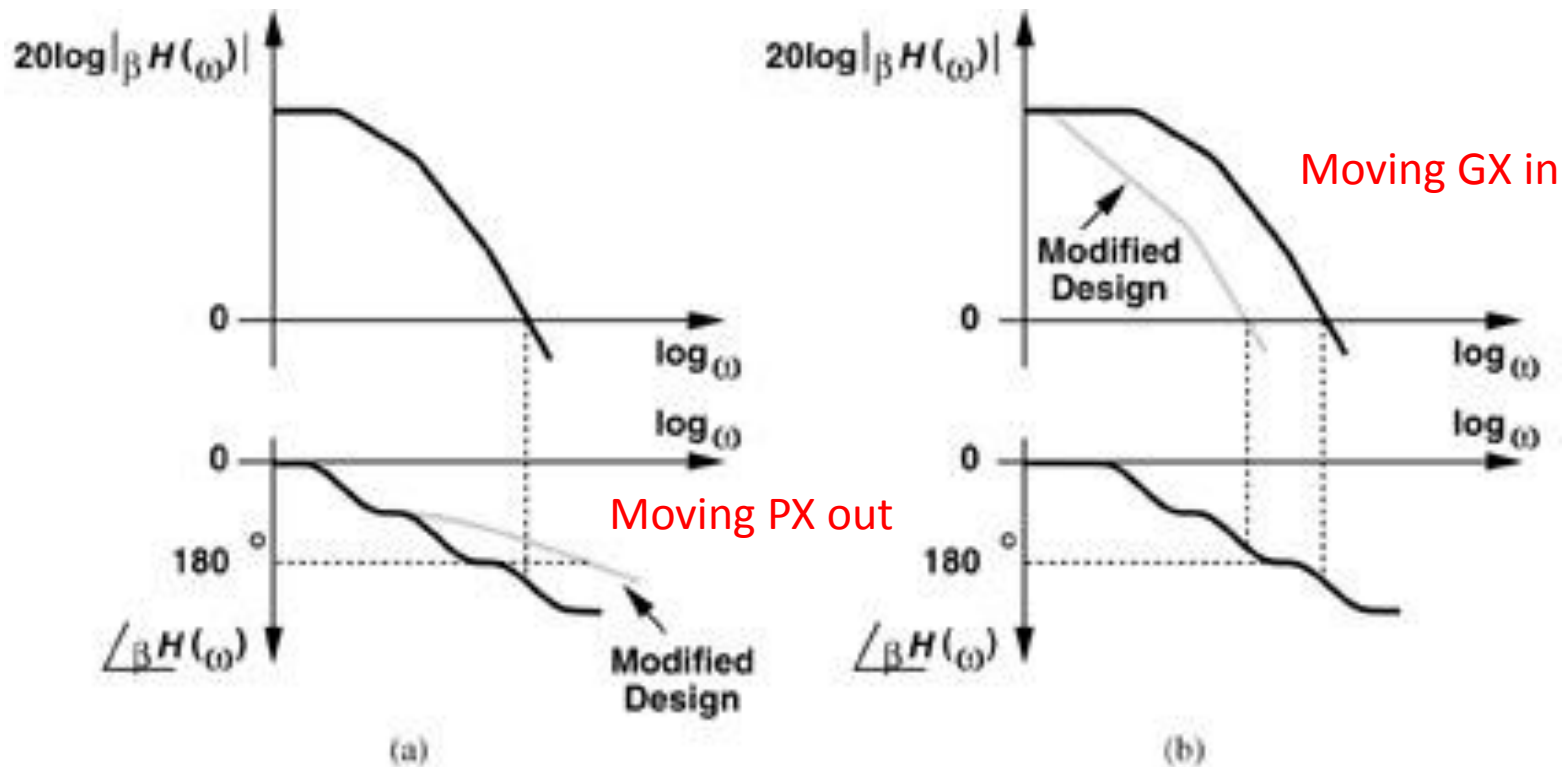


# Lecture 11

## IL2218 Analog electronics, advanced course

- Ch 10 Frequency compensation
  - Compensation to improve gain margin
  - Compensation of two-stage op amps
  - Right half-plane zero problem

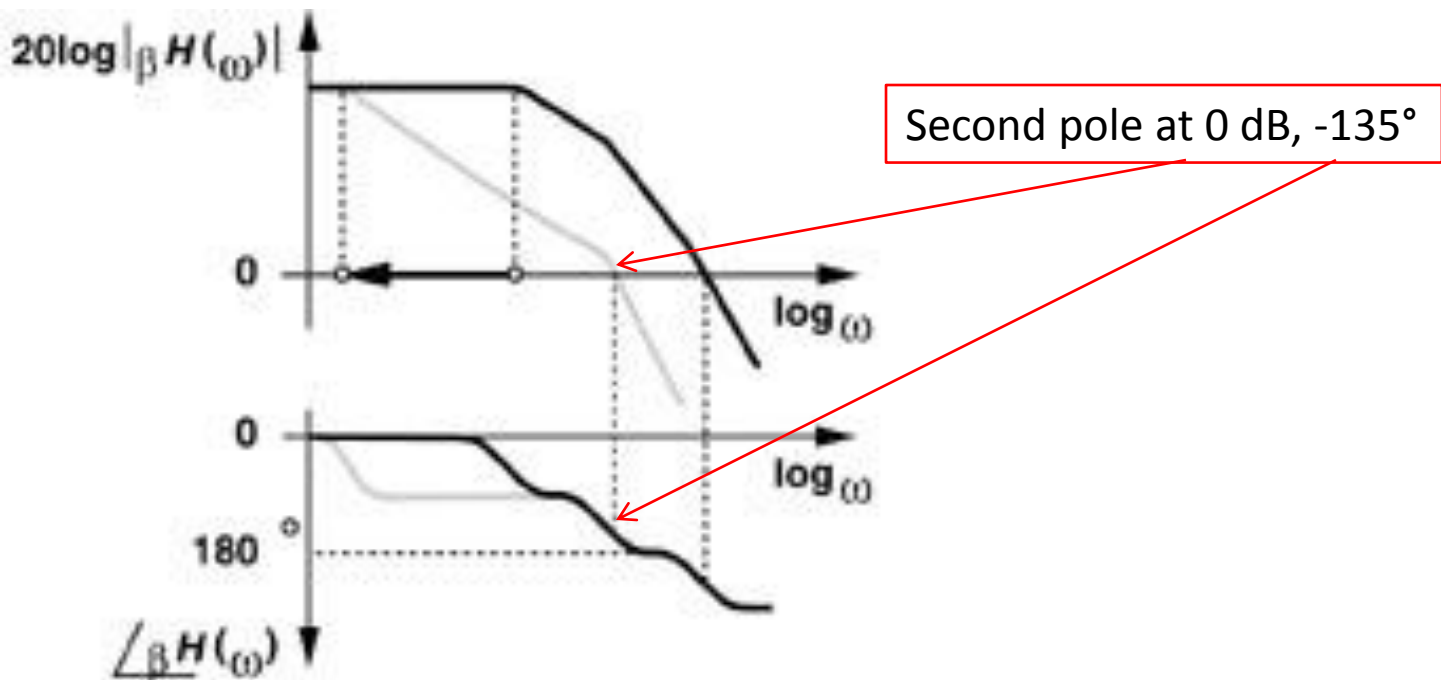
# Frequency compensation



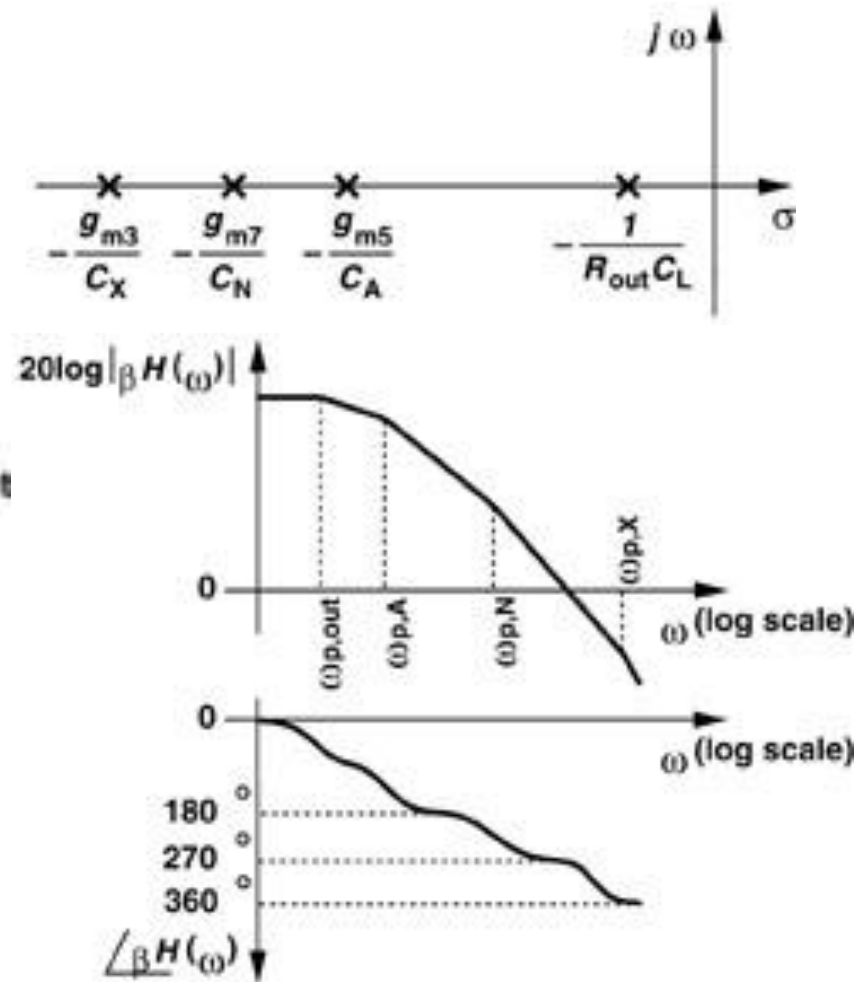
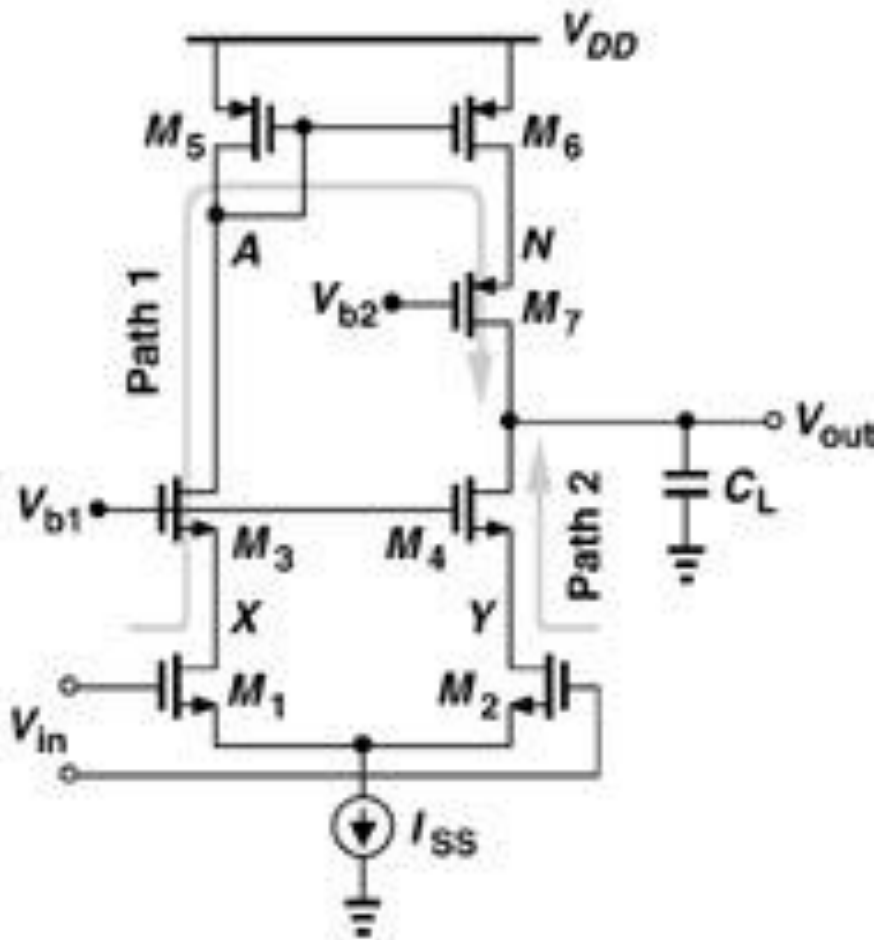
Compensation is the manipulation of gain and/or pole positions to improve phase margin.

# Dominating pole

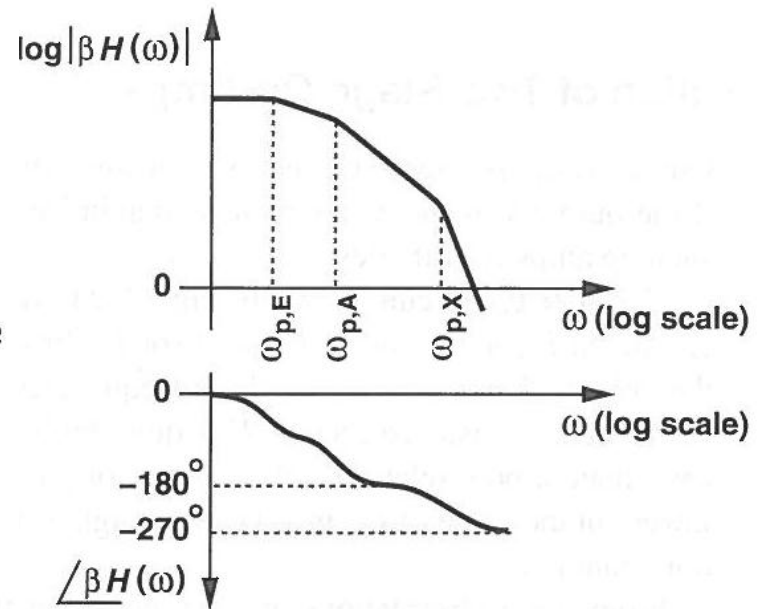
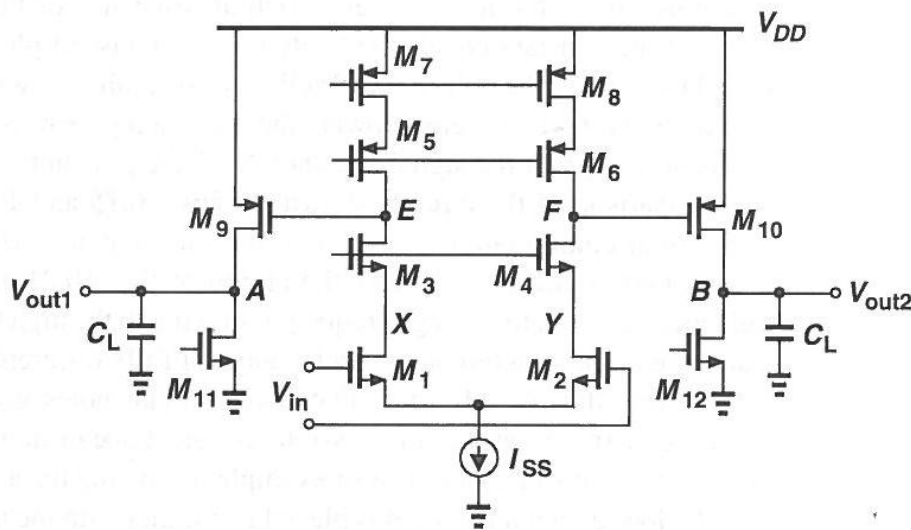
Translating the dominant pole toward the origin for 45° phase margin



# Telescopic op amp with Dominant pole at output

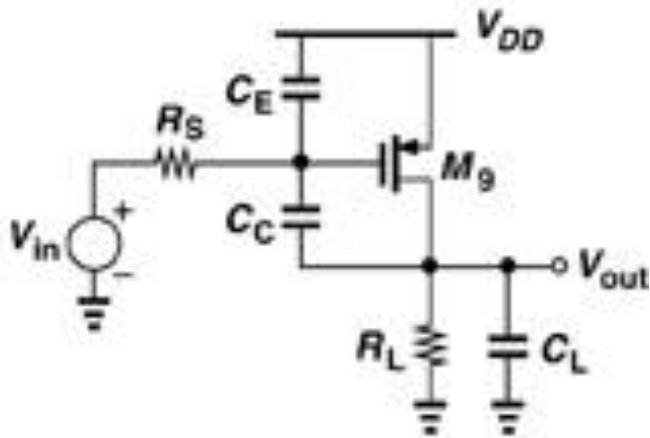


# Two stage Op amp



# Miller compensation of two stage Op amp

Simplified circuit of two stage op amp



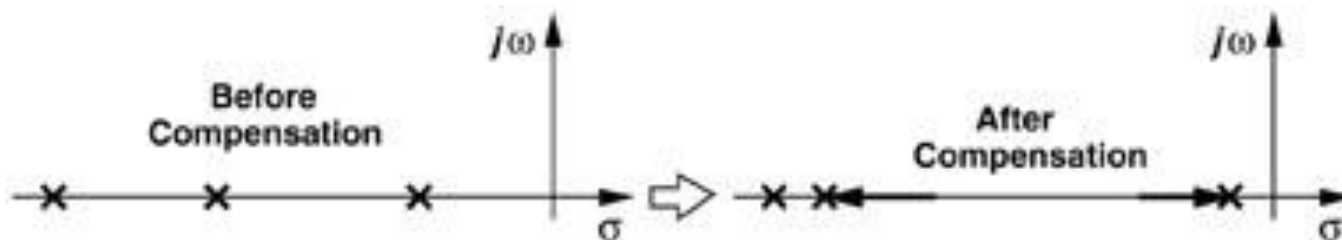
Miller compensation splits the poles. Moves output pole away from origin and moves intermediate pole closer to origin.

$$f_{p,in} = \frac{1}{2\pi(R_S[C_E + (1 + g_m R_L)C_C] + R_L(C_C + C_L))}$$

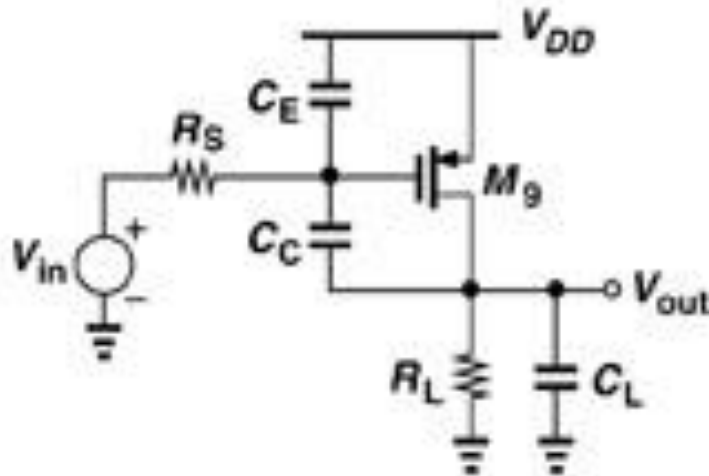
$$f_{p,in} \approx \frac{1}{2\pi R_S[C_E + (1 + g_m R_L)C_C]}$$

$$f_{p,out} = \frac{R_S(1 + g_{m9}R_L)C_C + R_S C_E + R_L(C_C + C_L)}{2\pi R_S R_L(C_E C_C + C_E C_L + C_C C_L)}$$

$$f_{p,out} \approx \frac{R_S g_{m9} R_L C_C + R_L C_C}{2\pi R_S R_L(C_E C_C + C_C C_L)} = \frac{g_{m9}}{2\pi(C_E + C_L)}$$

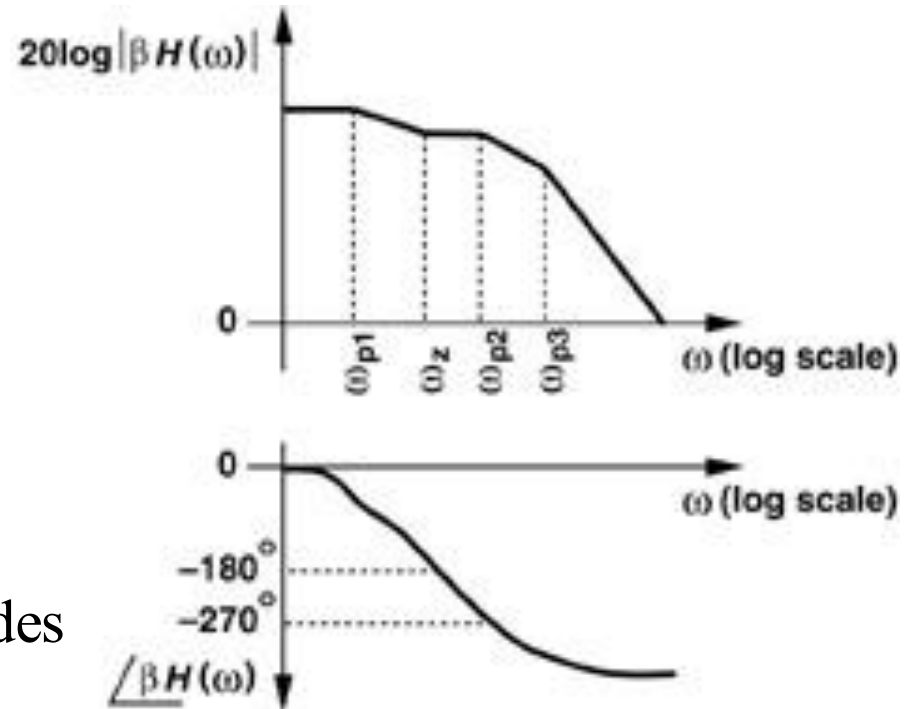


# Right half plane zero



Recall, transfer function includes  $(1 - s/\omega_z)$  numerator term and

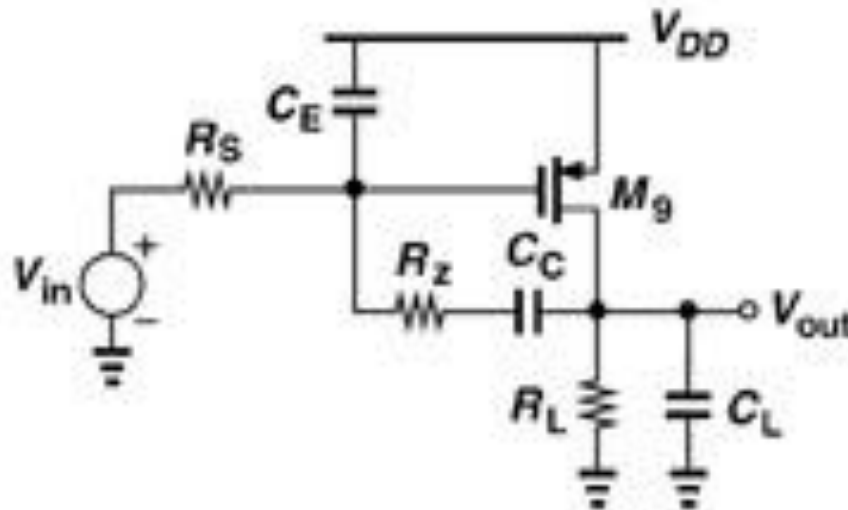
$$f_z(RHP) = \frac{g_{m9}}{2\pi C_C}$$



RHP zero introduces negative phase shift while maintaining high gain

→ **Dangerous**

# RHP Zero removal



$$f_Z = \frac{1}{2\pi C_C (1/g_{m9} - R_Z)}$$

$R_Z$  is typically realized by a MOS transistor in the triode region

It is possible to set  $R_Z$  to cancel first non-dominant pole

$$f_Z = \frac{1}{2\pi C_C (1/g_{m9} - R_Z)}$$

Could set  $R_Z = 1/g_{m9}$ , or cancel other non-dominant pole

$$\frac{1}{C_C (1/g_{m9} - R_Z)} = \frac{-g_{m9}}{C_L + C_E}$$

$$R_Z = \frac{C_L + C_E + C_C}{g_{m9} C_C} \approx \frac{C_L + C_C}{g_{m9} C_C}$$

# Problem 10.11

**10.11.** In the two-stage op amp of Fig. 10.43,  $W/L = 50/0.5$  for all transistors except for  $M_{5,6}$ , for which  $W/L = 60/0.5$ . Also,  $I_{SS} = 0.25$  mA and each output branch is biased at 1 mA.

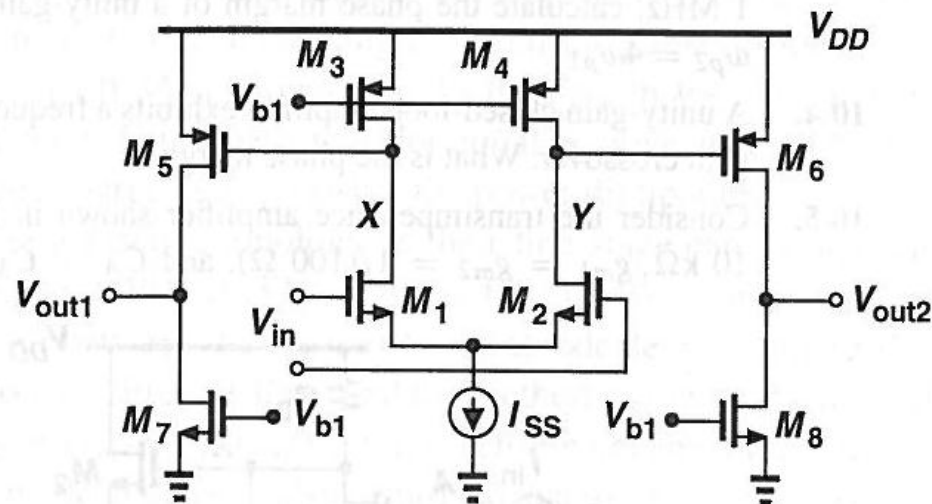


Figure 10.43

- Determine the CM level at nodes  $X$  and  $Y$ .
- Calculate the maximum output voltage swing.
- If each output is loaded by a 1-pF capacitor, compensate the op amp by Miller multiplication for a phase margin of  $60^\circ$  in unity-gain feedback. Calculate the pole and zero positions after compensation.