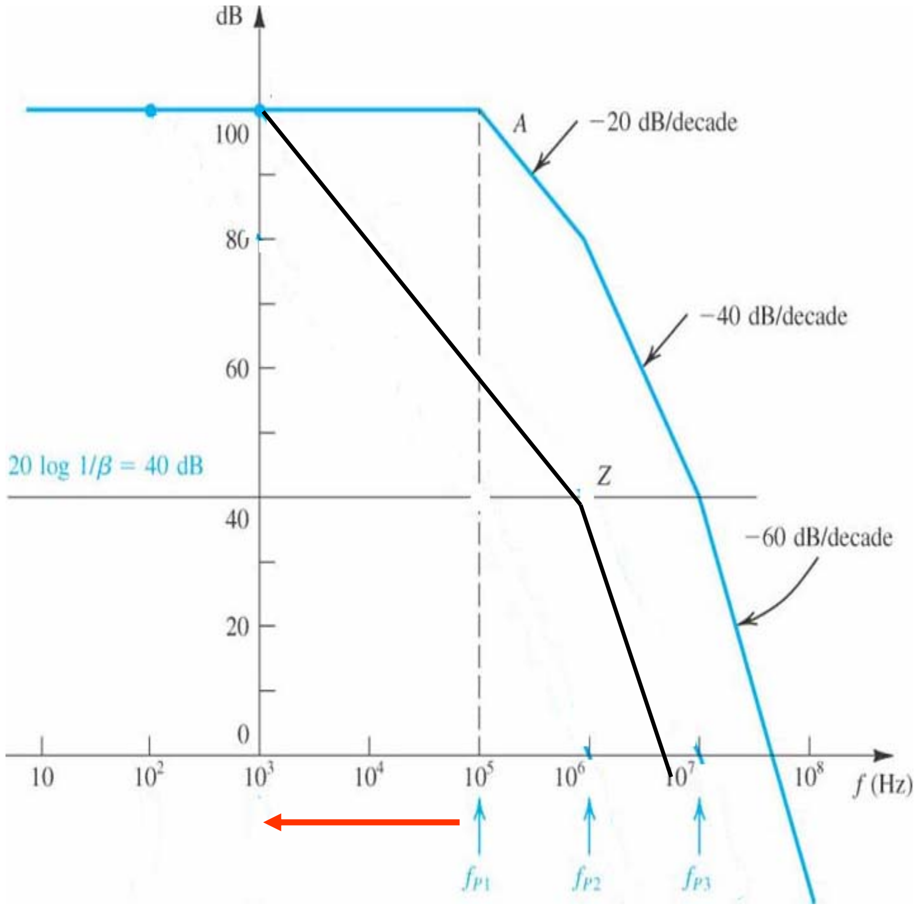
Lect. 10: Frequency Compensation

Bode plots for multi-pole amplifier



Unstable feedback system

Any way of fixing it?

Move f_{p1} to lower frequency so that |A| intersects 20 log(1/β) with -20dB/decade slope,

➔ Frequency Compensation

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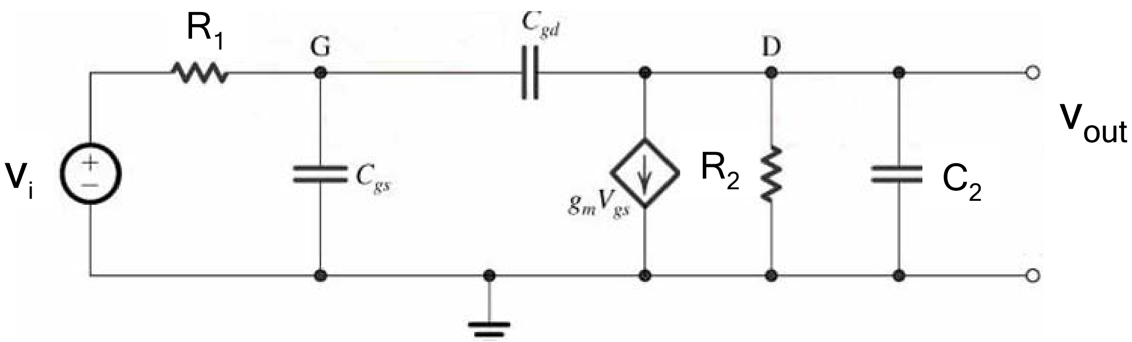
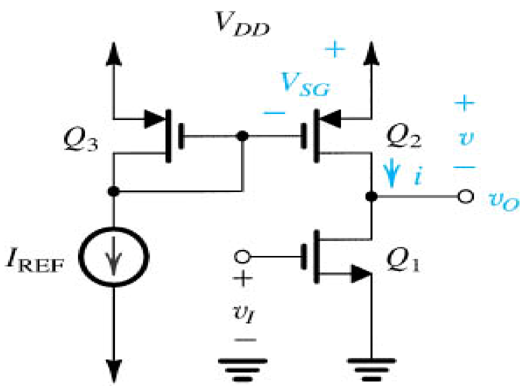
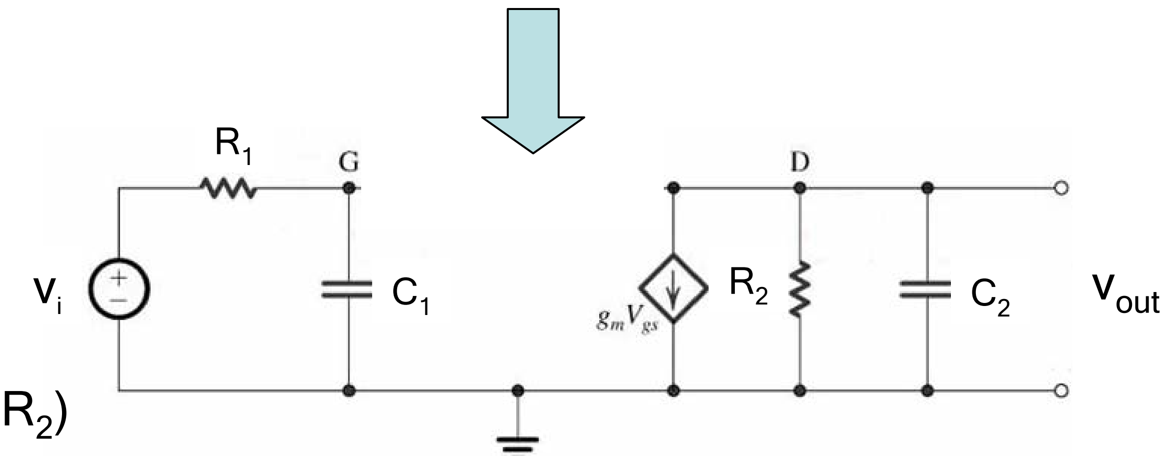
How to move a pole?

High-frequency small-signal model



CS amplifier with active load





$C_1 = C_{gs} + C_{gd}(1+g_m R_2)$

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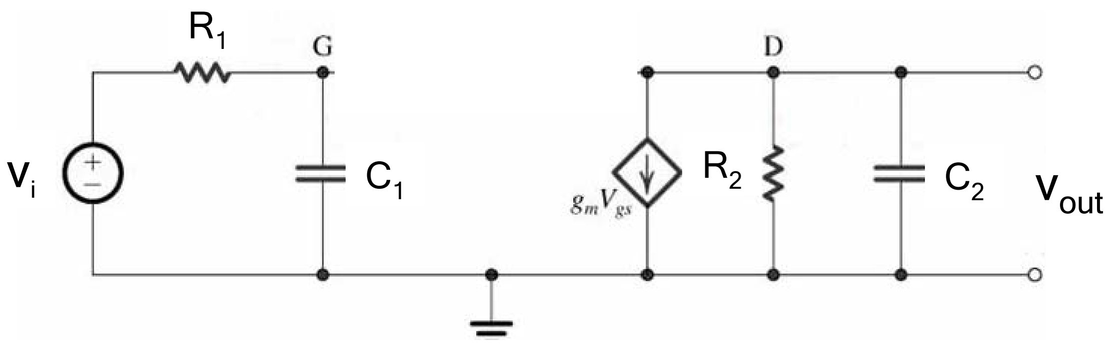

$$V_{out}(\omega) = -g_m V_{gs}(R_2 // \frac{1}{j\omega C_2}) = -g_m V_i(\omega) \frac{1/j\omega C_1}{(R_1 + 1/j\omega C_1)} \frac{R_2 / j\omega C_2}{(R_2 + 1/j\omega C_2)}$$

$$\frac{V_{out}(\omega)}{V_i(\omega)} = -g_m \frac{1}{(j\omega R_1 C_1 + 1)} \frac{R_2}{(j\omega R_2 C_2 + 1)}$$

$$\omega_{P1} = \frac{1}{C_1 R_1} \qquad \omega_{P2} = \frac{1}{C_2 R_2}$$

$$\omega_{P1} < \omega_{P2}$$

ω_{P1} can be made smaller by large C_1

➔ Large capacitors are not desired

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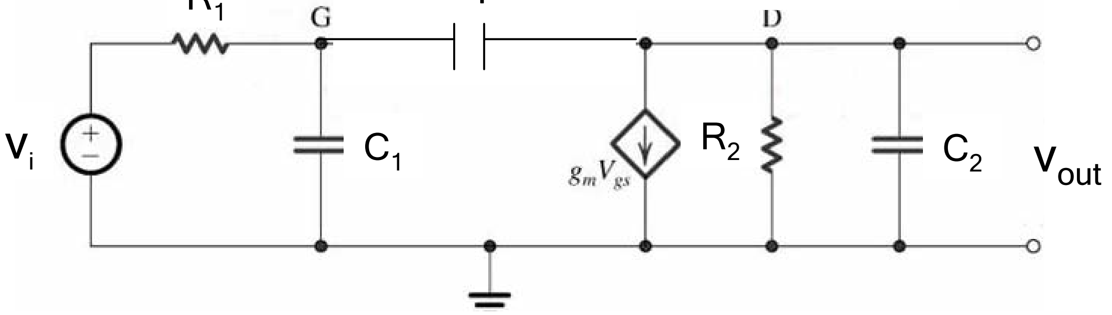
Use Miller effect

C_f : Feedback capacitor



$$\frac{V_o}{V_i} = \frac{\left(g_m - sC_f\right)R_2}{1 + s\left[C_1R_1 + C_2R_2 + C_f\left(g_mR_1R_2 + R_1 + R_2\right)\right] + s^2\left[C_1C_2 + C_f\left(C_1 + C_2\right)\right]R_1R_2}$$

$$D(s) = \left(1 + \frac{s}{\omega'_{P1}}\right)\left(1 + \frac{s}{\omega'_{P2}}\right) = 1 + s\left(\frac{1}{\omega'_{P1}} + \frac{1}{\omega'_{P2}}\right) + \frac{s^2}{\omega'_{P1}\omega'_{P2}} \simeq 1 + \frac{s}{\omega'_{P1}} + \frac{s^2}{\omega'_{P1}\omega'_{P2}} \quad (\omega'_{P1} << \omega'_{P2})$$

$$\omega'_{P1} = \frac{1}{C_1R_1 + C_2R_2 + C_f\left(g_mR_1R_2 + R_1 + R_2\right)} \simeq \frac{1}{C_f g_m R_1R_2} << \omega_{P1} = \frac{1}{C_1R_1}$$

$$\omega'_{P2} \simeq \frac{g_mC_f}{C_1C_2 + C_f\left(C_1 + C_2\right)} > \omega_{P2} = \frac{1}{C_2R_2}$$

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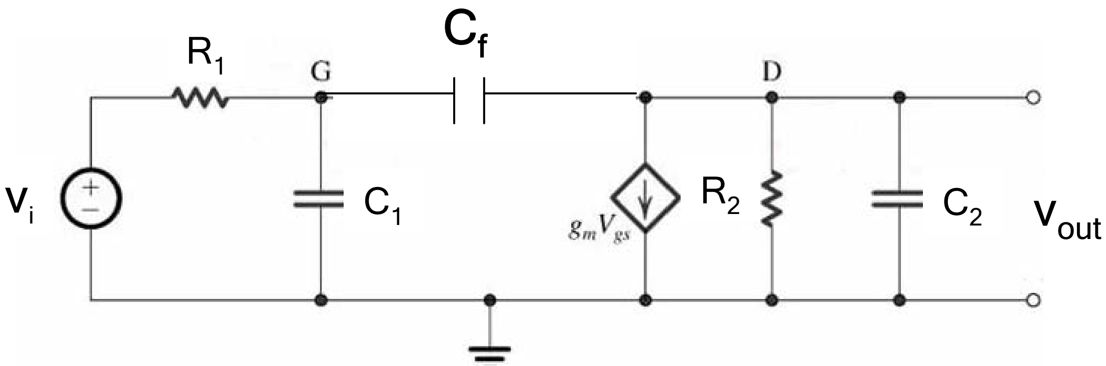
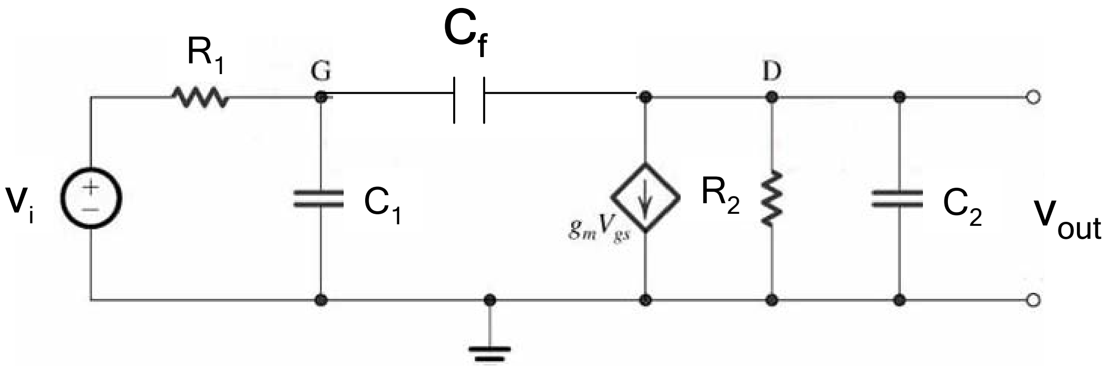


Addition of C_f between G and D ➔ Miller compensation

Move ω_{p1} to lower frequency
ω_{p2} to higher frequency: Pole splitting

➔ More phase margin: Safer for feedback

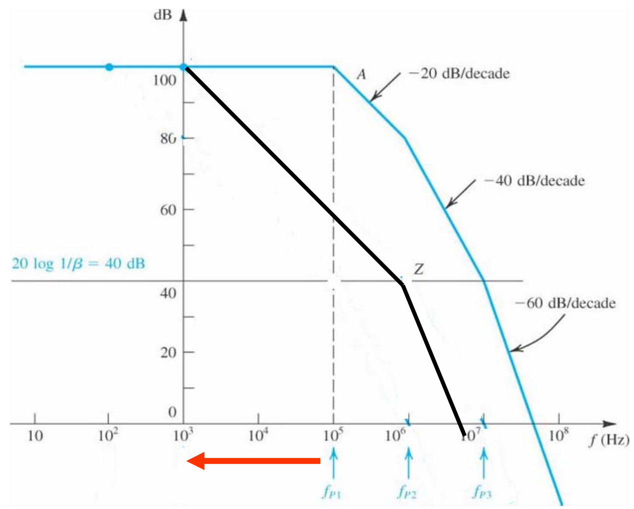
Lect. 10: Frequency Compensation



$$\frac{V_o}{V_i} = \frac{\left(sC_f - g_m\right)R_2}{1 + s\left[C_1R_1 + C_2R_2 + C_f\left(g_mR_1R_2 + R_1 + R_2\right)\right] + s^2\left[C_1C_2 + C_f\left(C_1 + C_2\right)\right]R_1R_2}$$

How about zero at $s=g_m/C_f$?

The positive zero adds phases
➔ Bad for phase margin



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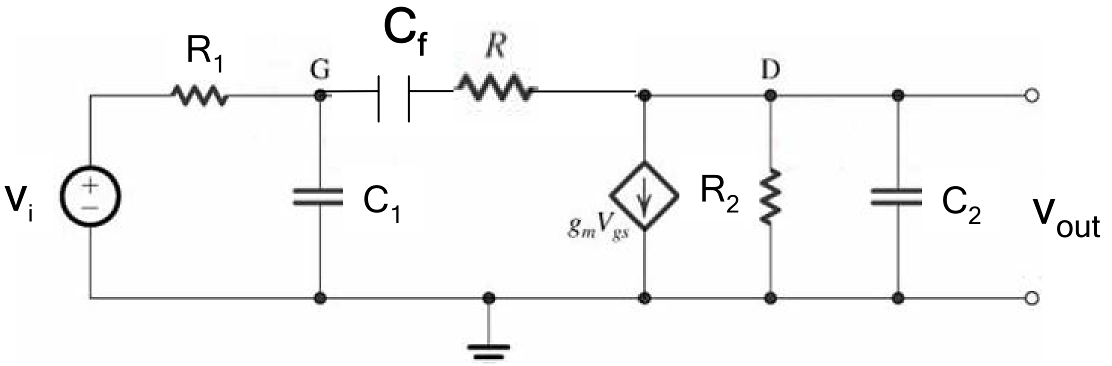
Solve the problem by adding a resistor



For zero, $V_{out}(s) = 0$, $$\frac{\mathbf{V}_{gs}}{R + \frac{1}{sC_f}} = g_m \mathbf{V}_{gs} \quad \therefore s = 1 \Big/ C_f \left(\frac{1}{g_m} - R \right)$$

If $R > 1/g_m$, zero will be on the negative real-axis

➔ It adds phase margin!