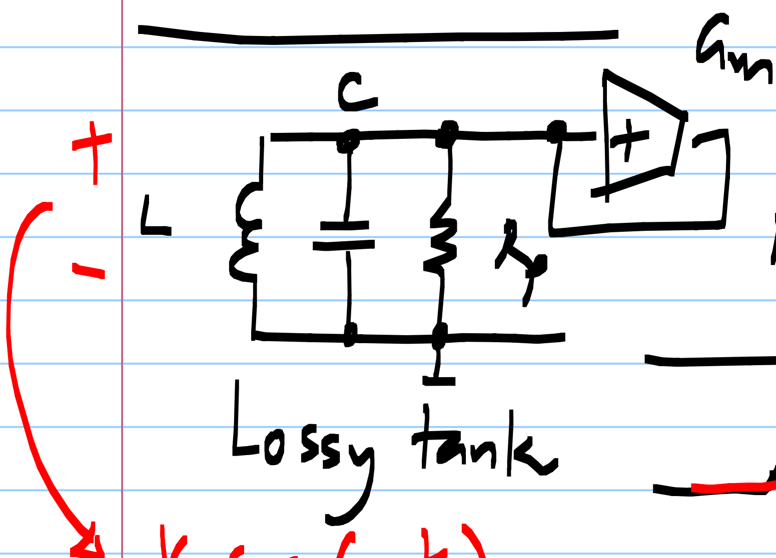
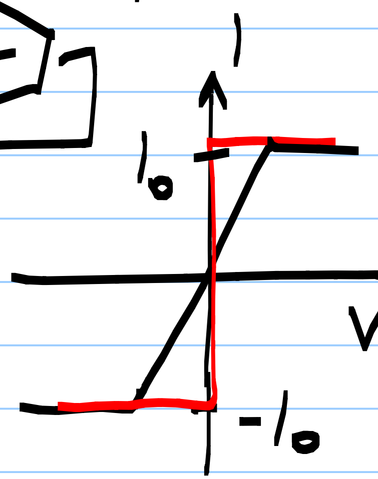
LC oscillator.

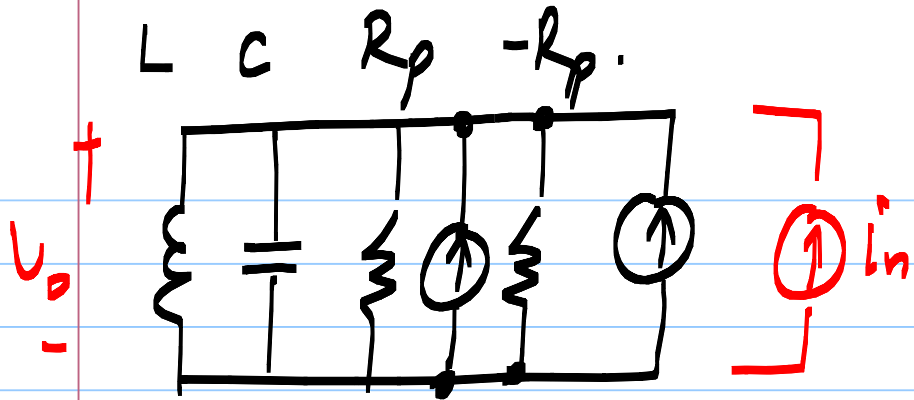




$V_p \cos(\omega_0 t)$

$V_p = \frac{4}{\pi} I_0 R_p$

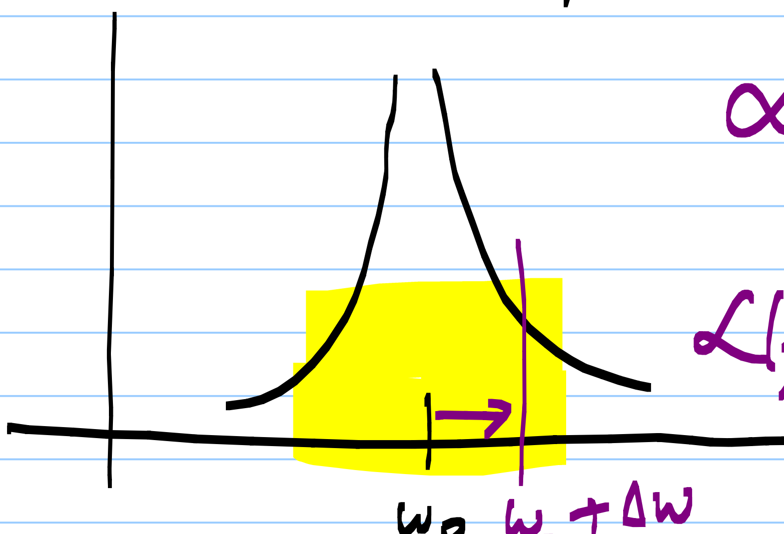
$\mathcal{L}(f) = \frac{A}{f^2}$



$$\left[\frac{4kT}{R_p} \quad \frac{4kT}{R_p}\right]$$

$$\left|\frac{V_o}{I_n}\right| = \frac{1}{\left|j\omega C + \frac{1}{j\omega L}\right|} = \left|\frac{[j\omega L]}{\underbrace{-\omega^2 LC}_{} + 1}\right|$$

$$1 - \frac{\omega^2}{\omega_0^2}$$



$$\propto \frac{1}{\Delta\omega^2}$$

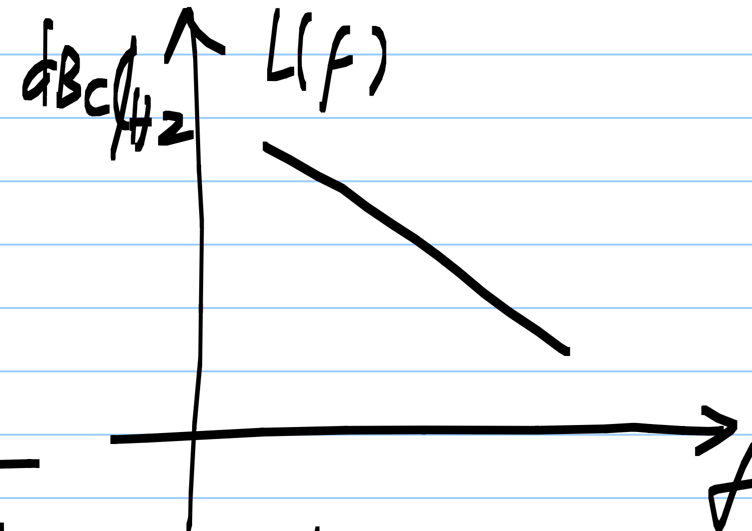
$$\mathcal{L}(f) \propto \frac{1}{f^2}$$

$$\propto \frac{1}{\omega^2 - \omega_0^2} = \frac{1}{2\omega_0(\Delta\omega)}$$

$$(\omega + \omega_0)\underbrace{(\omega - \omega_0)}$$

* Phase noise $L(f) \propto \frac{1}{f^2}$ due to thermal noise

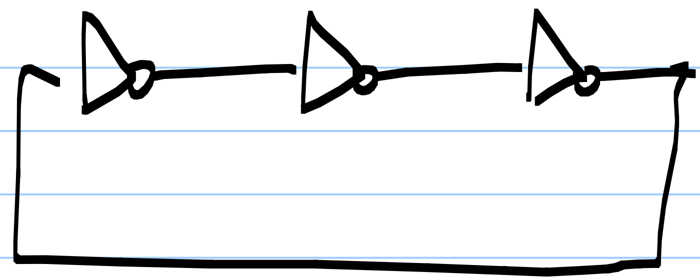
$$\left[L(f) = \frac{A}{f^2} \right]$$



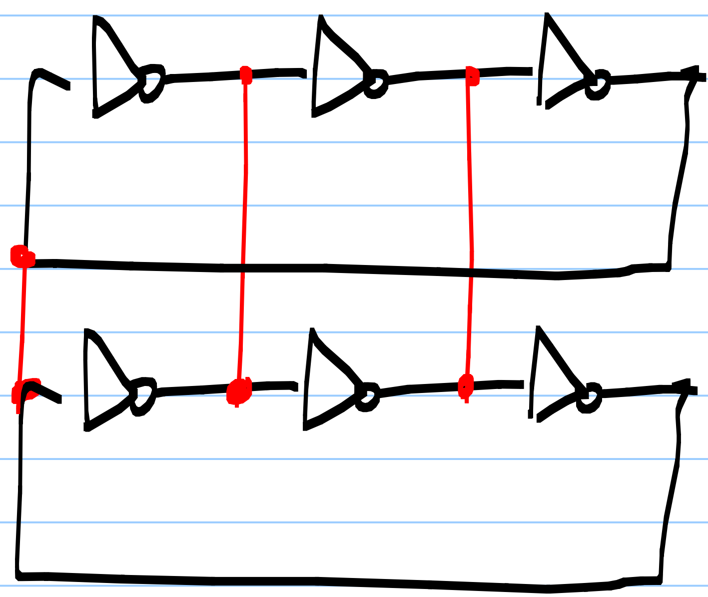
* Can have $\frac{1}{f^3}$, f^0 terms

Ring oscillator has a higher phase noise than LC oscillator

* Phase noise inversely proportional to power dissipation



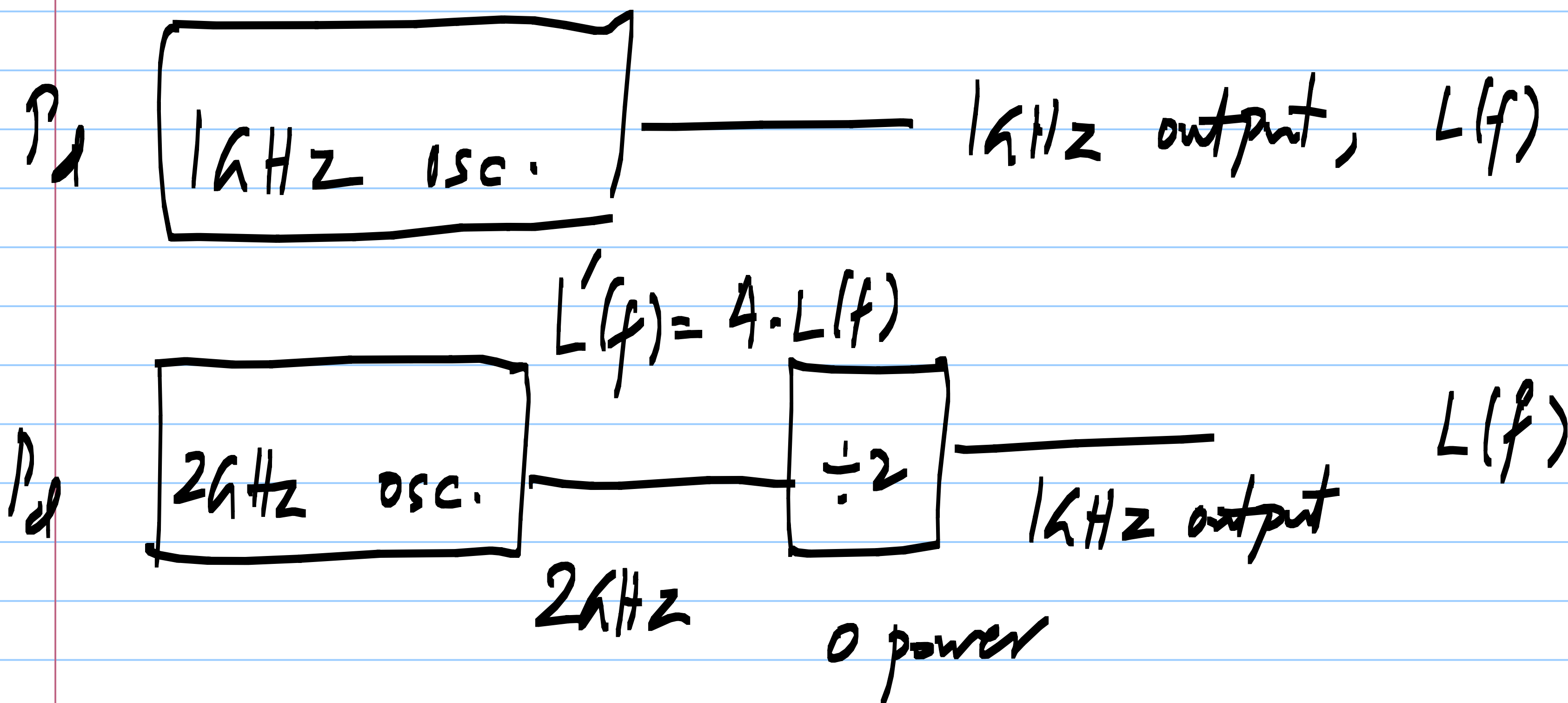
$P_d, \quad L(f)$



$2P_d, \quad \frac{L(f)}{2}$

For the same power dissipation, $L(f) \propto f_0^2$

f_0: oscillation frequency



Phase noise figure of merit.

$$L(f) = \alpha \cdot \frac{1}{f^2} \cdot f_0^2 \cdot \frac{1}{P_d}$$

$$\alpha = L(f) \cdot \frac{f^2}{f_0^2} \cdot P_d$$

CMOS oscillators

The Lower, the better

$$\frac{1}{\alpha} = \frac{1}{L(f)} \cdot \frac{f_0^2}{f^2} \cdot \frac{1}{P_d}$$

The higher, the better

Oscillator PN

$$FoM = 10\log_{10}\left[\frac{1}{L(f)} \cdot \frac{f_0^2}{f^2} \cdot \frac{1}{P_{d,mW}}\right]$$

~ 165 dB for Ring osc.

-190

~ 185 dB for LC osc.

Calculate the phase noise of ring & LC VCOs (FoM = 165dB, 185dB)

10GHz oscillator, 10mW power dissipation

Phase noise @ 1MHz offset

$$165\,dB = 10\log_{10}\left[\frac{1}{L(f)} \cdot\right.$$

$$FoM = 10\log_{10}\left[\frac{1}{L(f)}\cdot\left(\frac{f_0}{f}\right)^2\cdot\frac{1}{P_{d,mW}}\right]$$

$$= \underbrace{-10\log_{10}(L(f))}_{\text{Phase noise in dBc/Hz}} + 20\log_{10}\left(\frac{f_0}{f}\right) - 10\log_{10}(P_{d,mW})$$

10GHz

$\omega_n = 10\,\text{MHz}$

$\phi_{rms} =$

$\tau_{rms} =$

$$165\,dB = -L_{dB}(f) + 80\,dB - 10\,dB$$

$$L_{dB}(f) = (-165 + 70) = -95\,dBc/Hz$$

$185\,dB$: $L_{dB}(f) = -115\,dBc/Hz$

JKEN due to the VCO: $\left\{ \dfrac{2\pi^2 A}{\omega_n} \right\}$

$$2\int_0^\infty \underbrace{L_{vco}(f)} \cdot \left| \frac{\phi_{ck}(s)}{\phi_{nvco}(s)} \right|^2_{s=j2\pi f} df$$

$\omega_n/4$

$$\frac{4\pi^2 A}{\cancel{4\pi^2 f^2}} \frac{1}{\omega_n^2} \underbrace{\left| \frac{s^{\cancel{2}}/\cancel{\omega_n}\omega_z}{1 + s/\omega_z + s^2/\omega_n\omega_z} \right|^2_{s=j2\pi f}}$$