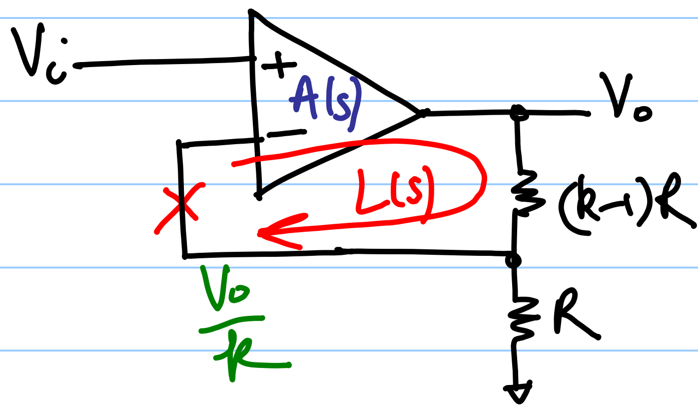
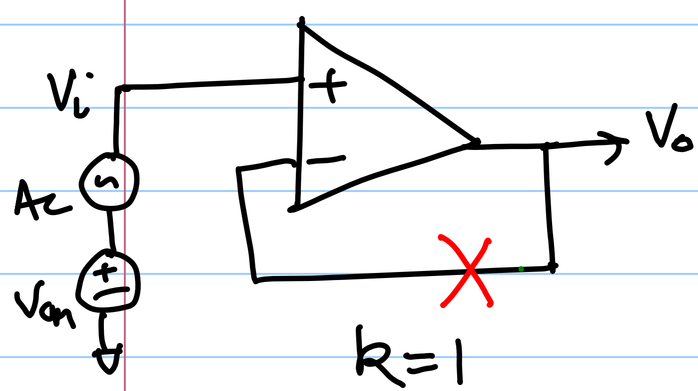
ECE 511 – Lecture 26

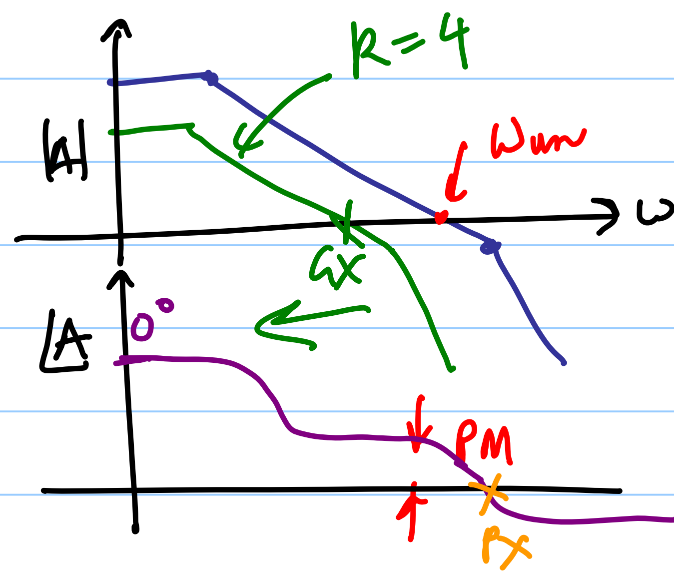
Note Title — 5/1/2014



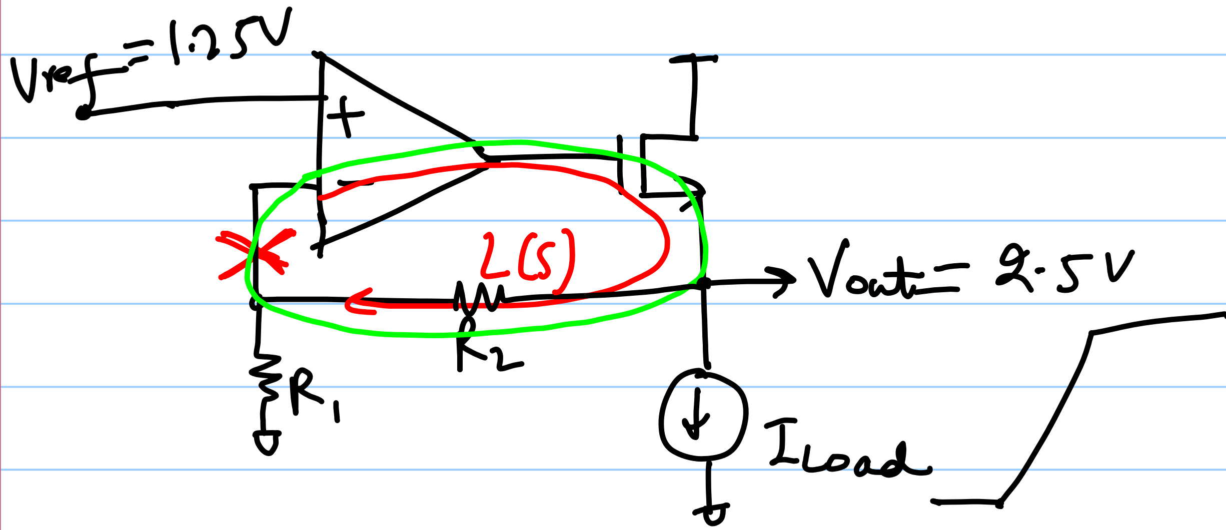
$L(s) = A(s) \cdot \frac{1}{k}$

closed-loop gain ≈ $k = 10$

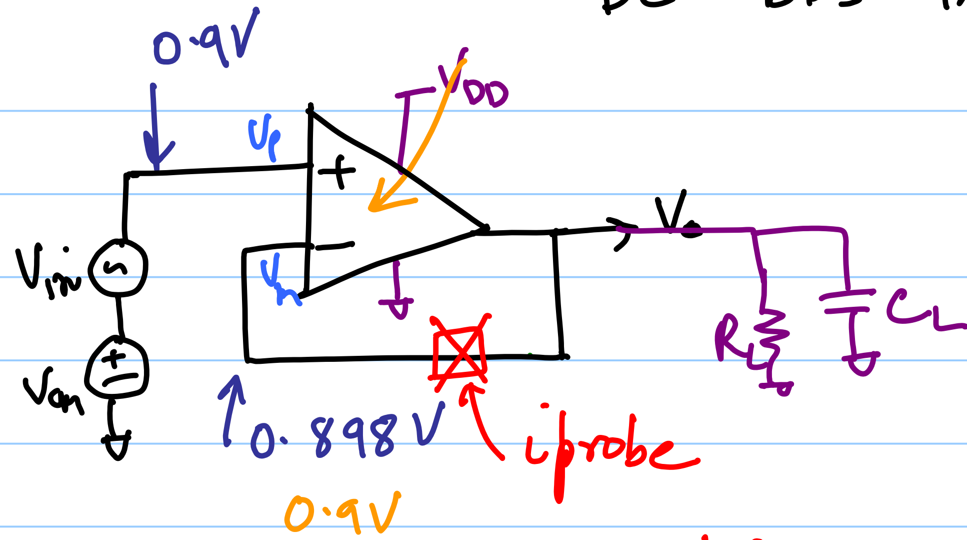




LDO Regulator



DC Bias the opamp

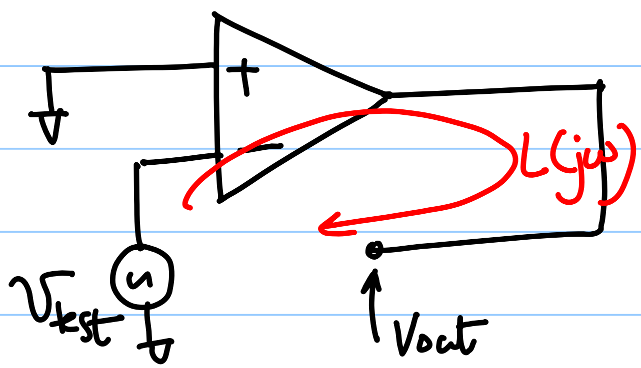


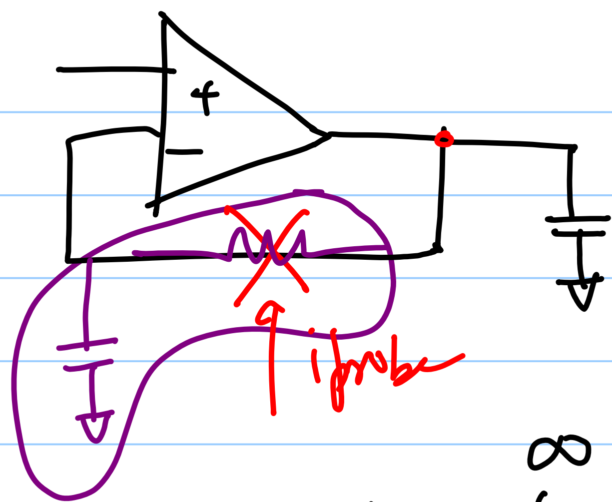
ΔV

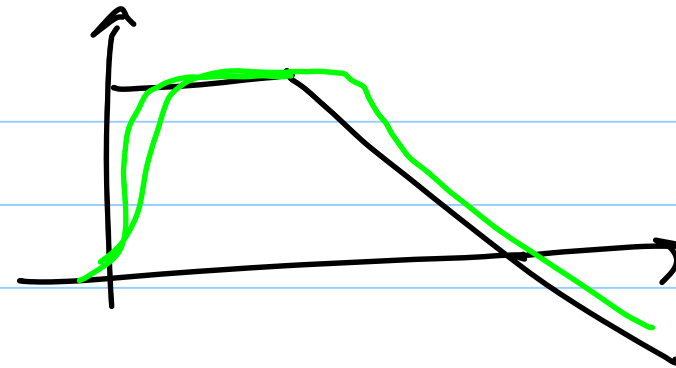
$(V_p - V_m) A = V_o$

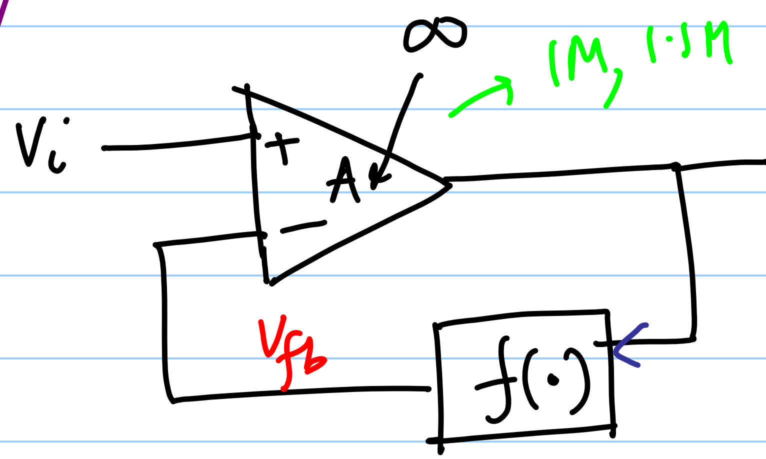
Stability Analysis .STB

AC

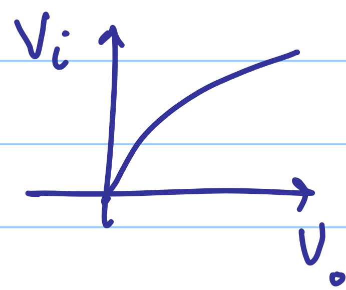








$$\frac{V_o}{V_i} \Rightarrow f^{-1}(\cdot)$$

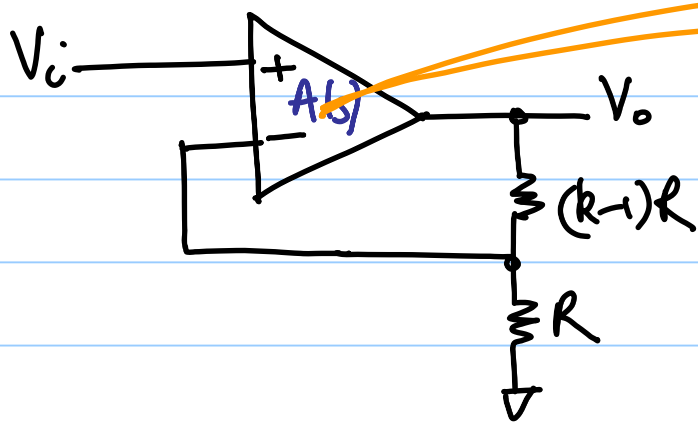


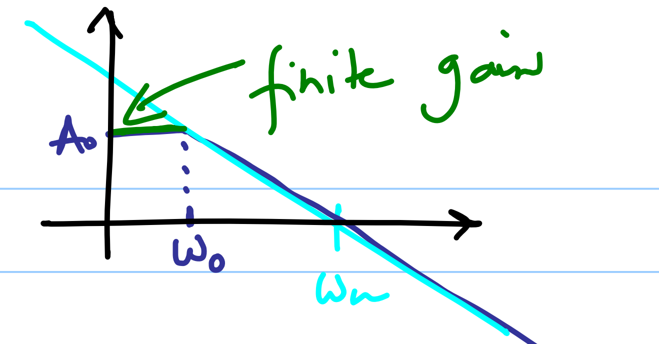
$$V_e = V_i - V_{fb} \to 0$$

$$0 = V_i - f(V_o)$$

$$\rightarrow \quad V_o \Rightarrow f^{-1}(V_i)$$

① gain





$$\frac{V_o}{V_i} = \frac{k\,L(s)}{1 + L(s)} \qquad L(s) = \frac{A(s)}{k}$$

at DC

$$A(s) = \frac{A_0}{\left(1 + s/\omega_0\right)}$$

$$\omega_u = A_0 \omega_0$$

$$A_{CL} = \frac{V_o}{V_i} = \frac{kL}{1 + L} = \frac{k \cdot \frac{A_0}{k}}{1 + \frac{A_0}{k}} = k \cdot \frac{A_0}{A_0 + k}$$

$$= \boxed{k} \cdot \frac{1}{\left(1 + \frac{k}{A_0}\right)}$$

ideal (→ k)

$$\frac{1}{(1+x)} \simeq 1 - x \qquad |x| \ll 1$$

$$= k \cdot \left(1 - \frac{k}{A_0}\right)$$

$$= k \cdot [1 - \epsilon]$$

DC gain Error

relative gain error (affect precision)

$$\epsilon = \frac{k}{A_0} \simeq \frac{1}{\text{Loop gain at DC}}$$

Ex. $k = \underline{10}$

for gain error $< 1\% = 10^{-2}$ $\Rightarrow$ $SNR = \frac{40 \text{ dB}}{6} = 7$ bit resolution

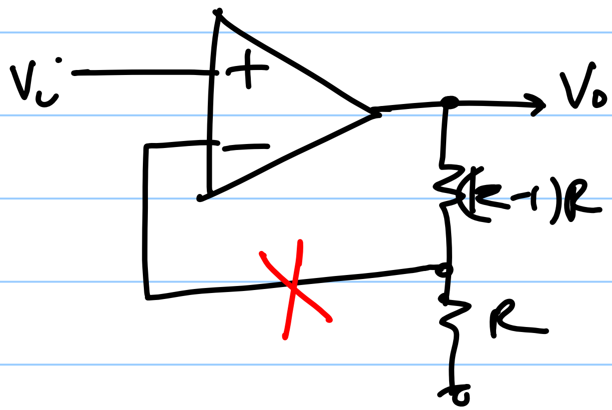
$$\varepsilon = \frac{k}{A_0}$$

$$\Rightarrow A_0 \geq \frac{k}{\varepsilon} = 1000$$

60 dB

$$N_{eff} = \frac{SNR - 1.76}{6}$$ (SNR in dB)

② Small-Signal BW



$$A(s) = \frac{A_0}{1+\left(\frac{s}{\omega_0}\right)}$$

$$L(s) = \frac{A_0/k}{1+s/\omega_0}$$

$$\frac{V_o}{V_i}(s) = \frac{k\,L(s)}{1+L(s)} = \frac{A(s)}{1+L(s)}$$

$$= \frac{\frac{A_0}{1+s/\omega_0}}{1+\frac{A_0/k}{1+s/\omega_0}} = \frac{A_0}{1+\frac{A_0}{k}} \times \frac{1}{1+\frac{s}{\omega_0\left(1+\frac{A_0}{k}\right)}}$$

$$= \underbrace{k \cdot \left(1 - \frac{k}{A_0}\right)}_{A_{CL}} \times \frac{1}{1 + \frac{s}{\omega_0\left(1 + \frac{A_0}{k}\right)}}$$

$$= \frac{A_{CL}}{1 + \frac{s}{\omega_{u,loop}}}$$

← 3dB BW of the amplifier

$$\omega_{u,loop} = \omega_0\left(1 + \frac{A_0}{k}\right)$$

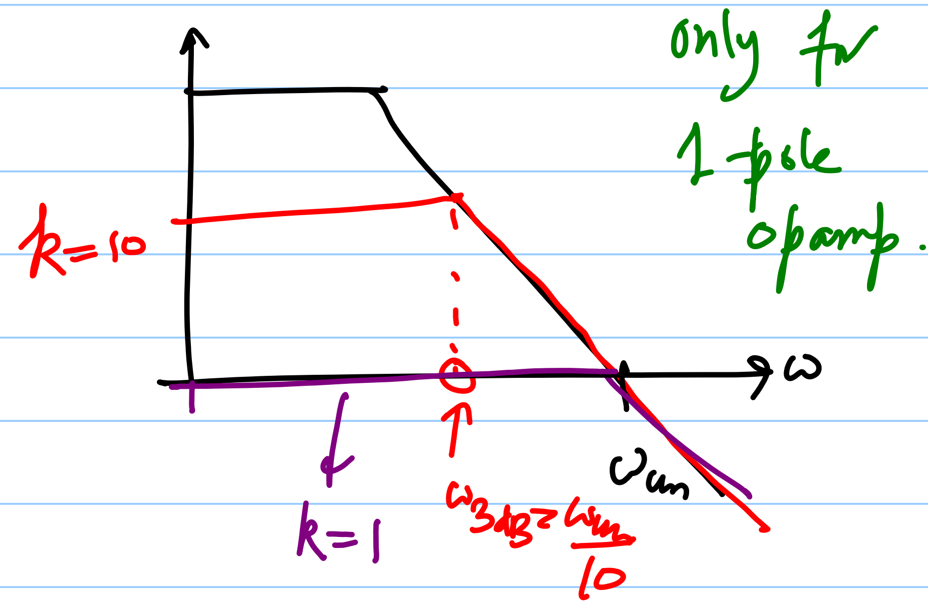
$$\simeq \frac{\omega_0 A_0}{k}$$

$$= \frac{\omega_{un}}{k}$$

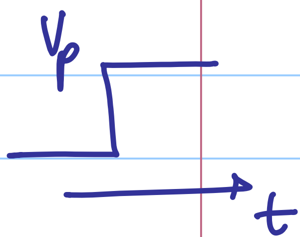
← of the opamp

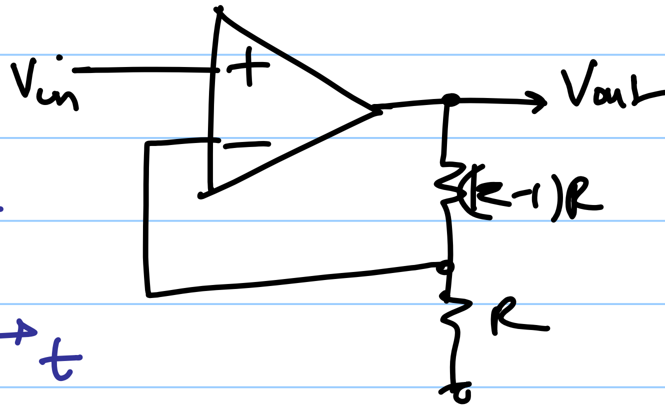
= ω_{3dB} of the closed-loop amplifier

$$\omega_{3dB} = \frac{\omega_{un}}{k} \Leftarrow \text{Gain} \times \text{BW trade off}$$



'k'





$$V_{in}(t) = V_p \cdot u(t)$$

$$\downarrow$$

$$V_{in}(s) = \frac{V_p}{s}$$

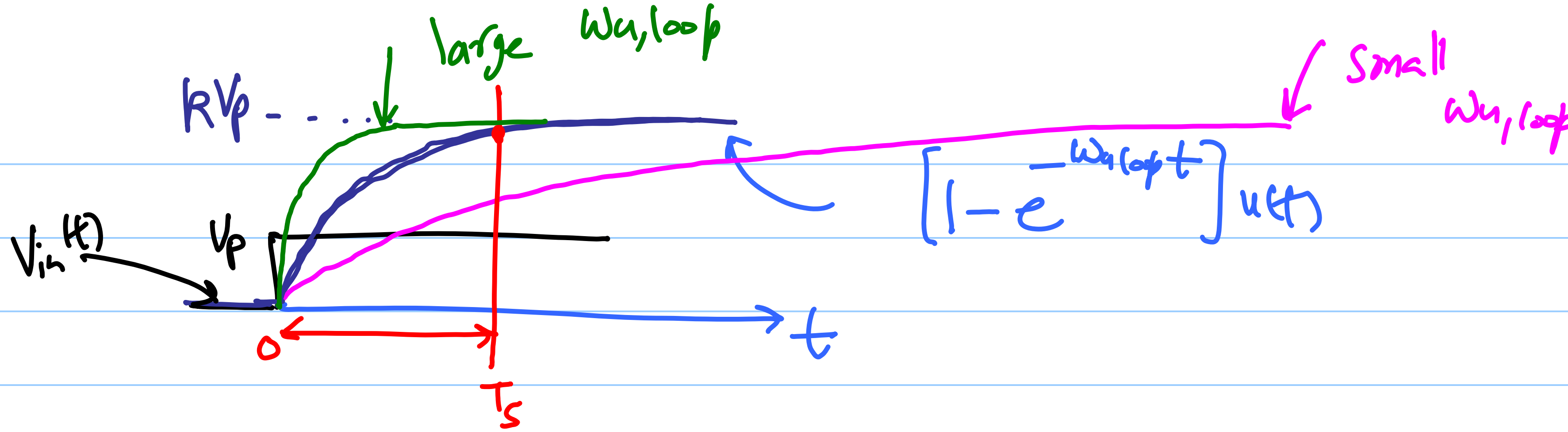
$$V_{out}(s) = \left(\frac{k L(s)}{1+L(s)}\right) V_{in}(s) = \frac{k}{1+\frac{s}{\omega_{u,loop}}} \times \frac{V_p}{s}$$

$$\omega_{u,loop} \rightarrow \frac{\omega_{un}}{k}$$

$$\frac{1}{s\left(1+\frac{s}{\omega_{u,loop}}\right)}$$

$$\downarrow \mathcal{L}^{-1}$$

$$V_{out}(t) = kV_p\left[1-e^{-\omega_{u,loop} t}\right]u(t)$$



for 99% settling of the output

$$\cancel{kV_p}\left(1-e^{-\omega_{u,loop}\cdot T_s}\right) = 0.99 \times \cancel{kV_p}$$

$$T_{s,99\%} = \frac{\ln(100)}{\omega_{u,loop}} = \tau \times \ln(100)$$

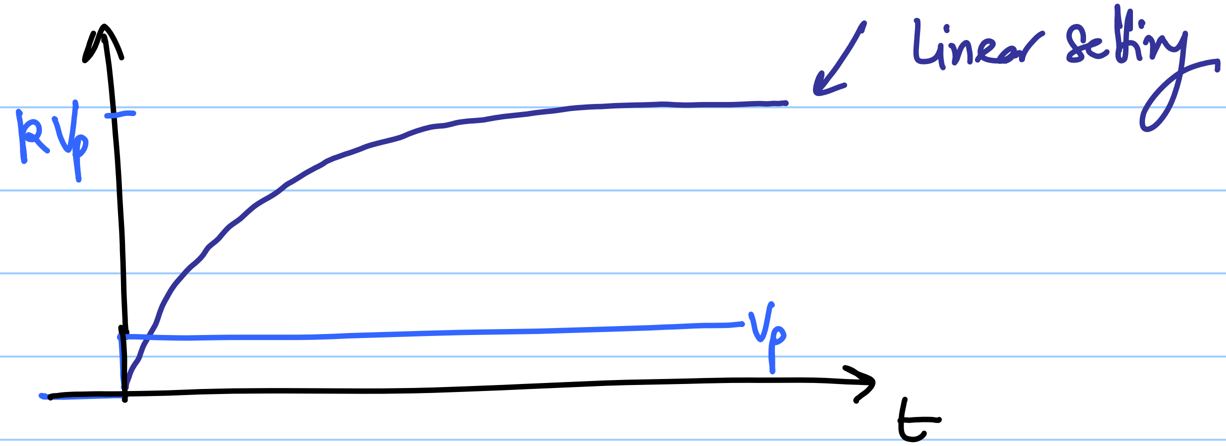
$$= 4.7\,\tau \quad \rightarrow \quad \tau = \frac{1}{\omega_{u,loop}}$$

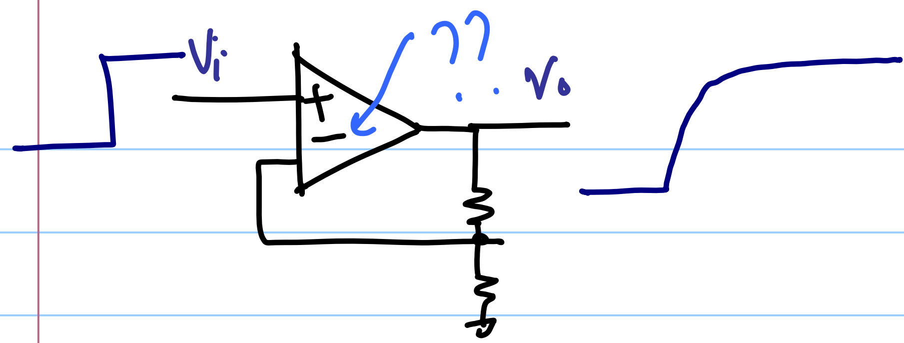
Settling accuracy / time $\Rightarrow$ $\omega_{u,loop}$

$\hookrightarrow$ ω_{un} for the opamp

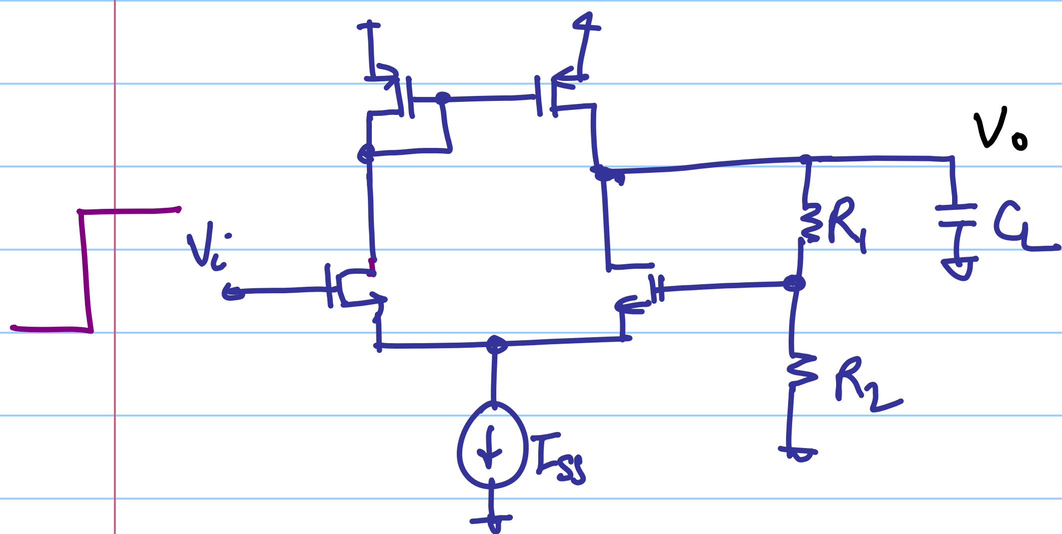
$\omega_{3dB} \Rightarrow \omega_{u,loop} = \dfrac{\omega_{un}}{k}$ ↗

$k \uparrow \Rightarrow$


kVp
Vp
t
Linear settling



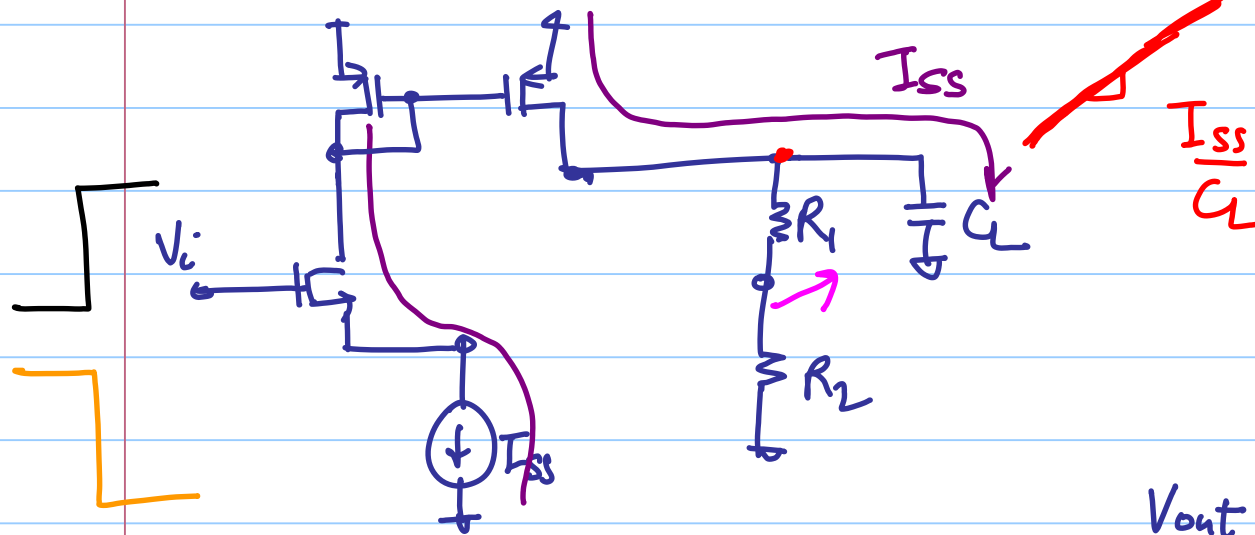
V_i
??
V_o

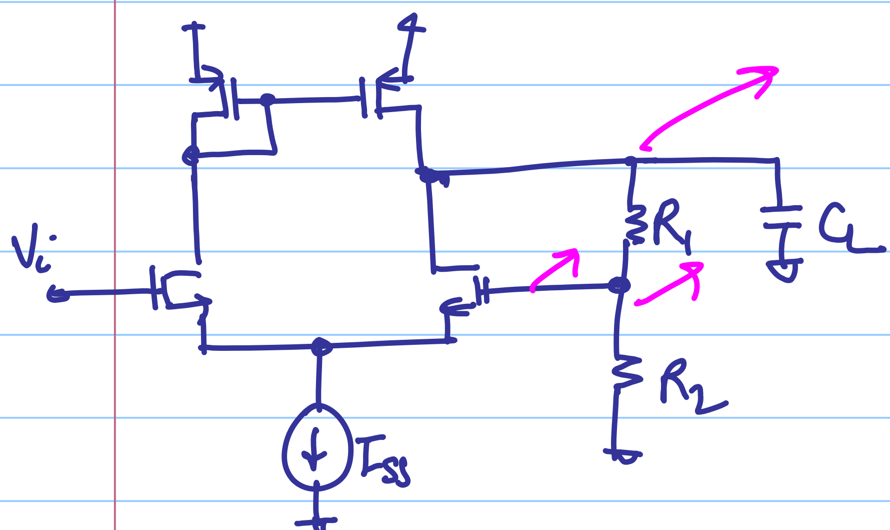


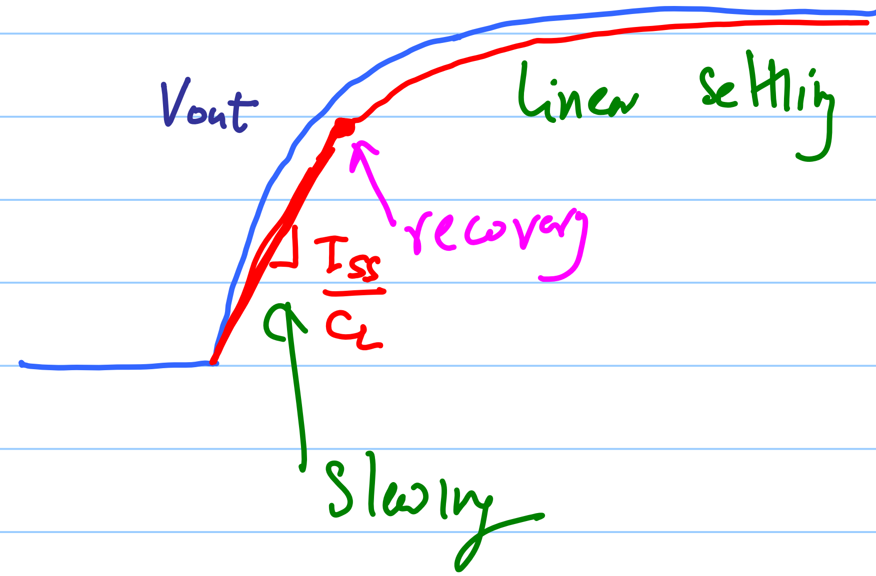
V_o
V_i
R_1
C_L
R_2
I_{SS}

Slewing

"fixed current charges/discharges a large cap"

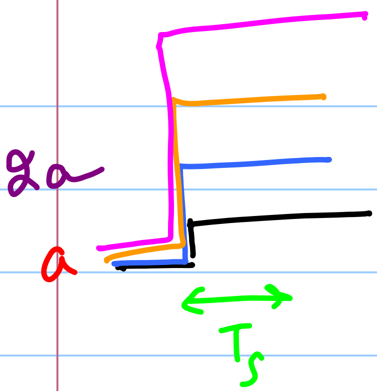






$k=1$

Linear Settling

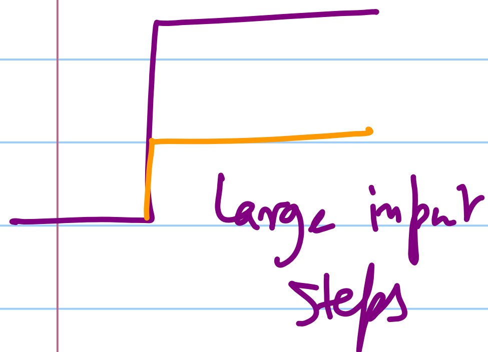


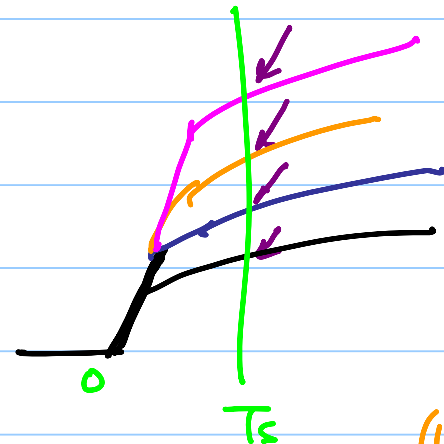
$$V_{final}\underbrace{\left(1-e^{-\omega_{u,loop}\cdot T_s}\right)}_{\alpha}$$

αa

$\alpha 2a$

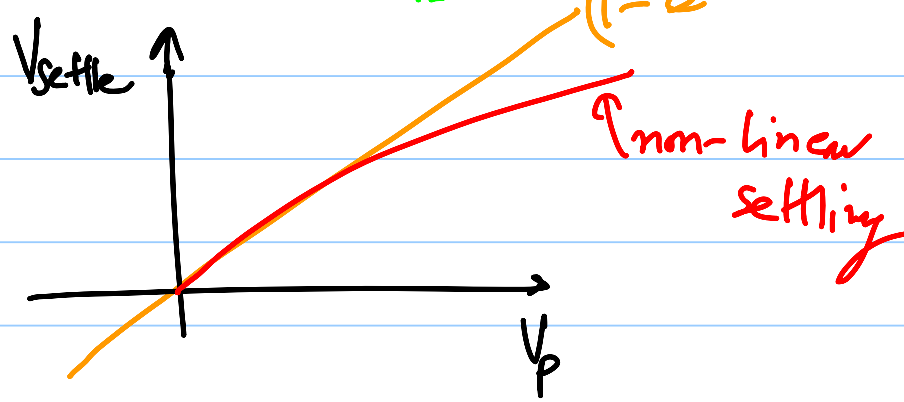
Slewing





Scaling is non-linear

$$\left(1-e^{-\omega_{3dB}T_s}\right)=\alpha$$



In two-stage op amp → Miller Compensation

$SR \le \frac{I_{SS}}{C_c}$ compared to $\frac{I_{SS}}{C_L}$