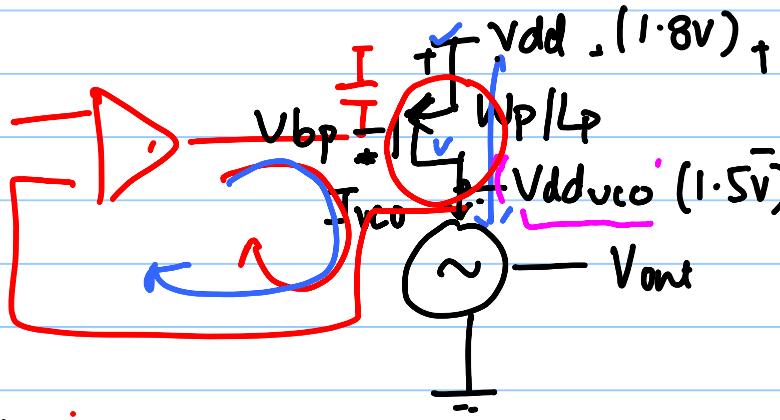
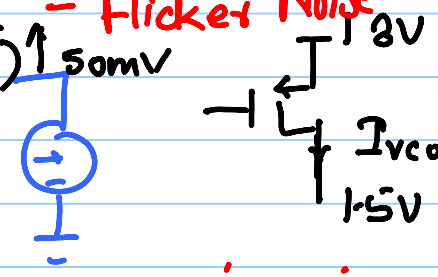
Lecture # 27.

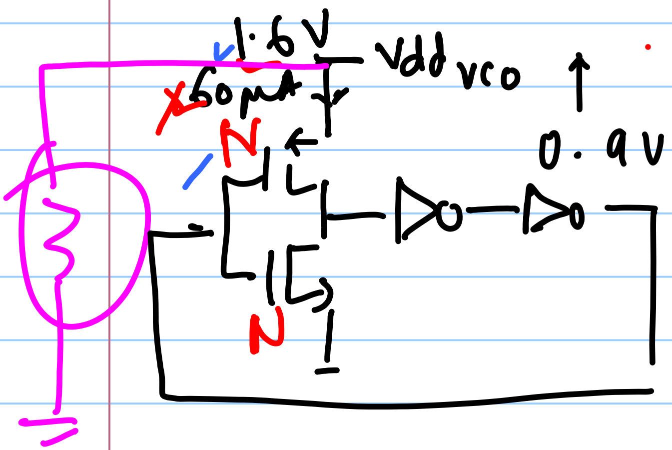
Note Title 28-07-2020

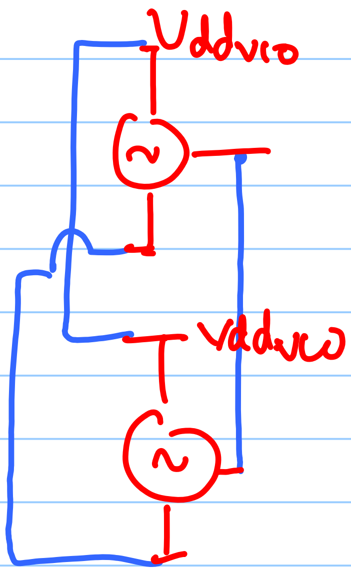
Ring Oscillator



- Supply Noise Rejection ✓ r_{ds}
- Flicker Noise $\propto \frac{1}{L}$







$\frac{W_p}{L_p} = 0.18\,\mu \rightarrow 1.8\,\mu m$ ✓

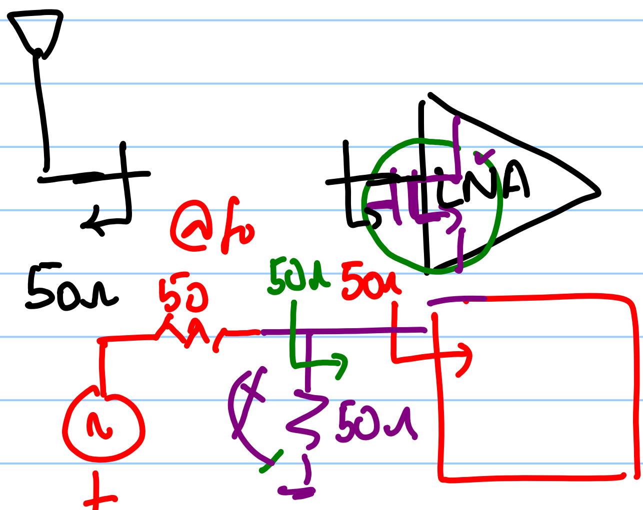
Transistor is in saturation.

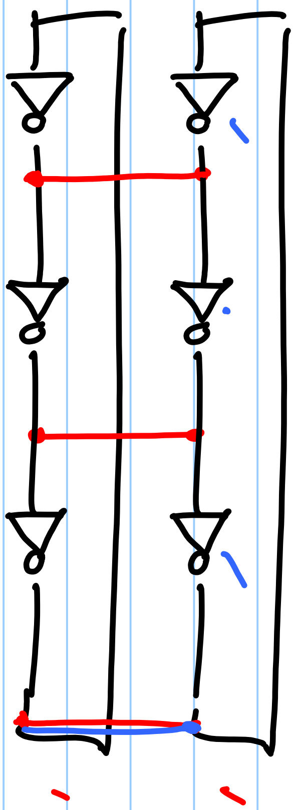
$\underbrace{V_{dd} - V_{bp} - |V_{TP}|}_{} \leq V_{dd} - V_{ddvco}$

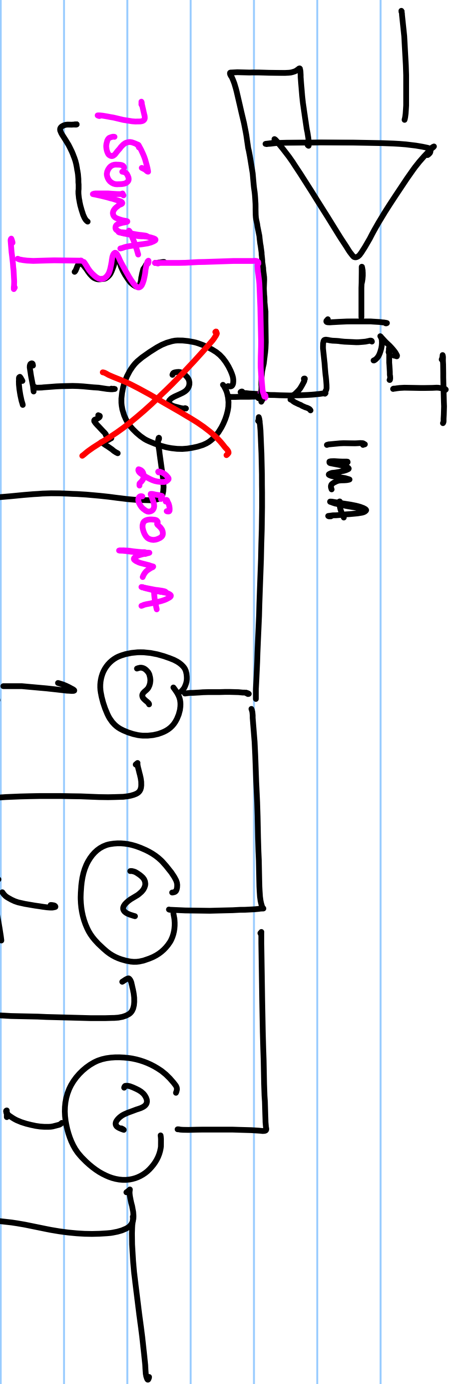
(1.8, 1.15V ↓, 0.6 ↑; 0.3V)

↓ = 50mV ('tt' corner $I_{vco} = 1mA$)

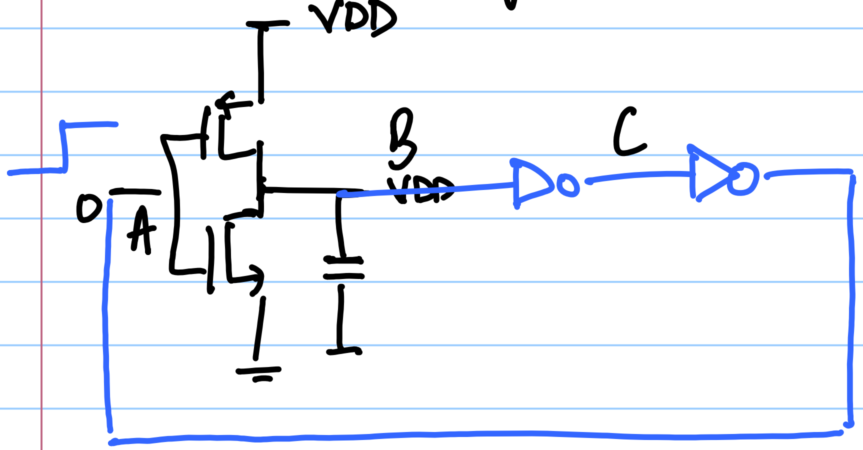
–	'ss' +50 mV	≈ 1mA
–	'ff' -50 mV	≈ 1mA

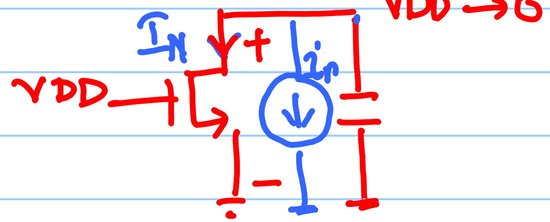





750mA
250mA
1mA

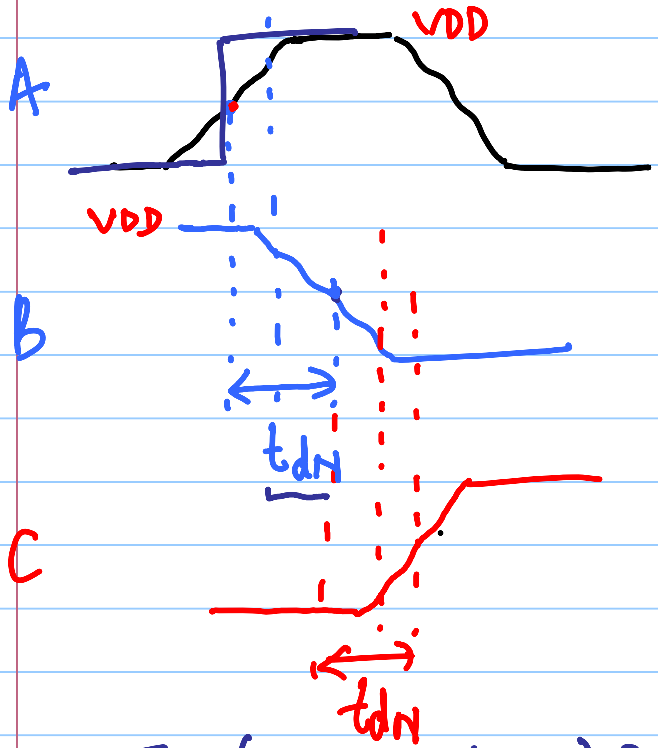
Phase Noise in Ring Oscillator



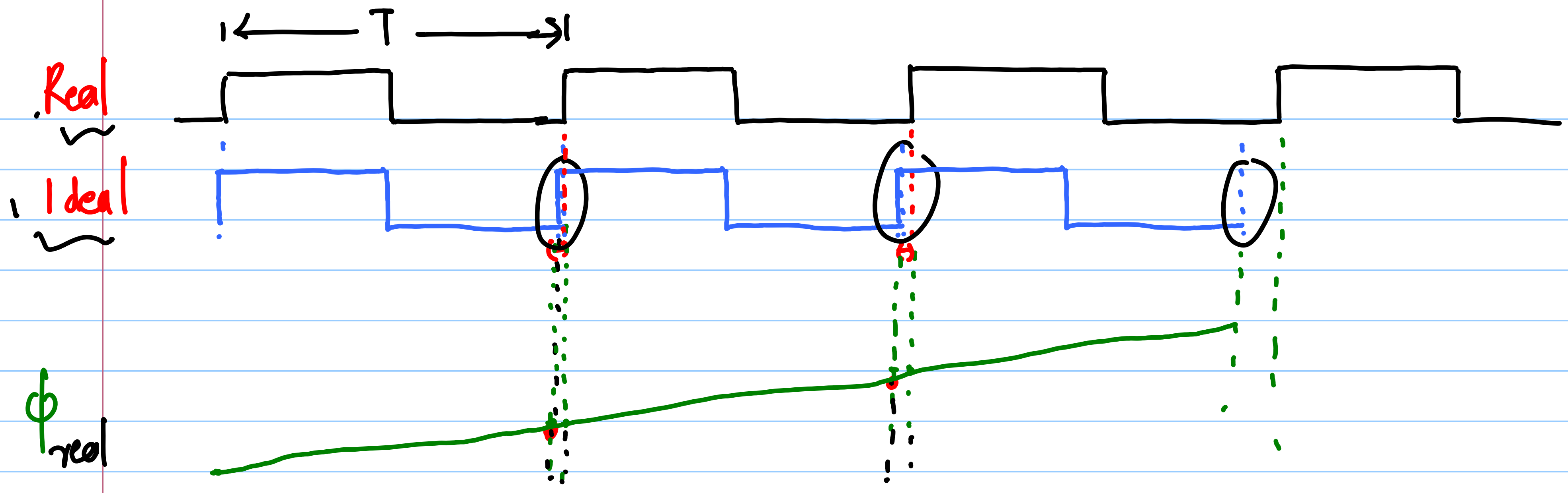


$VDD - 0 - V_{tn} < VDD$

$$\int dV_c = \frac{1}{C}\int_0^{t_{dN}} I_N + i_n \, dt$$ ✓



$T = (t_{dN} + t_{dP})3$



Period

$$\tau_i = \frac{1}{2\pi f_0}\left(\phi_{i+1} - \phi_i\right) = \frac{1}{2\pi f_0}\Delta\phi_i \qquad f_0 : \text{average frequency.}$$

S_ϕ : Power spectral density of phase noise.

$$S_{\Delta\phi}(f) = S_\phi(f)\left|\underbrace{1 - e^{-j2\pi f/f_0}}_{(1-e^{-sT})}\right|^2 = 4S_\phi(f)\sin^2(\pi f/f_0)$$

$$S_\tau(f) = \frac{1}{4\pi f_0^2}S_{\Delta\phi}(f) = S_\phi(f)\ \sin^2(\pi f/f_0)\Big/(\pi f_0)^2$$

$$S_\tau(f) = S_\phi(f)\,\frac{\sin^2(\pi f/f_0)}{(\pi f_0)^2}$$

Wiener-Khinchine Theorem

Period Jitter

$$\sigma_\tau^2 = \int_0^\infty S_\tau(f)\,df = \int_0^\infty S_\phi(f)\cdot\frac{\sin^2(\pi f/f_0)}{(\pi f_0)^2}\,df$$

$$\mathcal{L}(f) = \frac{S_\phi(f)}{2} = \frac{S_\omega}{f^2}$$

$$\sigma_\tau^2 = 2S_\omega\int_0^\infty \frac{1}{f^2}\,\frac{\sin^2(\pi f/f_0)}{(\pi f_0)^2}\,df = \frac{S_\omega}{f_0^3}$$

$$\boxed{\mathcal{L}(f) = \sigma_\tau^2\,\frac{f_0^3}{f^2}}$$

$$\int S_{\phi out}(f)\cdot df$$

$$I_N = I_{dNsat} = \frac{1}{2} \mu C_{ox} \frac{W}{L} (V_{dd} - V_{tN})^2 \checkmark$$

$$\checkmark S_{in,N} = 4kT\gamma_N g_m = 4kT\gamma_N \frac{2 I_{dNsat}}{V_{DD} - V_{th}} = \frac{8kT\gamma_N I_{dNsat}}{V_{DD} - V_{tr}}$$

$$\frac{1}{C} \int_0^{t_{dN}} I_N + i_{nN} \, dt = \frac{V_{dd}}{2}$$

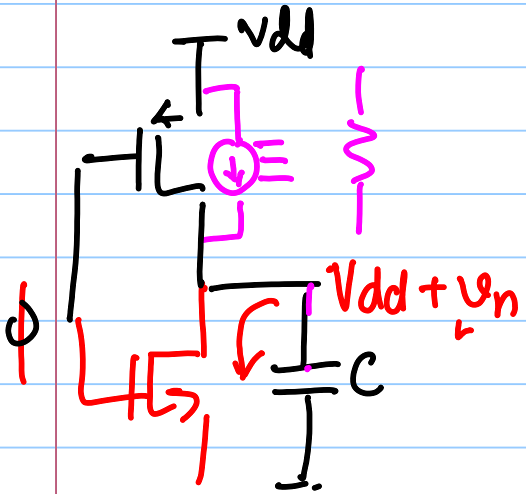
$$t_{dN} \equiv \langle t_{dN} \rangle = \frac{C V_{dd}}{2 I_N} \checkmark$$

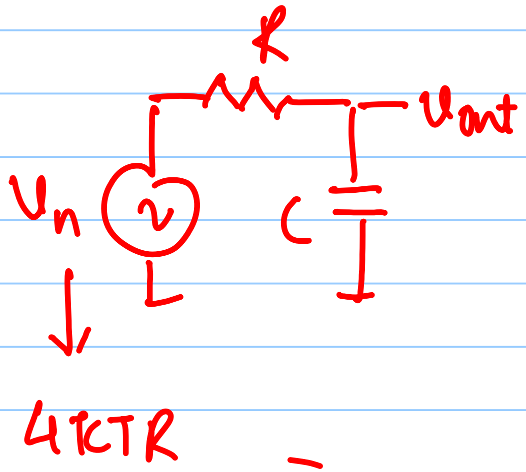
$$\sigma_{t_{dN}}^2 = \frac{1}{I_N^2} \left\langle \left(\int_0^{t_{dN}} i_{nN} \, dt \right)^2 \right\rangle$$

$$S_{t_{dN}} = \frac{t_{dN}^2}{I_N^2} \operatorname{sinc}^2(f t_{dN}) \, S_{i_{nN}}$$

$$\sigma_{tdN}^2 = \int_0^\infty S_{tdN} \cdot df = \frac{t_{dN}}{\pi I_N^2} S_{i,n} \int_0^\infty \frac{\sin^2 x}{x^2} dx$$

$$\sigma_{tdN}^2 = \frac{4kT\gamma_N t_{dN}}{I_N (V_{dd} - V_{tn})} \checkmark + \frac{\langle v_n^2 \rangle}{(I_n/C)^2}$$





$$\langle v_{out}^2 \rangle = \frac{kT}{C}$$

$$\sigma_{tdN}^2 = \frac{4kT\gamma_N t_{dN}}{I_N (V_{dd} - V_{tn})} \checkmark + \frac{kTC}{I_N^2} \checkmark$$

$$\sigma_{tdP}^2 = \frac{4kT\gamma_p t_{dP}}{I_P (V_{dd} - |V_{tP}|)} + \frac{kTC}{I_P^2} \checkmark$$

$$f_0 = \frac{1}{M(t_{dN} + t_{dP})} = \frac{1}{M} \frac{1}{\left(\frac{CV_{dd}}{2I_N} + \frac{CV_{dd}}{2I_P} \right)} = \frac{2I/C}{MV_{dd}}$$ ✓

$$\langle t_{dN} \rangle = \frac{CV_{dd}}{2I_N}$$

$$\langle t_{dP} \rangle = \frac{CV_{dd}}{2I_P}$$

$$\sigma_\tau^2 = M(\sigma_{tdN}^2 + \sigma_{tdP}^2)$$ ✓

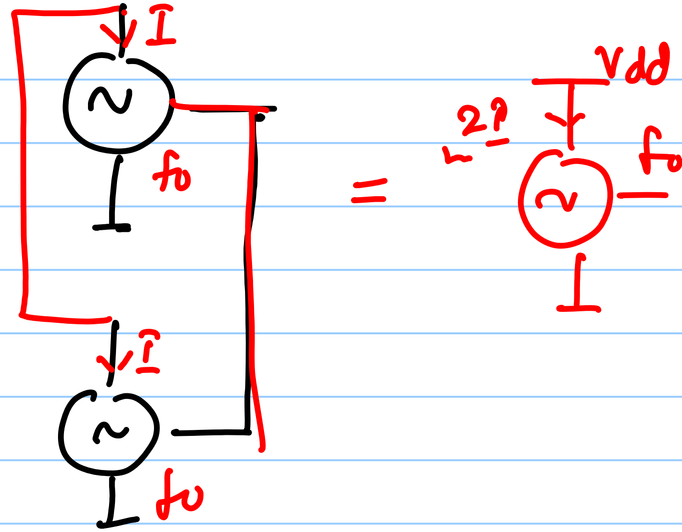
$$\sigma_\tau^2 = \frac{kT}{If_0}\left[\frac{2}{V_{dd} - V_t}(\gamma_N + \gamma_P) + \frac{2}{V_{dd}}\right]$$ ✓

$$\mathcal{L}(f) = \sigma_\tau^2 \frac{f_0^3}{f^2} = \frac{kT}{I}\left[\frac{2}{V_{dd} - V_t}(\gamma_N + \gamma_P) + \frac{2}{V_{dd}}\right]\left(\frac{f_0}{f}\right)^2$$

- No "M"

- $\mathcal{L}(f) \propto \frac{1}{I}$

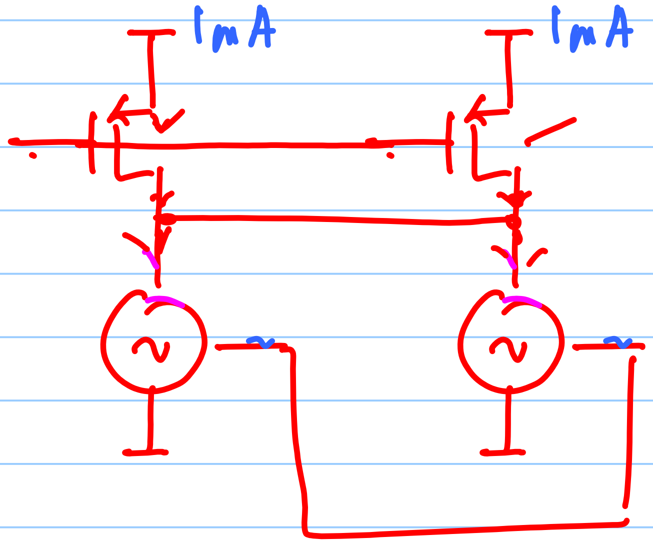
- $\mathcal{L}(f) \propto \frac{1}{V_{dd}-V_t}$



1.5V | 0.9V

3 stages

1 5 stages

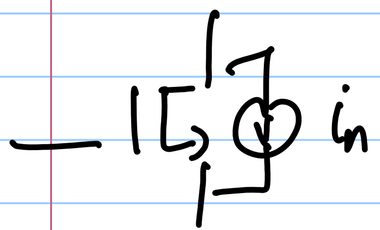


- Noise Summary
  - Spot Noise @ any freq.
  - Integrated Noise (10^4 Hz —)

Flicker Noise

Abidi : "Phase Noise in Ring Osc."

$$\mathcal{L}(f) = \frac{C_{ox}}{8 M I}\left(\frac{\mu_N K_{fN}}{L_N^2} + \frac{\mu_p K_{fp}}{L_p^2}\right)\frac{f_0^2}{f^3}$$



$S_{i_n}(f) = 4kT\gamma_N g_{mN}$ ✓ Thermal Noise

$$S_{i_n,1/f}(f) = \frac{K_{fN}}{WL\,C_{ox}\,f}\,g_m^2 \quad \text{Flicker Noise}$$