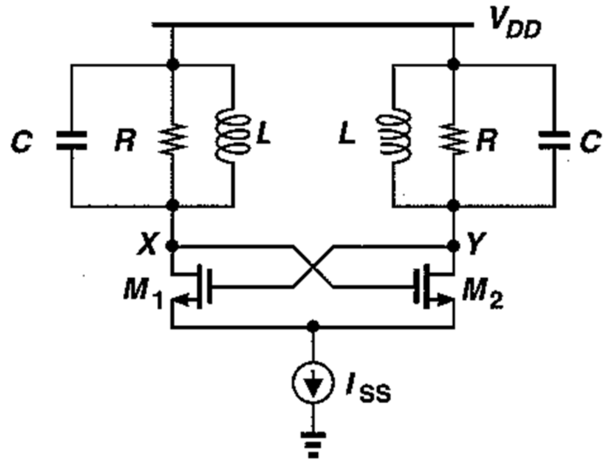
Cross-Coupled LC Oscillator



VS

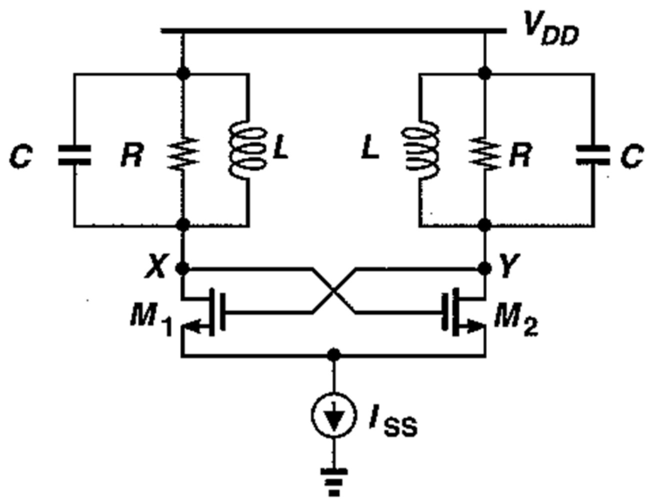






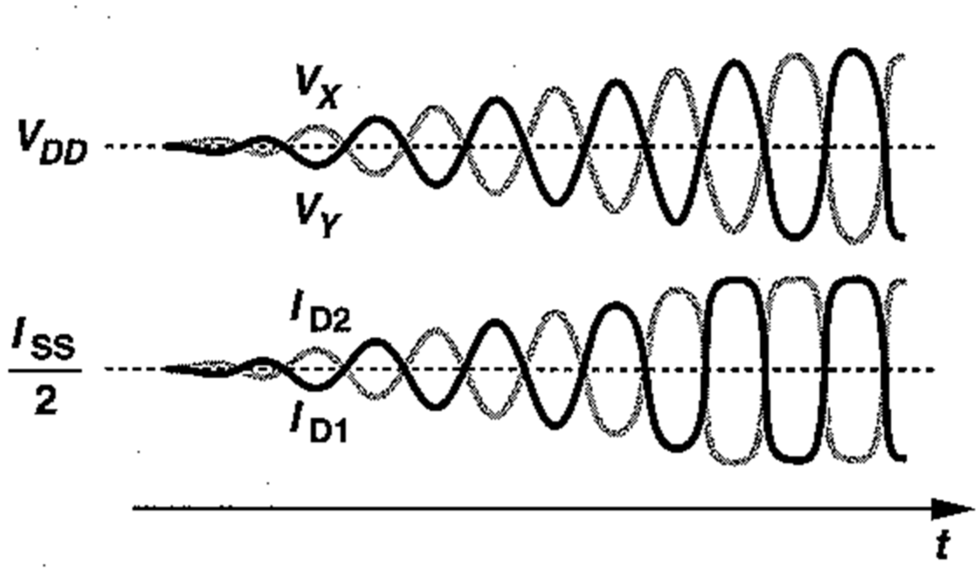
➔ Cross-Coupled LC Oscillator

Cross-Coupled LC Oscillator

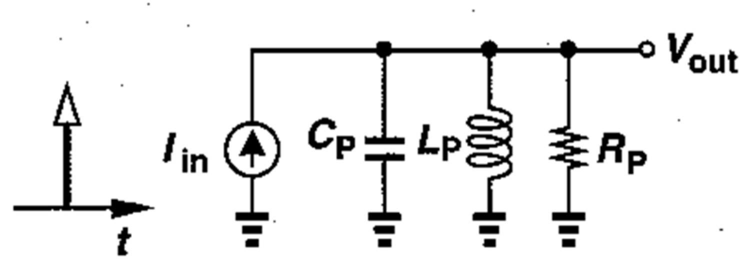


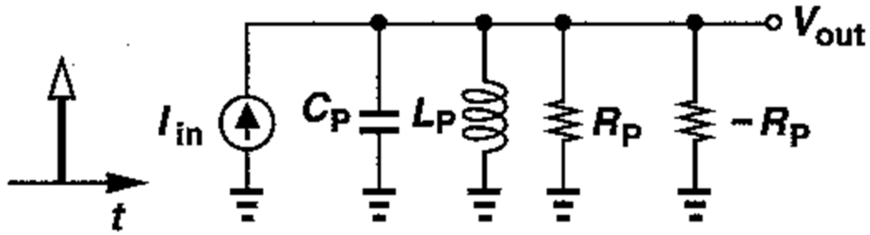
What initiates oscillation?

What limits oscillation?

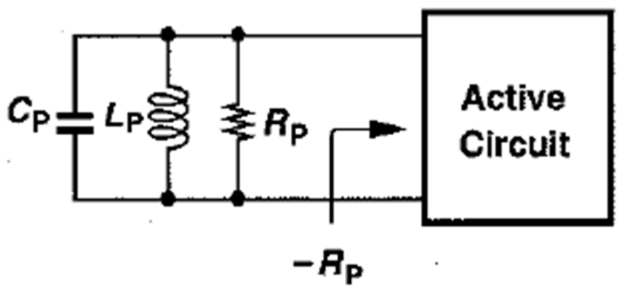


Negative G_m Oscillator



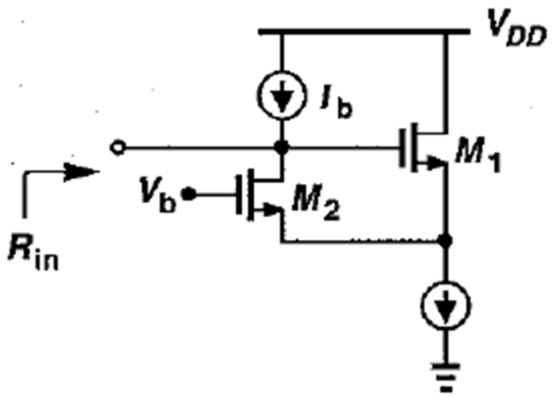


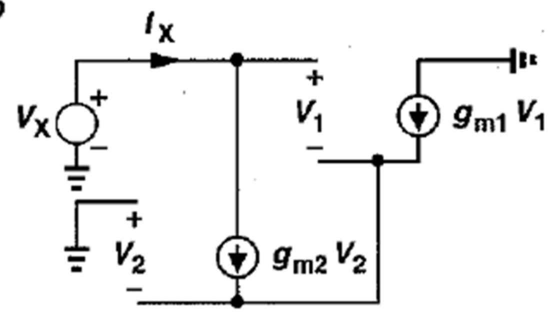
How do you make negative resistance circuit?



Active circuit with negative resistance in small signal

Negative Resistance Circuits



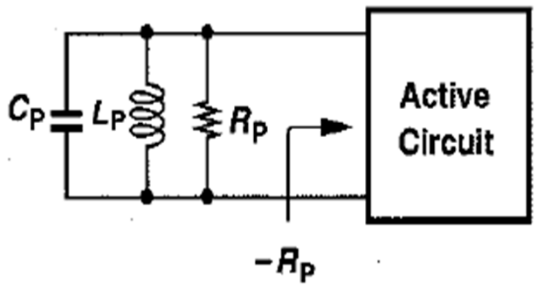


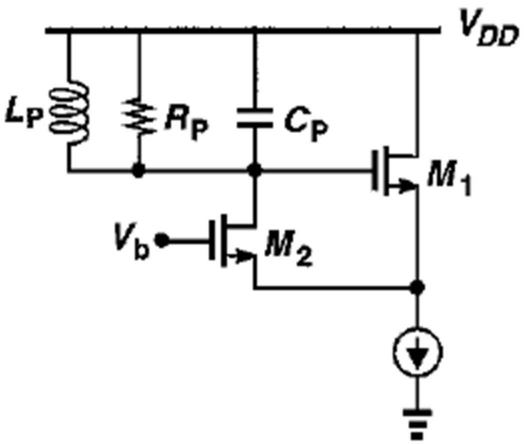
$$V_X = V_1 - V_2$$

$$I_X = g_{m2} V_2 = -g_{m1} V_1$$

$$V_X = -\frac{I_X}{g_{m1}} - \frac{I_X}{g_{m2}}$$

$$R_{in} = \frac{V_X}{I_X} = -\frac{1}{g_{m1}} - \frac{1}{g_{m2}}$$





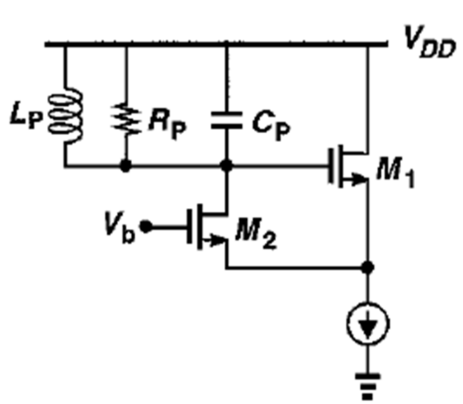
Negative G_m oscillator

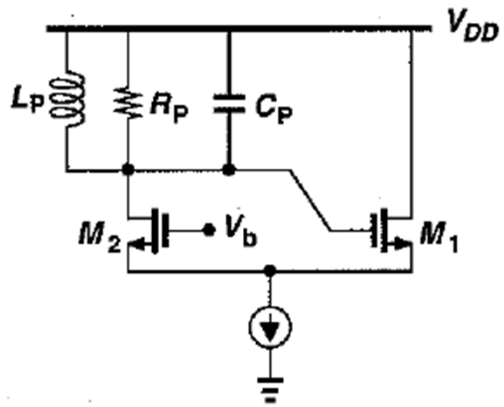
Oscillation frequency?

Oscillation condition?

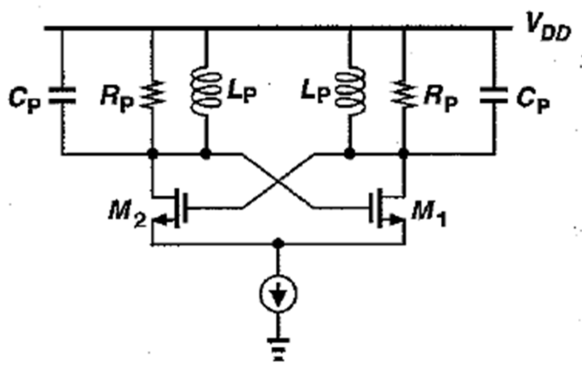
$$R_p = \frac{2}{g_m}$$

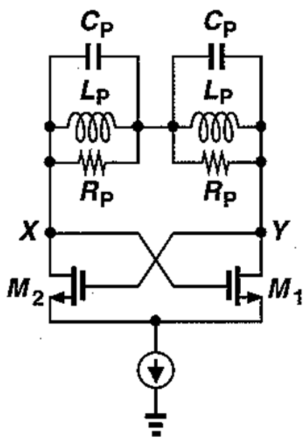
Negative-G_m Oscillator

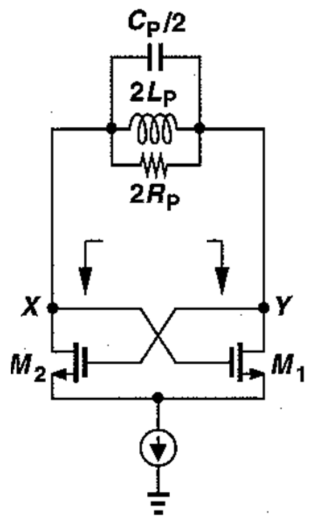




Differential Negative-G_m Oscillator







$$R_{in} = -\frac{1}{g_{m1}} - \frac{1}{g_{m2}}$$

$$2R_p = \frac{2}{g_m}$$

$$g_m R_p = 1$$

Same configuration as cross-coupled LC oscillator

Negative-G_m Oscillator

There many different types of oscillator circuits.

Sometimes your circuit oscillates when you do not want it.
(unwanted feedback)

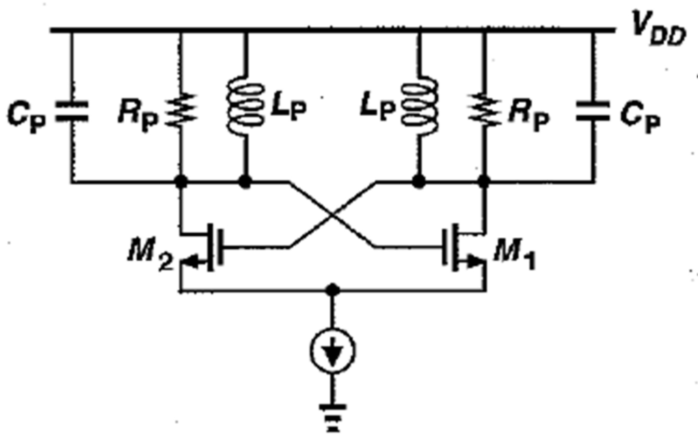
LC vs ring oscillators?

- LC provides cleaner oscillation (Smaller phase noise)

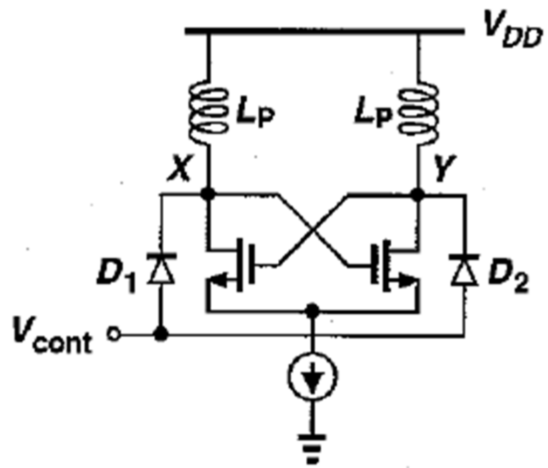
- RO is easier to implement for CMOS IC

- For very high-frequency applications, LC are used

Voltage-Controlled LC Oscillator



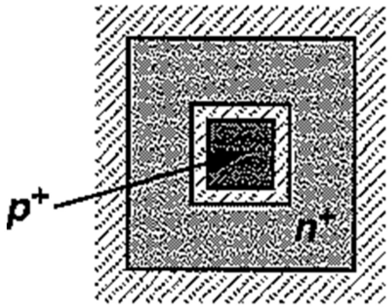
Easiest to tune C_p with varactors



R_p is usually due to parasitic resistance for the inductor

Varactors

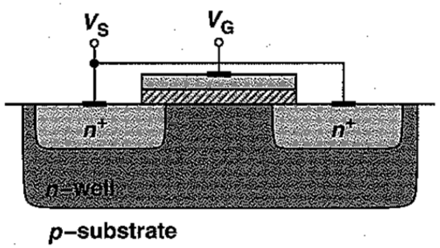
Reverse biased PN junction

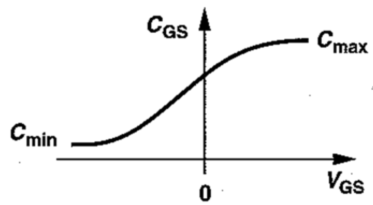


$$C_{var} = \frac{C_0}{(1 + \frac{V_R}{\phi_B})^m}$$

Tuning range is limited
Very nonlinear

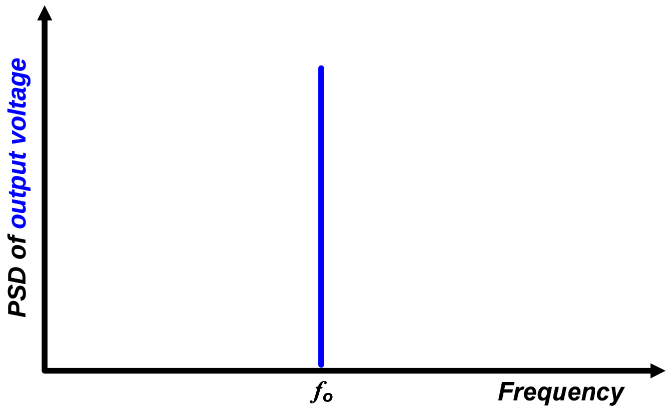
Accumulation MOS Varactor



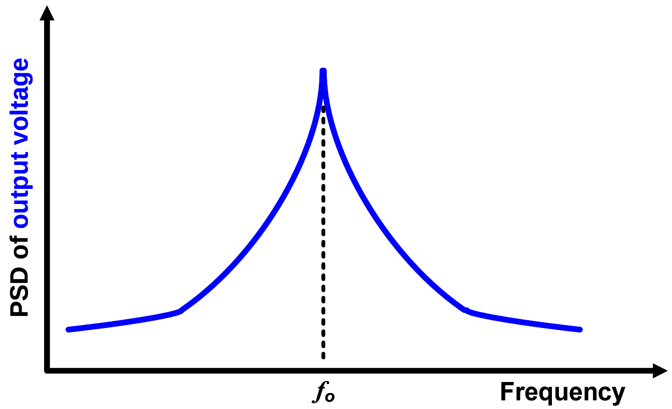


Phase Noise

- Ideal oscillator *vs* Real oscillator

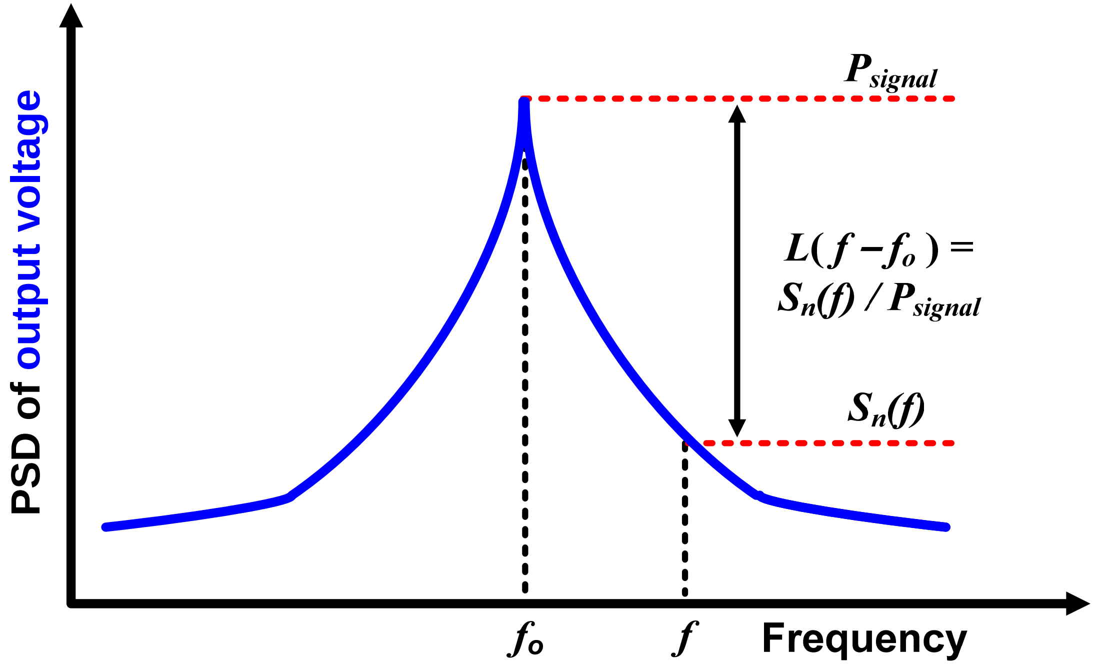


Ideal Oscillator



Real Oscillator

Phase Noise



– Phase noise represented as single sideband noise (SSN) in log(dB) scale.

$$L(\omega) = 10\log\frac{S_n(\omega-\omega_o,\omega-\omega_o)}{P_{signal}(\omega_o)}\ (dBc/\mathrm{Hz}) \quad \sim \frac{4kT}{P_{dissipation}}\left(\frac{\omega_o}{2Q\omega}\right)^2$$

Design Exercise