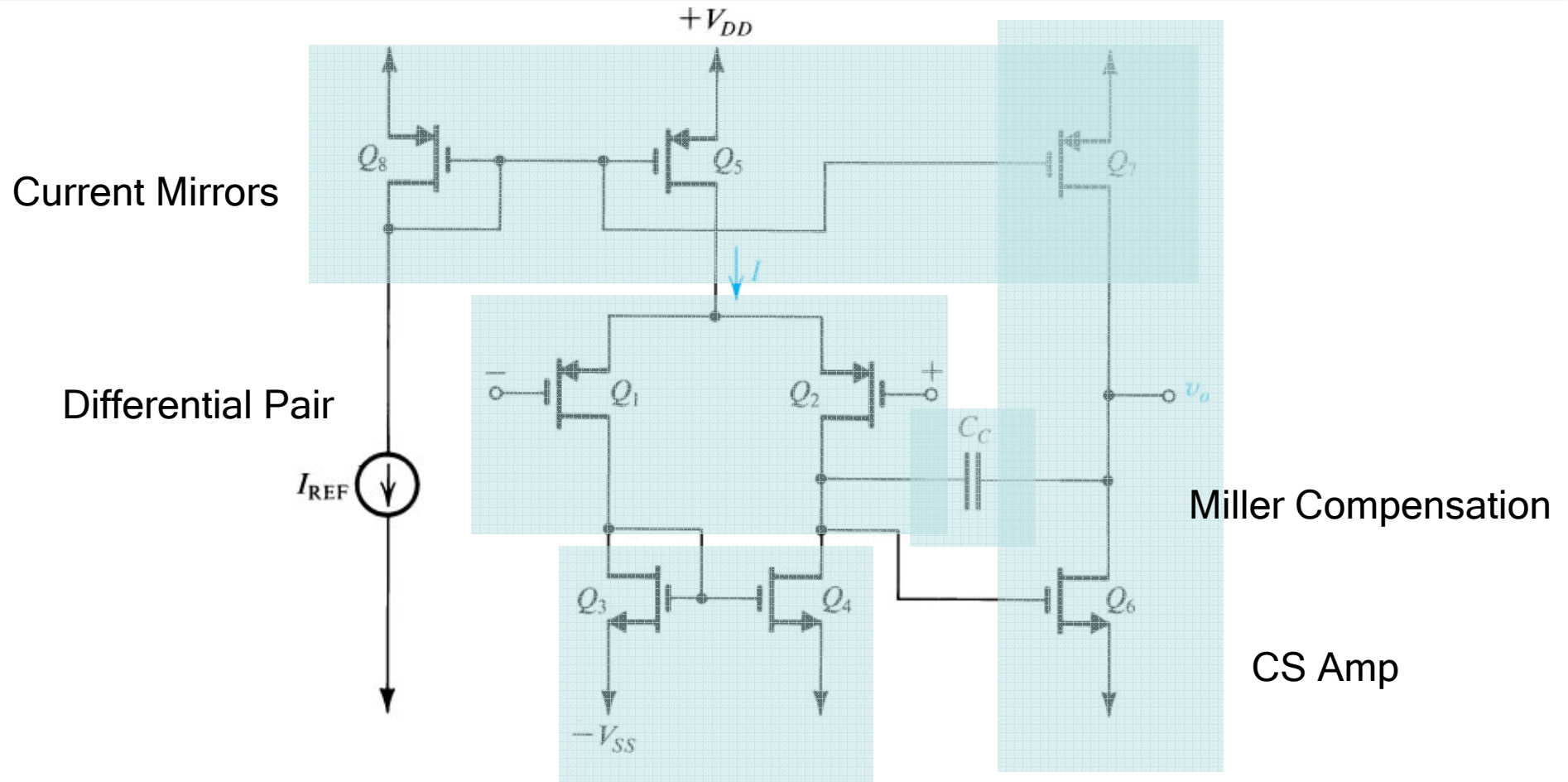


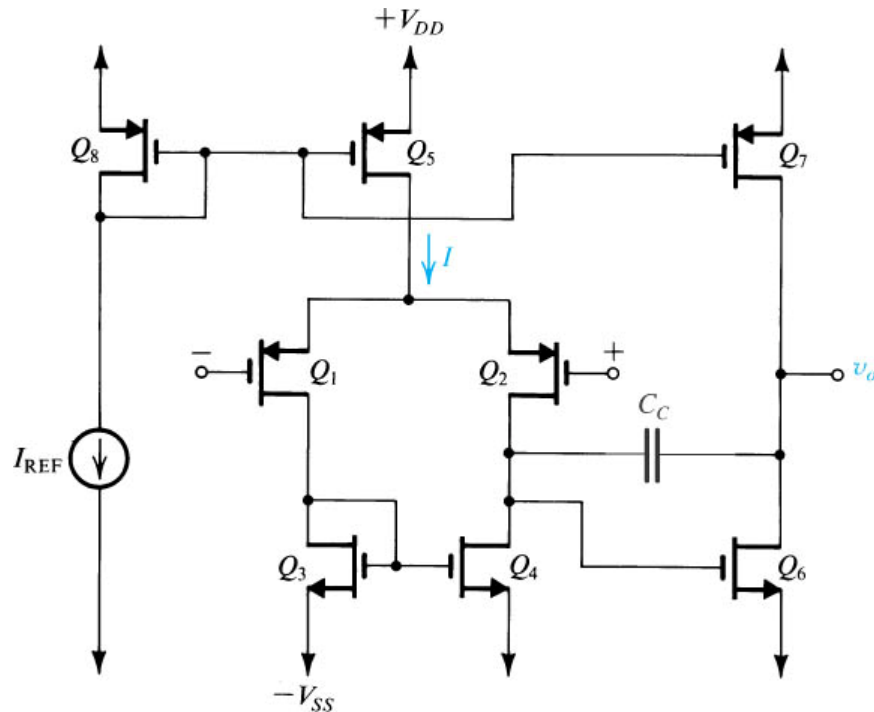
Lect. 12: Two-Stage Amplifier (9.1 in S&S)



Transconductance Amplifier (OTA: Operational Transconductance Amplifier)

Lect. 12: Two-Stage Amplifier

Input Common-Mode Range



Large $I \rightarrow$ Large V_{SG5} , V_{SG1} , V_{GS3}
 \rightarrow Small input CM range

Q_1 , Q_2 should be in saturation

$$V_{SD1} > V_{SG1} - |V_{tp}|$$

$$V_{S1} - V_{D1} > V_{S1} - V_{ICM} - |V_{tp}|$$

$$V_{ICM} > V_{D1} - |V_{tp}|$$

$$V_{ICM, \min} = -V_{ss} + V_{GS3} - |V_{tp}|$$

Q_5 should be in saturation

$$V_{SD5} > V_{SG5} - |V_{tp}|$$

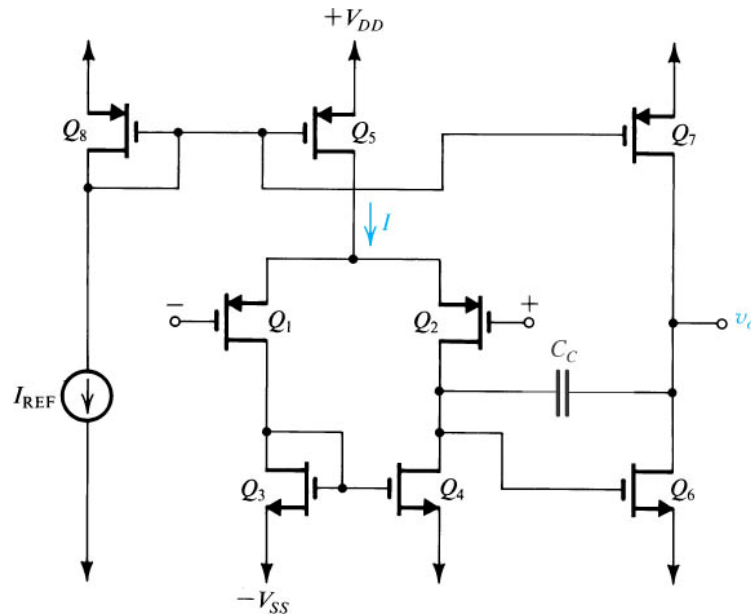
$$V_{S5} - V_{D5} > V_{S5} - V_{G5} - |V_{tp}|$$

$$V_{D5} < V_{G5} + |V_{tp}| = V_{DD} - V_{SG5} + |V_{tp}|$$

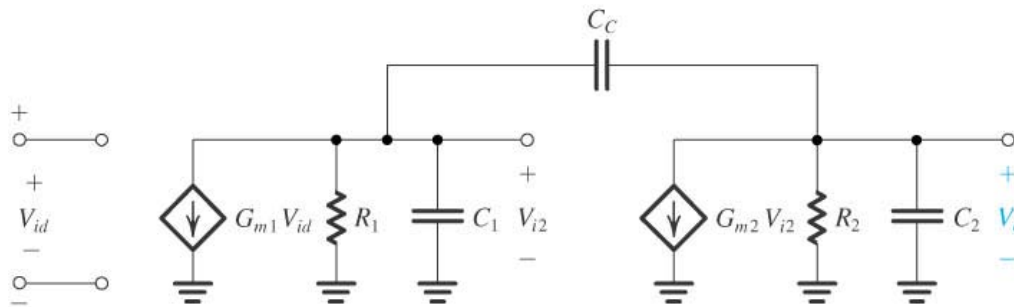
$$V_{ICM} + V_{SG1} < V_{DD} - V_{SG5} + |V_{tp}|$$

$$V_{ICM, \max} = V_{DD} - V_{SG5} - V_{SG1} + |V_{tp}|$$

Lect. 12: Two-Stage Amplifier



Small Signal Model



Voltage Gain (DC)

Two CS amps in cascade

$$G_{m1} = g_{m1} = g_{m2} \text{ (Ignoring Body Effect)}$$

$$R_1 = r_{o2} // r_{o4}$$

$$A_{v1} = -g_{m2} (r_{o2} // r_{o4})$$

$$G_{m2} = g_{m6}$$

$$R_2 = r_{o6} // r_{o7}$$

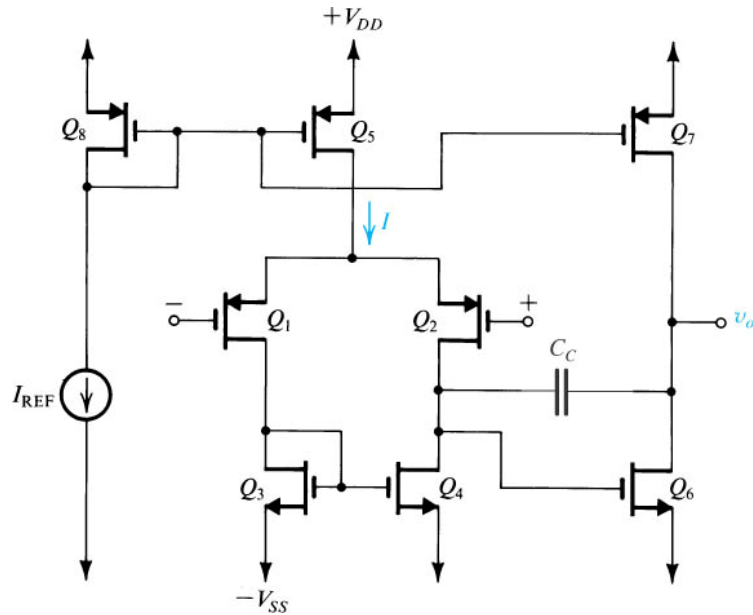
$$A_{v2} = -g_{m6} (r_{o6} // r_{o7})$$

$$A_v = g_{m2} g_{m6} (r_{o2} // r_{o4}) (r_{o6} // r_{o7})$$

$$R_{in}: \text{infinity}$$

$$R_{out}: r_{o6} // r_{o7}$$

Lect. 12: Two-Stage Amplifier



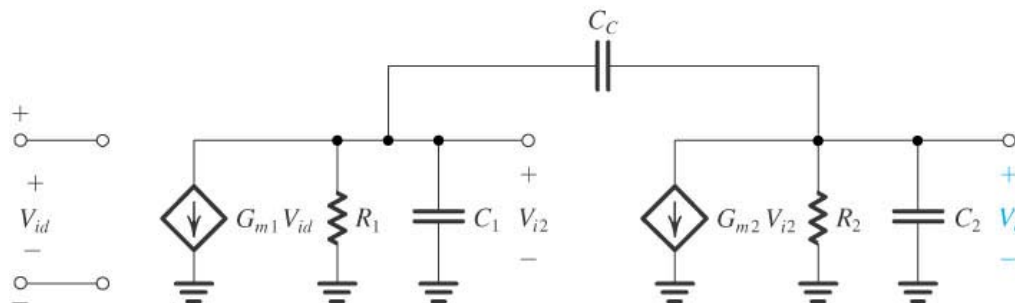
Frequency Response

$$C_1 = C_{gd2} + C_{db2} + C_{gd4} + C_{db4} + C_{gs6}$$

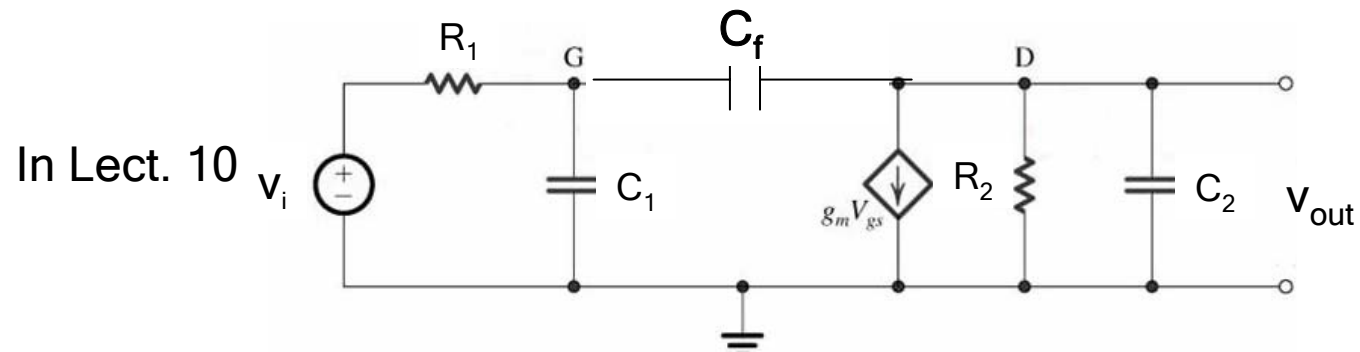
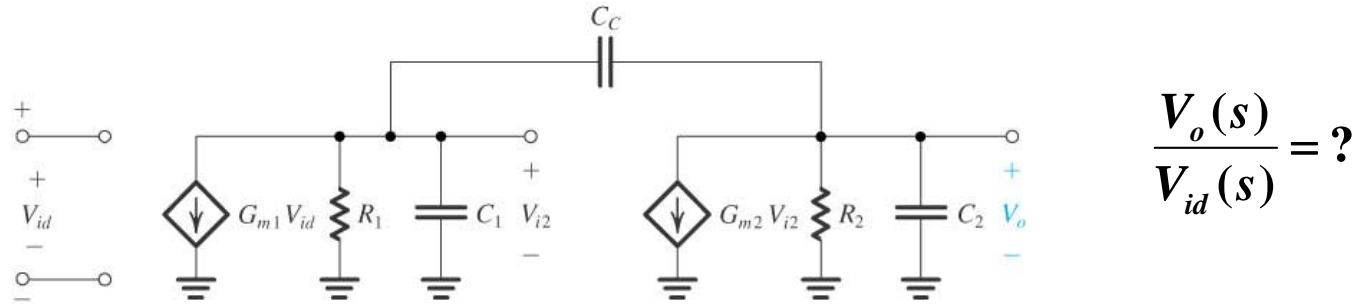
$$C_2 = C_{db6} + C_{db7} + C_{gd7} + C_L$$

(C_{gd6} is included in C_C)

$C_2 \gg C_1$ since C_L is usually larger



Lect. 12: Two-Stage Amplifier

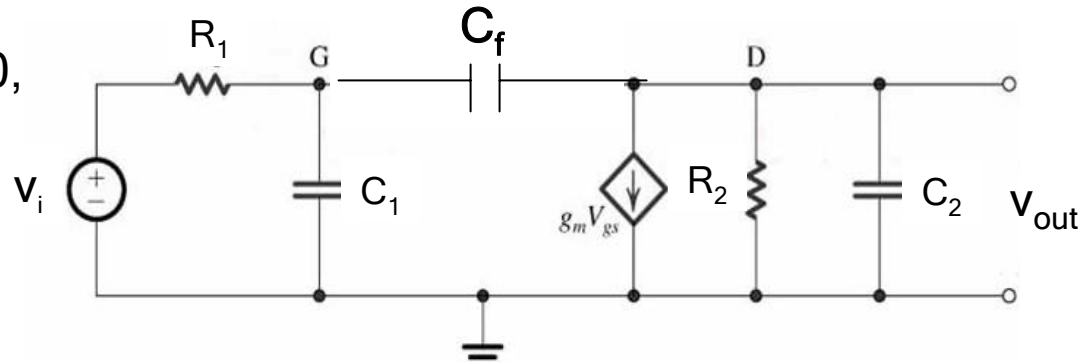


$$\frac{V_o}{V_i} = \frac{(g_m - sC_f)R_2}{1 + s[C_1R_1 + C_2R_2 + C_f(g_mR_1R_2 + R_1 + R_2)] + s^2[C_1C_2 + C_f(C_1 + C_2)]R_1R_2}$$

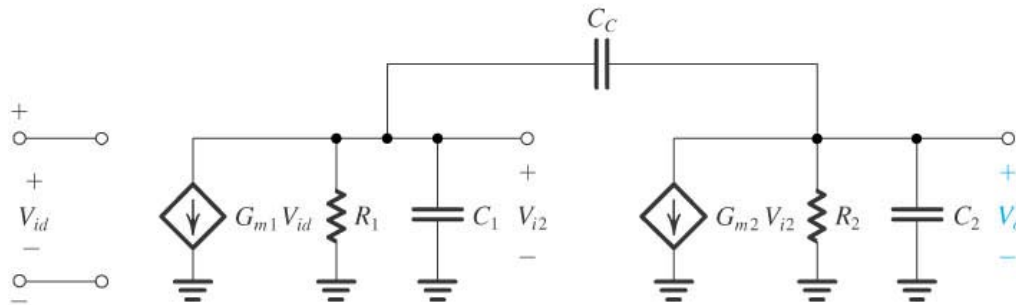
Since $V_i = G_{m1}V_{id}R_1$, $\frac{V_o(s)}{V_{id}(s)} = G_{m1}R_1 \frac{V_o}{V_i}$ Same Pole-Zero characteristics!

Lect. 12: Two-Stage Amplifier

In Lect. 10,



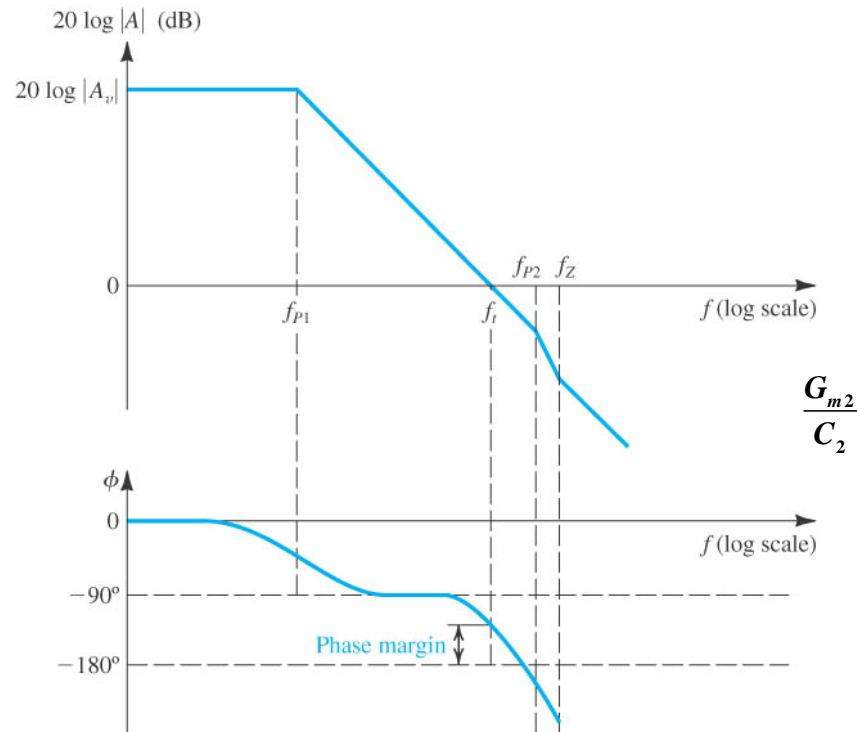
$$\omega_{P1} \approx \frac{1}{C_f g_m R_1 R_2} \quad \omega_{P2} \approx \frac{g_m C_f}{C_1 C_2 + C_f (C_1 + C_2)} \quad \omega_Z = \frac{g_m}{C_f}$$



$$\omega_{P1} \approx \frac{1}{C_C G_{m2} R_1 R_2} \quad \omega_{P2} \approx \frac{G_{m2} C_C}{C_1 C_2 + C_C (C_1 + C_2)} \approx \frac{G_{m2}}{C_2} \quad \omega_Z = \frac{G_{m2}}{C_C}$$

Lect. 12: Two-Stage Amplifier

Assume we want the following Bode plot so that sufficient phase margin is allowed.



$$\omega_{P1} \approx \frac{1}{C_C G_{m2} R_1 R_2}$$

$$\omega_{P2} \approx \frac{G_{m2}}{C_2}$$

$$\omega_Z = \frac{G_{m2}}{C_C}$$

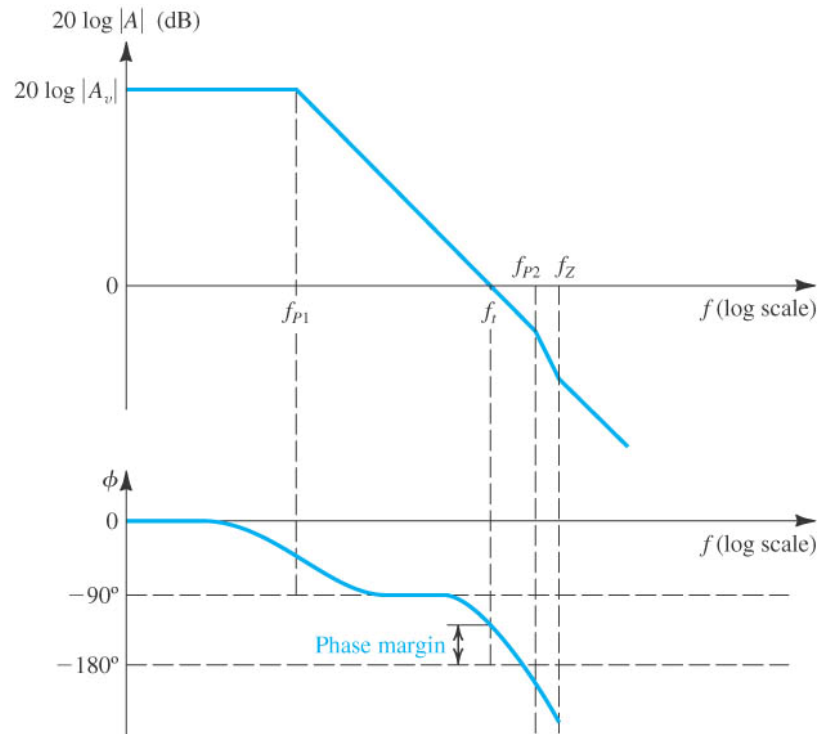
$$\omega_{P1} < \omega_t < \omega_{P2}, \omega_Z$$

$$\begin{aligned} \omega_t &= |A_v| \omega_{P1} \\ &\approx G_{m1} G_{m2} R_1 R_2 \frac{1}{C_C G_{m2} R_1 R_2} = \frac{G_{m1}}{C_C} \end{aligned}$$

$$\omega_t < \omega_{P2} \implies \frac{G_{m1}}{C_C} < \frac{G_{m2}}{C_2}$$

$$\omega_t < \omega_Z \implies \frac{G_{m1}}{C_C} < \frac{G_{m2}}{C_C} \implies G_{m1} < G_{m2}$$

Lect. 12: Two-Stage Amplifier



$$\omega_{P1} \approx \frac{1}{C_C G_{m2} R_1 R_2}$$

$$\omega_{P2} \approx \frac{G_{m2}}{C_2}$$

$$\omega_Z = \frac{G_{m2}}{C_C}$$

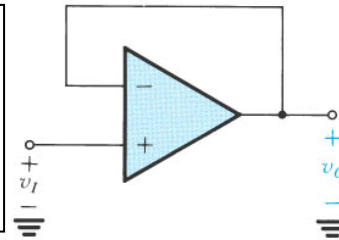
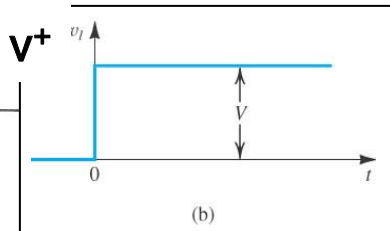
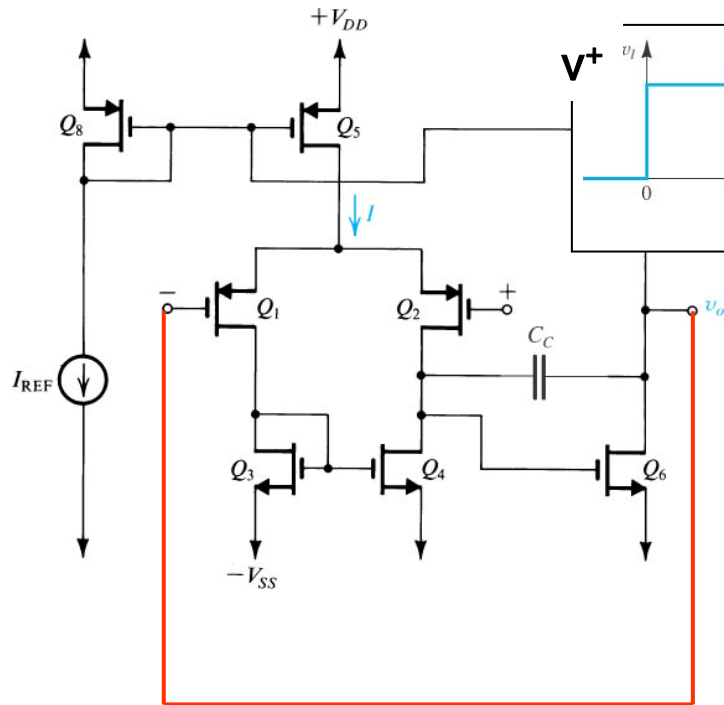
More phase margin is possible with a resistor in series with C_C

→ Different Pole-Zero characteristics!

Lect. 12: Two-Stage Amplifier

Slew Rate

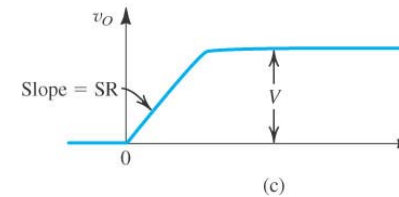
What does the circuit do?



Apply step input at $v^+ \rightarrow v_o(t)=?$

Q_2 off \rightarrow I through $Q_1, Q_3 \rightarrow$ I through C_C

$$v_o(t) = \frac{I}{C_C} t$$



Slew Rate: Maximum rate of v_o change $SR = \left. \frac{dv_o}{dt} \right|_{\max} = \frac{I}{C_C}$