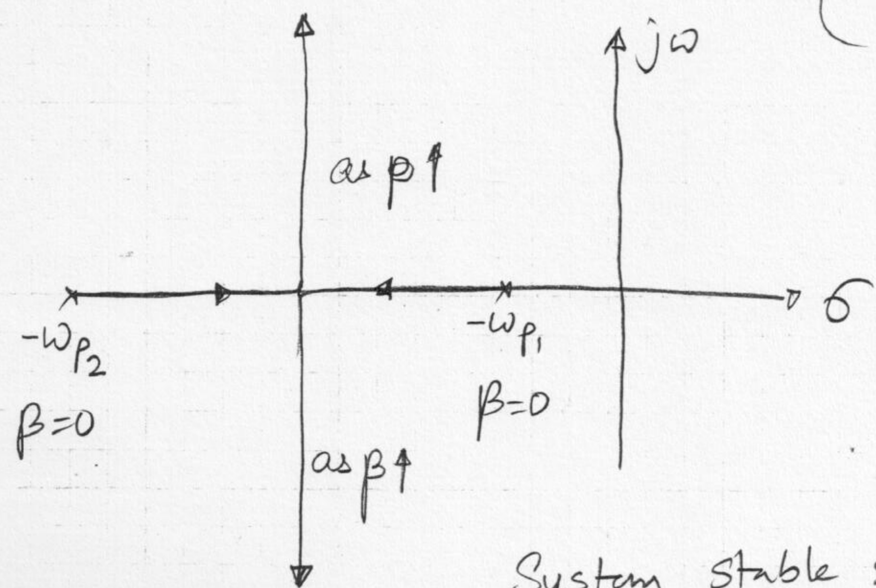
STAEDTLER® No. 937 811E Engineer's Computation Pad

Two pole system.

$$A(s) = \frac{1}{\left(1+\frac{s}{\omega_{p_1}}\right)\left(1+\frac{s}{\omega_{p_2}}\right)}$$



System stable since both poles left half plane.

Note on Phase Margin

PM of 45° $\quad |T(j\omega_u)| = 1 \quad \angle T(j\omega_u) = -135^\circ$

Closed Loop Gain

$$\frac{Y(s)}{X(s)} = \frac{A(j\omega_u)}{1+T(j\omega_u)} = \frac{A(j\omega_u)}{1+1\times\exp(-j135^\circ)}$$

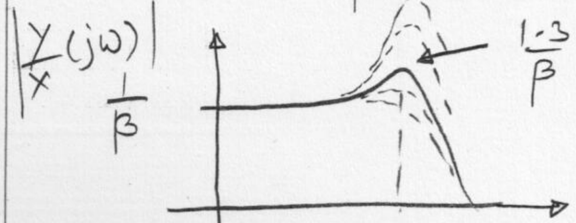
$\angle\beta A(j\omega_u) = -135^\circ$

$|\beta A(j\omega_u)| = 1$

$\Rightarrow |A(j\omega_u)| = |1/\beta|$

$$= \frac{A(j\omega_u)}{0.29-0.71j}$$

$$\left|\frac{Y(s)}{X(s)}\right| = \frac{1/\beta}{|0.29-0.71j|} = \frac{1.3}{\beta} \leftarrow \text{peaking}$$

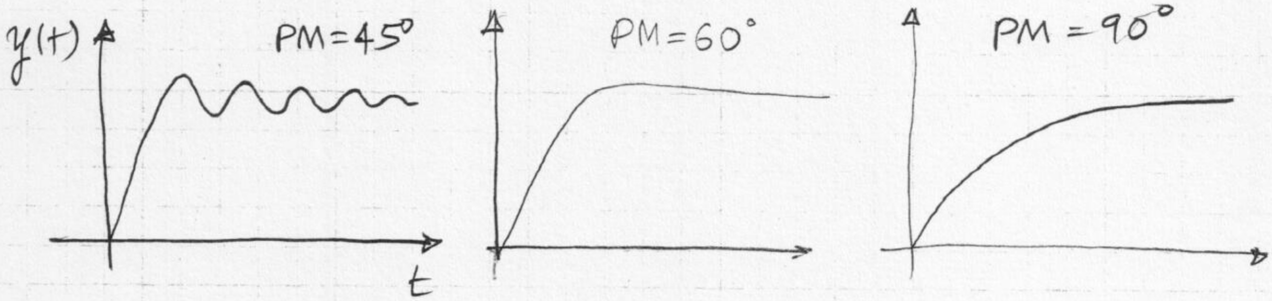


Peaking keeps increasing as PM ⇓

Oscillatory behavior.

STAEDTLER® No. 937 811E Engineer's Computation Pad

Closed loop transient response (Razavi pp. 419)



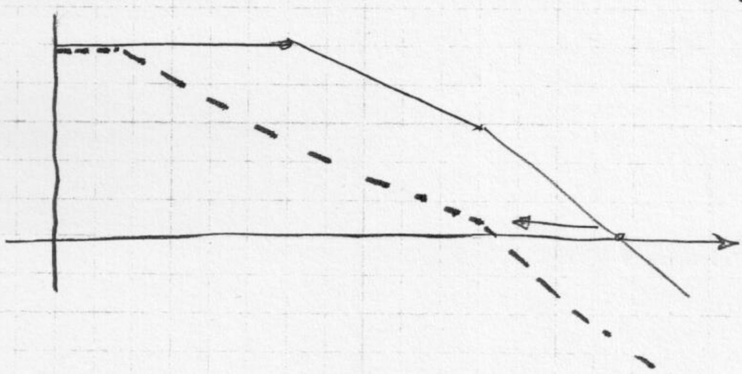
→ Valid only for small signal analysis.

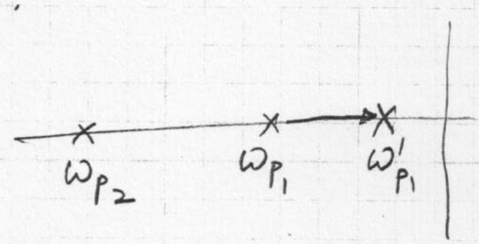
FREQUENCY COMPENSATION

$|\beta A(j\omega)| < 1$ way before $\angle \beta A(j\omega) = -180°$

How?

① Drop gain vs frequency – get gain crossover pulled to low frequency.





→ low frequency gain maintained.

→ Bandwidth reduced a lot.

Example – Add tons of cap at ω_{p_1} node.

→ Not really good solution.

STAEDTLER® Engineer's Computation Pad

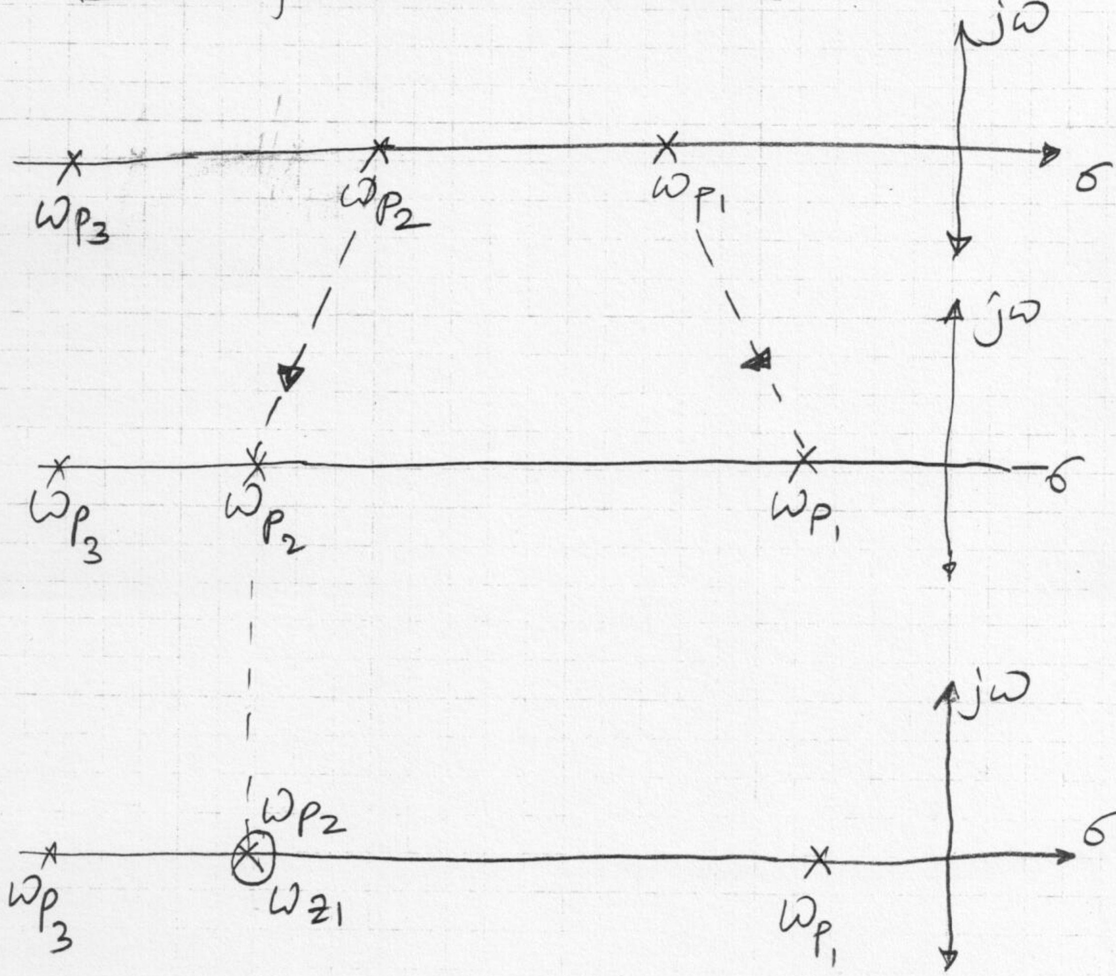
2. Minimize overall phase shift – push Px out.

→ Minimize number of poles in signal path

→ # of stages limited – low gain/swing

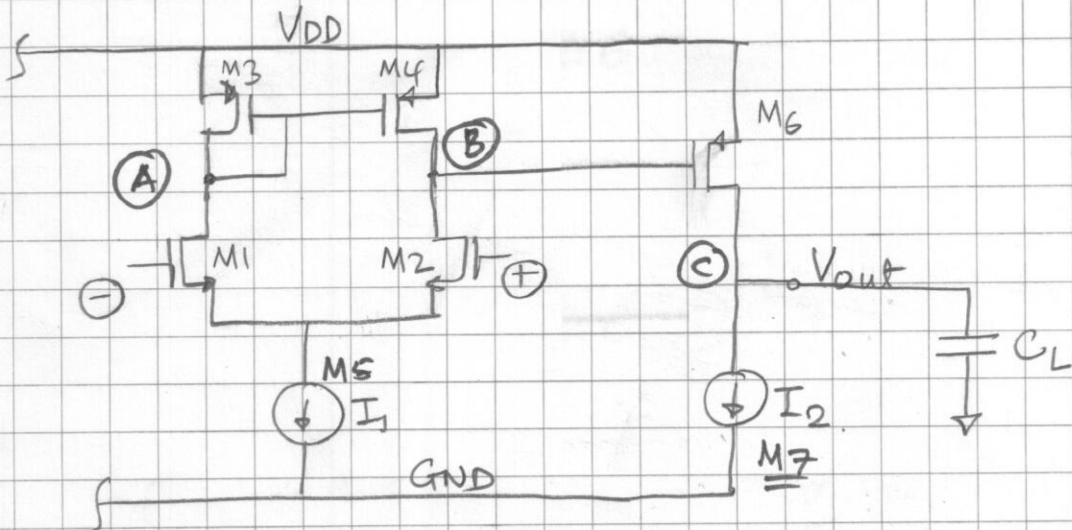
Not great solution either.

Enter freq. compensation



Make sure compensation trick holds true over PVT

Back to Two Stage OTA

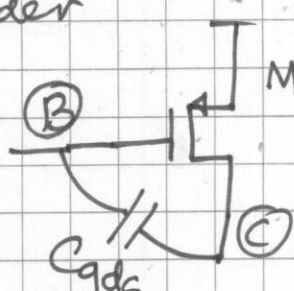


Signal path.
Each node → contributes pole $\omega_{p_i} \approx \frac{g_i}{C_i}$

$g_A = g_{ds_1} + g_{m_3} + g_{ds_3} \approx g_{m_3}$ ← Low imp. node

$g_B = g_{ds_2} + g_{ds_4}$
$g_C = g_{ds_6} + g_{ds_7}$] High Impedance Nodes

Consider



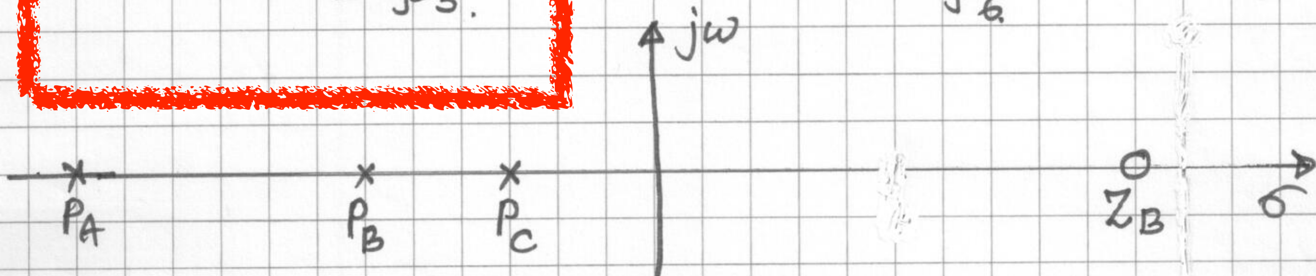
C_{gd6} around inverting stage

→ RHP zero $\frac{g_{m6}}{C_{gd6}}$ z_B

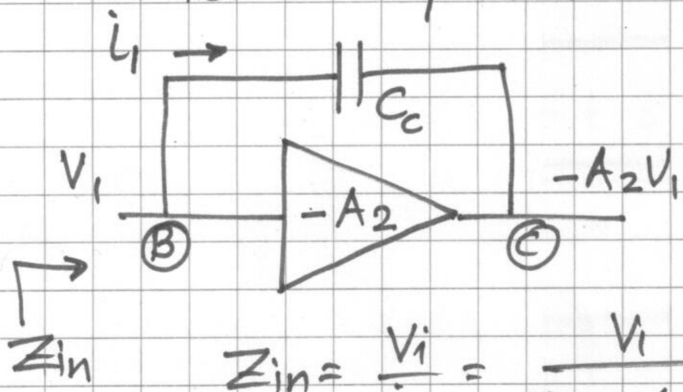
$$\boxed{\omega_A = \frac{g_{m3}}{2C_{gs3}}}$$

Text

$\omega_B = \frac{g_{ds2} + g_{ds4}}{C_{gs6}}$; $\omega_c = \frac{g_{ds6} + g_{ds7}}{C_L}$



Miller Compensation — Concept

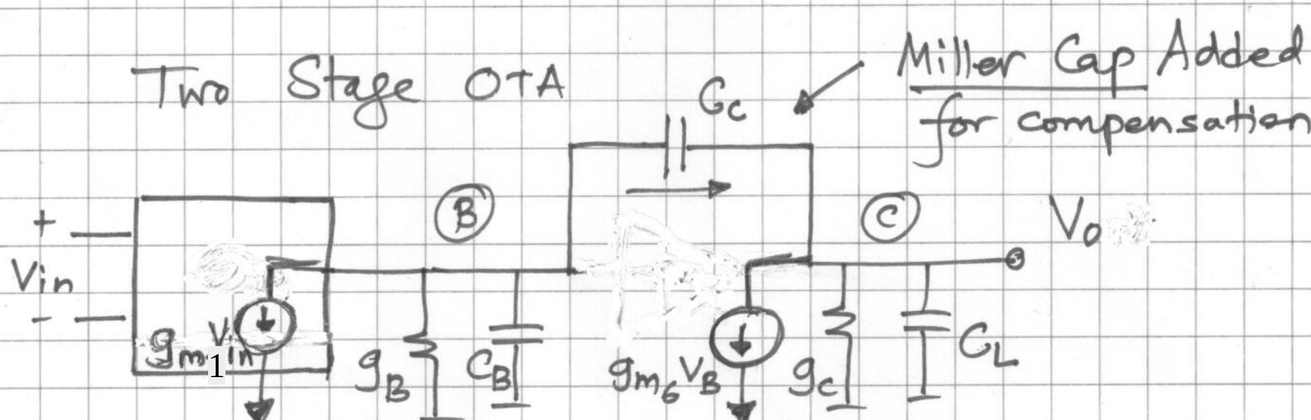


$$Z_{in} = \frac{V_1}{i_1} = \frac{V_1}{[V_1 - (-A_2V_1)]\,sC_c} = \frac{V_1}{V_1[1+A_2]C_c\,s}$$

$$= \frac{1}{\underbrace{(1+A_2)C_c}\,s}$$

Capacitance multiplied by $\underline{\underline{(1+A_2)}}$ ← will move P_B a lot.
large $g_m r_o$

Two Stage OTA



$$g_{m1}V_{in} + (g_B + sC_B)V_B + sC_c(V_B - V_o) = 0 \quad \text{— (1)}$$

$$sC_c(V_B - V_o) = g_{m6}V_B + (g_c + sC_L)V_o \quad \text{— (2)}$$

Need to Eliminate V_B

$$\longrightarrow \quad V_B = \frac{[g_c + s(C_L + C_c)]}{(sC_c - g_{m6})}\,V_o \quad \text{— (3)}$$

Substituting (3) in (1)

$$g_{m1} V_{in} + \left[\frac{[g_B + s(C_B + C_c)][g_c + s(C_L + C_c)]}{[sC_c - g_{m6}]} - sC_c \right] V_o = 0$$

$$[sC_c - g_{m6}]\, g_{m1} V_{in} + \underbrace{\left([g_B + s(C_B + C_c)][g_c + s(C_L + C_c)] - sC_c[sC_c - g_{m6}] \right)}_{\text{Simplify}} V_o = 0$$

Simplify ↓ $g_B g_c + s(C_B + C_c) g_c + s(C_L + C_c) g_B + sC_c g_{m6} + s^2(C_B C_L + C_c C_L + C_B C_c)$

ignore $g_c, g_B \ll g_{m6}$

$$(sC_c - g_{m6})\, g_{m1} V_{in} + \left(g_B g_c + sC_c g_{m6} + s^2(C_B C_L + C_c C_L + C_B C_c) \right) V_o = 0$$

$$\frac{V_o}{V_{in}} = \underbrace{\left(\frac{g_{m1}}{g_B}\right)\left(\frac{g_{m6}}{g_c}\right)}_{\text{DC gain}} \frac{\left(1 - \frac{sC_c}{g_{m6}}\right)}{\left(1 + s\frac{C_c}{g_B} \cdot \frac{g_{m6}}{g_c} + s^2\left(\frac{C_B C_L + C_c C_L + C_B C_c}{g_B \cdot g_c}\right)\right)}$$

RHP zero.

DOMINANT POLE APPROXIMATION.

Consider two poles P_D, P_{ND} such that

$P_D \ll P_{ND}$

Then $\left(1 + \frac{s}{P_D}\right)\left(1 + \frac{s}{P_{ND}}\right) = 1 + \left(\frac{1}{P_D} + \frac{1}{P_{ND}}\right)s + \frac{s^2}{P_D P_{ND}}$

$$= 1 + \frac{s}{P_D} + \frac{s^2}{P_D P_{ND}}.$$

compare

DOMINANT POLE. $P_D = \dfrac{g_B \; g_c}{C_c \; g_{m6}} = \dfrac{g_B / C_c}{(g_{m6}/g_c)}$

$\uparrow$ 2nd stage gain, large #

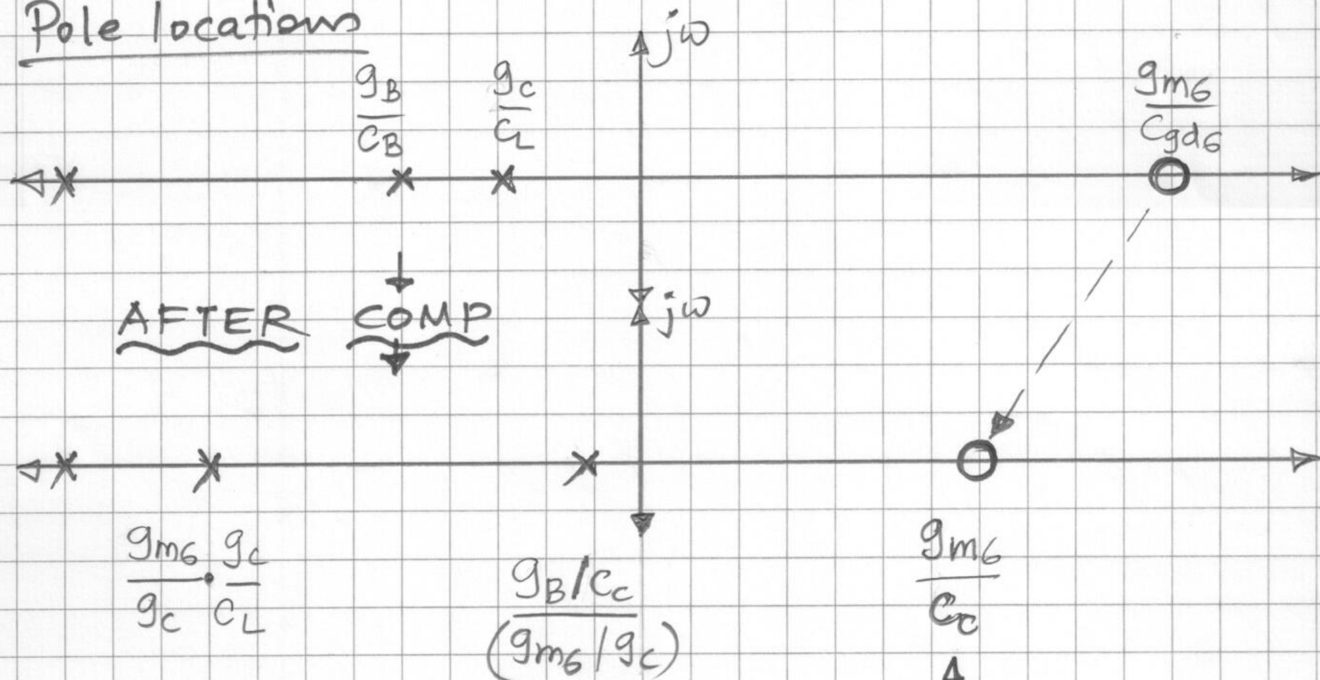
NON-DOM POLE $P_{ND} = \dfrac{g_B \cdot g_c}{(C_B C_L + \underline{\underline{C_c C_L}} + C_B C_c)} \cdot \dfrac{C_c \; g_{m6}}{g_B \cdot g_c}$

$\cong \dfrac{g_{m6} \; C_c}{C_L \cdot C_c}$ $\qquad$ C_B small Compared to C_L, C_c

$\cong \dfrac{g_{m6}}{C_L} = \boxed{\dfrac{g_{m6}}{g_c}} \cdot \dfrac{g_c}{C_L}$

2nd stage gain large #

Zero
Pole locations



RHP zero
Bad News!!

RHP zero — Phase gets worse while gain is lifted up.

$\dfrac{g_{m6}}{C_c} \leftarrow$ large

Need to Take care of RHP zero!