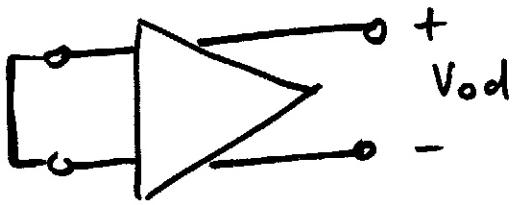
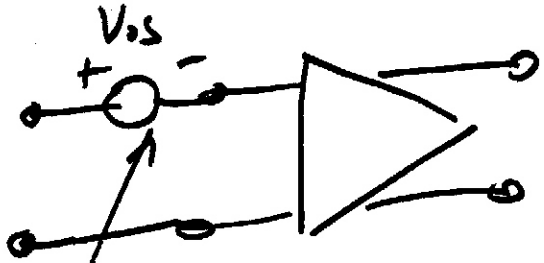
OFFSET VOLTAGES (CURRENTS)



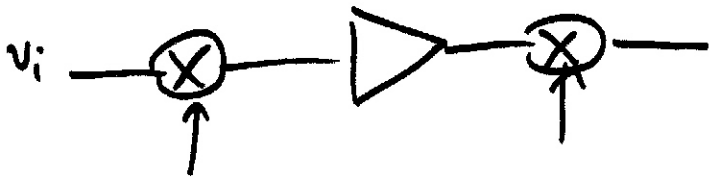
OFFSET VOLTAGE DUE TO MISMATCHES

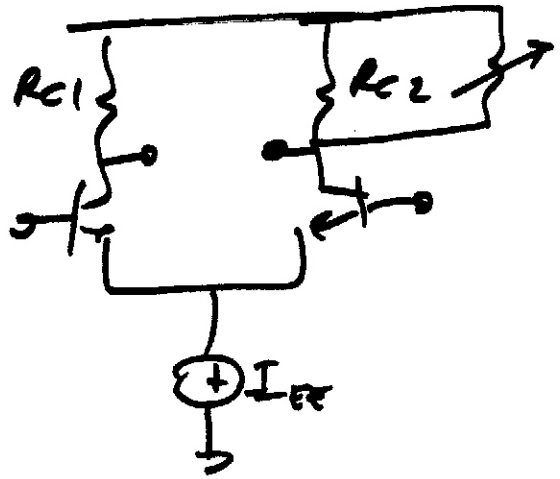


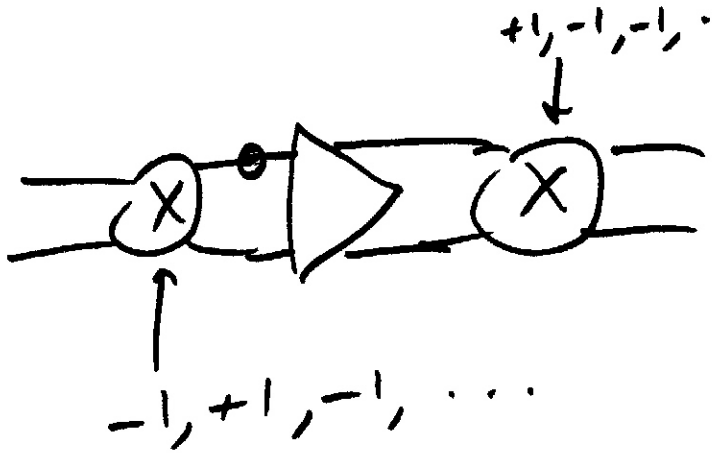
ZERO-OFFSET AMP

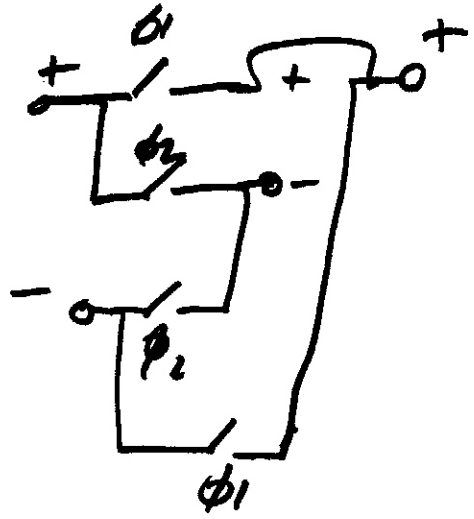
OFFSET VOLTAGE (INPUT REF)

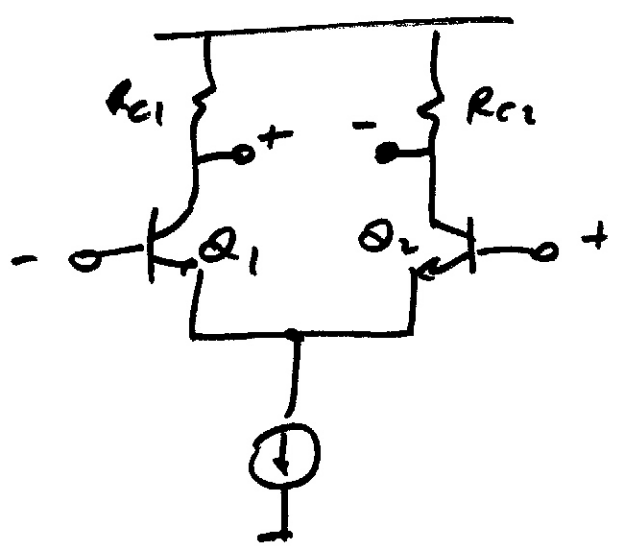
SOLUTIONS: — TRIM OFFSET











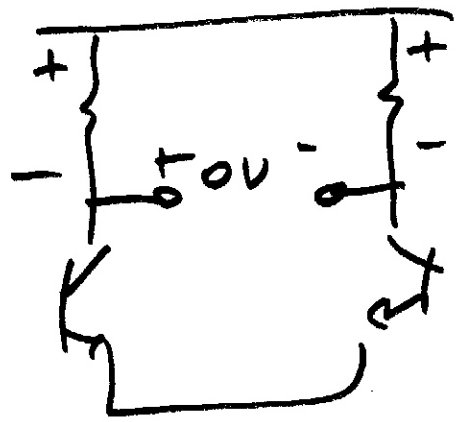
$$R_C = \frac{R_{C1}+R_{C2}}{2} \qquad I_S = \frac{I_{S1}+I_{S2}}{2}$$

$$\Delta R_C = R_{C1} - R_{C2} \qquad \Delta I_S .$$

$$v^+ - v^- = V_{BE2} - V_{BE1}$$

$$= \frac{kT}{q}\left(\ln \frac{I_{C2}}{I_{S2}} - \ln \frac{I_{C1}}{I_{S1}}\right)$$

$$V_{di} = \frac{kT}{q}\left(\ln \underbrace{\frac{I_{C2}}{I_{C1}}} + \ln \frac{I_{S1}}{I_{S2}}\right)$$



$$I_{C1} \cdot R_{C1} = I_{C2} \cdot R_{C2}$$

$$\frac{I_{C1}}{I_{C2}} = \frac{R_{C2}}{R_{C1}}$$

$$V_{OS} = \frac{kT}{q}\left\{ \ln\left(\frac{R_{C1}}{R_{C2}}\right) + \ln\left(\frac{I_{S1}}{I_{S2}}\right) \right\}$$

$$= \frac{kT}{q}\left[\ln\left(\frac{R_C + \frac{\Delta R_C}{2}}{R_C - \frac{\Delta R_C}{2}}\right) + \ln\left(\frac{I_S + \frac{\Delta I_S}{2}}{I_S - \frac{\Delta I_S}{2}}\right)\right]$$

$$= \frac{kT}{q}\left\{ \ln\left(\frac{1 + \frac{\Delta R_C}{2}}{1 - \frac{\Delta R_C}{2}}\right) + \ln\left(\quad\right)\right\}$$

$$\ln\left\{\left(1 + \frac{\Delta R_C}{2}\right)\left(1 + \frac{\Delta R_C}{2}\right)\right\} + \ln\left(\quad\right)$$

$$V_{OS} = \frac{kT}{q}\left\{\ln\left(1+\frac{\Delta R_C}{R_C}\right) + \ln\left(1+\frac{\Delta I_S}{I_S}\right)\right\}$$

$$\ln(1+\delta) \simeq \delta$$

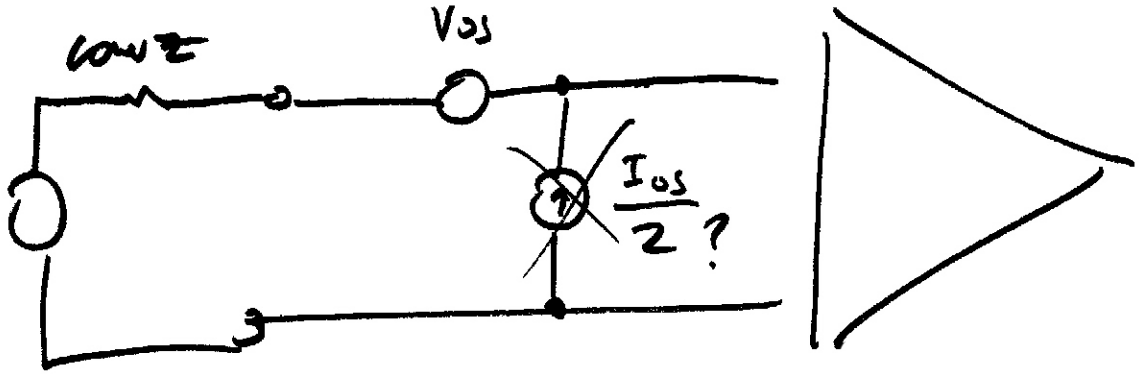
$$\boxed{V_{OS} = \frac{kT}{q}\left\{\frac{\Delta R_C}{R_C} + \frac{\Delta I_S}{I_S}\right\}}$$

$$= 25\,mV\left(\underbrace{\left|\frac{\Delta R_C}{R_C}\right|}_{1\%} + \underbrace{\left|\frac{\Delta I_S}{I_S}\right|}_{5\%}\right) = \underline{1.5\,mV}$$

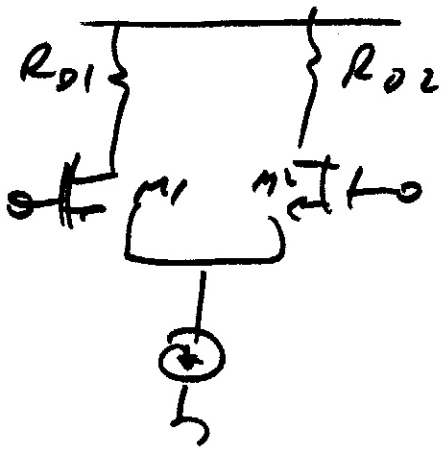
$$\boxed{\sigma_{V_{OS}}^2 = \left(\frac{kT}{q}\right)^2\left(\sigma_{\frac{\Delta R_C}{R_C}}^2 + \sigma_{\frac{\Delta I_S}{I_S}}^2\right)}$$

$$= \sqrt{(25m)^2\left|(1\%)^2 + (5\%)^2\right|} = \underline{1.3\,mV}$$

CURRENT OFFSET ? β MISMATCH $\Rightarrow$



MOSFET OFFSET



$I_{D1} R_{D1} = I_{D2} R_{D2}$

TRIM CONDITION!

$$V_{id} = V_{GS1} - V_{GS2}$$

$$= V_{T1} + \sqrt{\frac{2I_{D1}}{\mu C_{ox}\left(\frac{W}{L}\right)_1}} - V_{T2} - \sqrt{\frac{2I_{D2}}{\mu C_{ox}\left(\frac{W}{L}\right)_2}}$$

$$V_{OS} = \Delta V_T + \sqrt{\frac{2I_D}{\mu C_{ox}\left(\frac{W}{L}\right)}}\left(\sqrt{\frac{1-\frac{\Delta I_D}{2I_D}}{1-\frac{\Delta\left(\frac{W}{L}\right)}{2\left(\frac{W}{L}\right)}}} - \sqrt{\frac{1+\cdots}{1+\cdots}}\right)$$

$$= \Delta V_T + V_{od}\left(\sqrt{\left(1-\frac{\Delta I_D}{2I_D}\right)\left(1+\frac{\Delta\left(\frac{W}{L}\right)}{2\left(\frac{W}{L}\right)}\right)} - \sqrt{+\,-}\right)$$

$$\left(\sqrt{1-\frac{\Delta I_D}{2I_D}+\frac{\Delta\left(\frac{W}{L}\right)}{2\left(\frac{W}{L}\right)}} - \sqrt{\cdots}\right)$$

$$\sqrt{1+\delta} = 1+\frac{1}{2}\delta$$

$$= 1-\frac{\Delta I_D}{4I_D}+\frac{\Delta\left(\frac{W}{L}\right)}{4\left(\frac{W}{L}\right)} - 1 - \frac{\Delta I_D}{4I_D}\cdots$$

$$\boxed{V_{OS} = \Delta V_T + \frac{V_{od}}{2}\left(-\frac{\Delta I_D}{I_D}+\frac{\Delta\left(\frac{W}{L}\right)}{\frac{W}{L}}\right)}$$

$$\frac{\Delta I_D}{I_D} = -\frac{\Delta R_D}{R_D}$$

$$V_{OS} = \Delta V_T + \frac{V_{OV}}{2}\left(\frac{\Delta R_D}{R_D} + \frac{\Delta \left(\frac{W}{L}\right)}{\frac{W}{L}}\right)$$

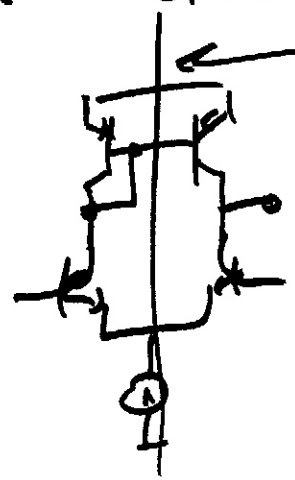
ΔV_T: ~10mV, LAYOUT ~1mV

$\frac{V_{OV}}{2}$: ~100mV

MOSFETS HAVE LARGER OFFSET VOLTAGE

BUT MUCH SMALLER OFFSET CURRENTS!

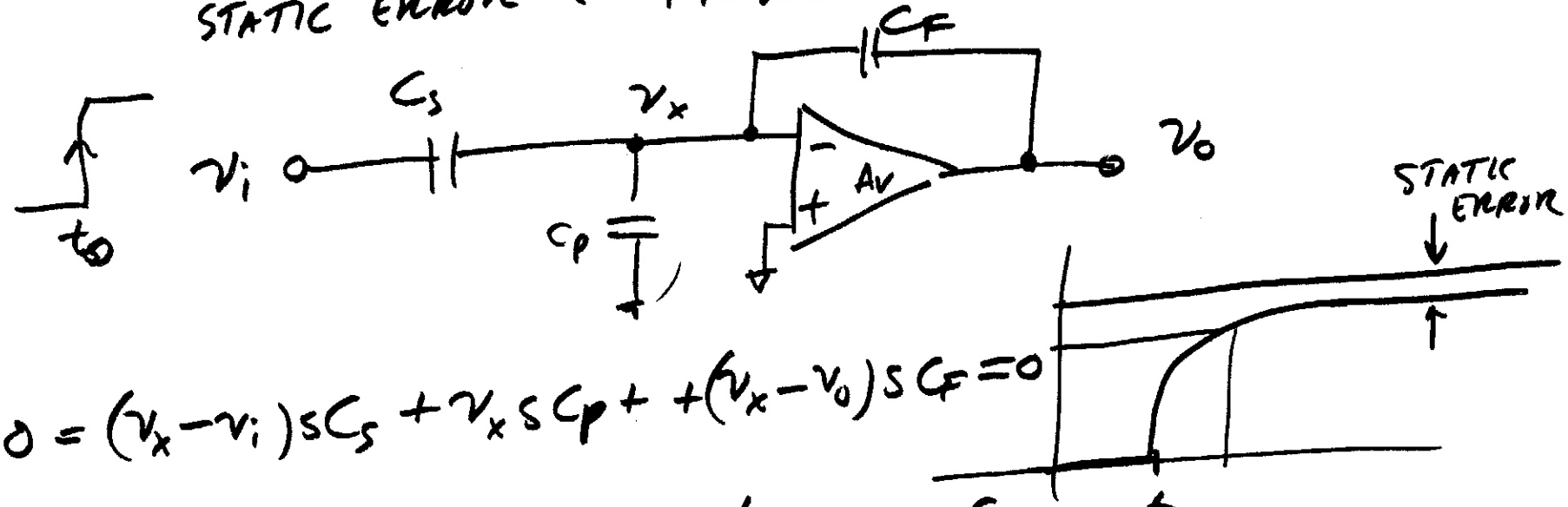
SYSTEMATIC OFFSET



SETTLING TIME ← DYNAMIC ERRORS

↓

STATIC ERROR ← FINITE GAIN



$$0 = (v_x - v_i)sC_S + v_x s C_p + (v_x - v_o)s C_F = 0$$

$$v_x(C_S + C_p + C_F) = v_i C_S + v_o C_F$$

$$F \equiv \frac{C_F}{\underbrace{C_S + C_p + C_F}_{C_T}}$$

$$v_x = F \cdot v_o + F \cdot \frac{C_S}{C_F} \cdot v_i$$

$$\frac{-v_o}{F A_V} = F \cdot v_o + F \cdot \frac{C_S}{C_F} v_i$$

ORIGIN OF ERROR TERM!

$$\frac{v_o}{v_i} = \frac{-\frac{C_S}{C_F}}{\frac{1}{A_V \cdot F} + 1} = \frac{C}{1 + \underbrace{\frac{1}{A_V F}}_{T}}$$

T LOOP GAIN

$$\simeq C\left(1 - \underbrace{\frac{1}{T}}_{\text{RELATIVE ERROR}}\right)$$

$\Rightarrow$ STATIC ERROR

A_V : LARGE SIGNAL GAIN

EX CLOSED LOOP GAIN = $-4 = C$

$C_F = 1pF \quad C_S = 4pF \quad C_p = 1pF$

$$F = \frac{C_F}{C_F + C_S + C_p} = \frac{1}{6}$$

C_p DOES HURT US! $\quad F \neq 1/C$

ERROR $< 0.1\%$

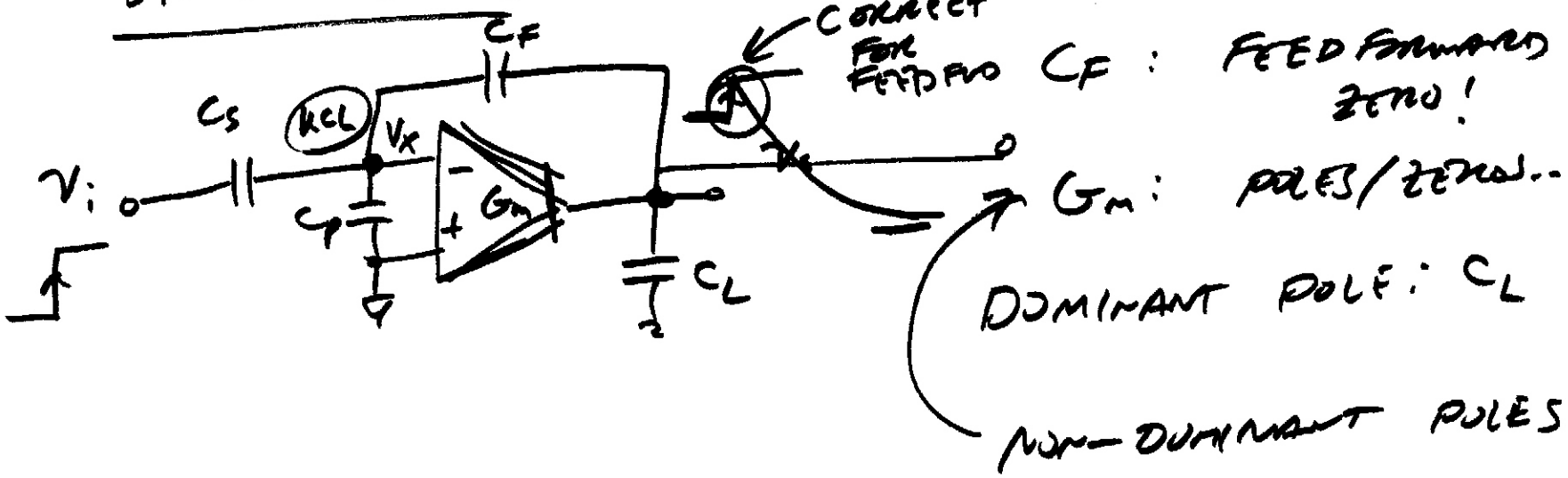
$$\frac{1}{F A_V} < 0.1\%$$

$$F A_V > 1000$$

$$\boxed{A_V > 6000}$$

OVER THE DESIRED O/P RANGE!

DYNAMIC ERRORS : LINEAR SETTLING



$$V_X (C_S + C_P + C_F) = V_i C_S + V_o C_F$$

$$V_X = \frac{C_S}{C_F} \cdot F \cdot V_i + F \cdot V_o$$

$$V_o s C_L + G_m V_X + (V_i - V_X)\, s C_F = 0$$

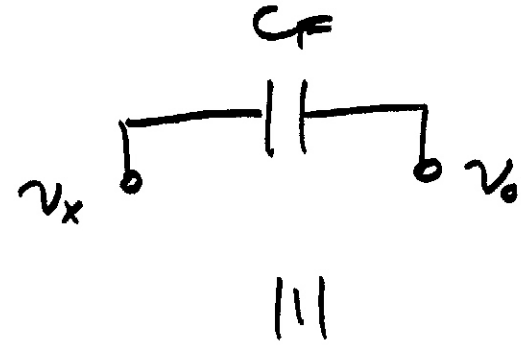
$$V_o\, s (C_L + C_F) = V_X (s C_F - G_m)$$

$$\frac{v_1}{v_i} = \frac{\frac{C_s}{C_F} F \left(sC_F - G_m \right)}{FG_m + s\left(C_L + C_F(1-F)\right)}$$

$$= \frac{\left(-\frac{C_s}{C_F}\right) F G_m \left(1 - \frac{sC_F}{G_m}\right)}{F G_m \left(1 + s \frac{C_L + C_F(1-F)}{FG_m}\right)}$$

$$= \frac{\left(-\frac{C_s}{C_F}\right)\left(1 - s/z\right)}{\left(1 + s/p\right)}$$

$$z = \frac{G_m}{C_F} \qquad p = \frac{FG_m}{C_L + C_F(1-F)} = \frac{FG_m}{C_{L,eff}}$$



$-1/F$

$$C_1 = C_F(1 - A_V) = C_F(1 + 1/F)$$

$$C_2 = C_F(1 - 1/A_V) = C_F(1 - F)$$

MILLER CAP

STEP RESPONSE :

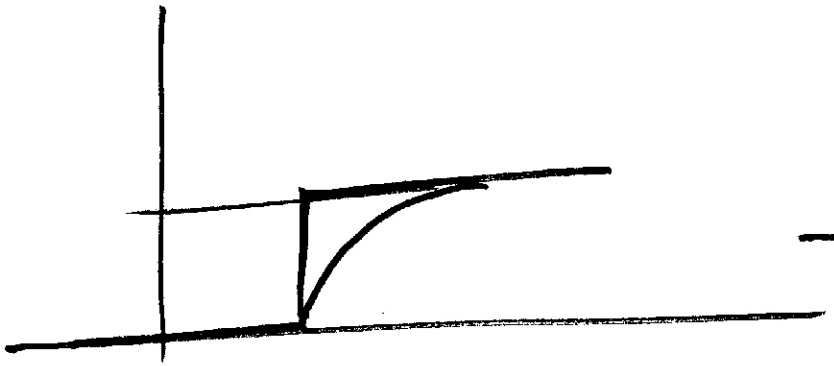
$$H(s) = C \frac{(1 - s/z)}{(1 + s/p)}$$

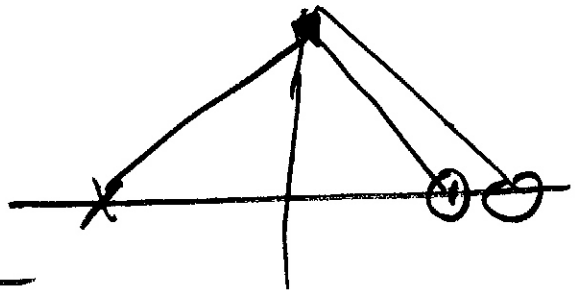
(RHP zero: $1 - s/z$; LHP pole: $1 + s/p$)

$$v_o(t) = \mathcal{L}^{-1}\left\{ H(s) \cdot \frac{V_{in}}{s} \right\}$$

$$= -V_{in}|C| \left\{ 1 - \underbrace{\left(1 + \frac{p}{z}\right) e^{pt}}_{\text{DYNAMIC ERROR TERM}} \right\}$$

TIME CONSTANT $\quad 1/p = \tau = \dfrac{C_{eff}}{F \cdot G_m}$





$$\left(\frac{P}{Z}\right) = -F\frac{C_F}{C_{Leff}} = -1$$

$$v_o(t) = -V_{in}(C)\left\{\left(-\right. 1-(1+\varepsilon)e^{Pt}\right\}$$

$$= -V_{in}(C)\left\{1-\underbrace{\varepsilon e^{Pt}}\right\}$$