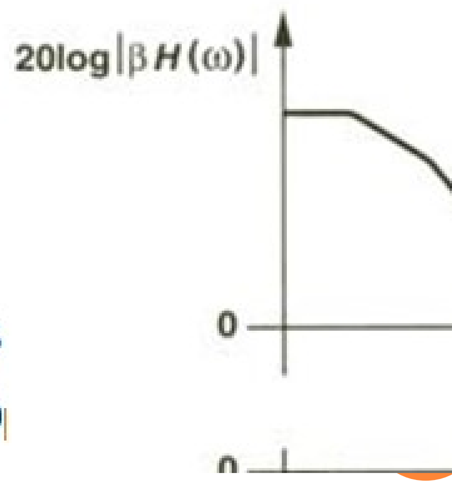
Frequency compensation

- Typical op amp circuits contain many poles. For this reason, op a usually be "compensated," that is, the open-loop transfer functio modified such that the closed-loop circuit is stable and the time r well-behaved.
- Stability can be achieved by minimizing the overall phase shift, thus pushing the phase crossover *out*.

Mo

Discussion:

- ☐ This approach requires that we attempt to minimize the number of poles in the signal path by proper design.
- ☐ Since each additional stage contributes at least one pole, this means the numb



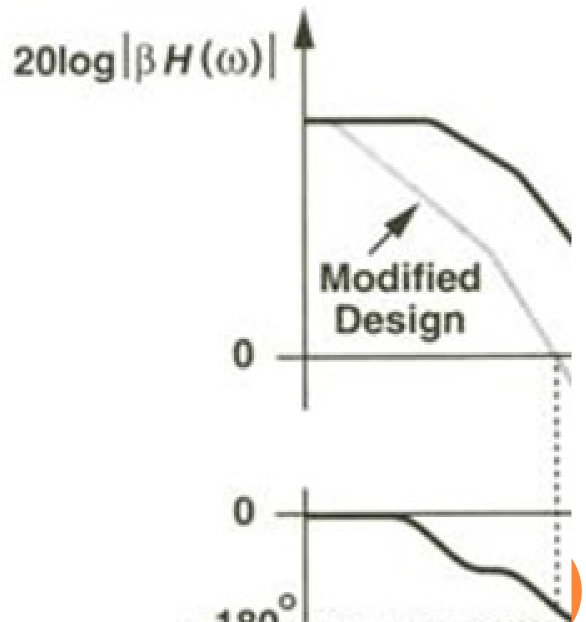
Frequency compensation (cont'd)

- Stability can be achieved by dropping the gain thereby pushing the gain crossover *in*.

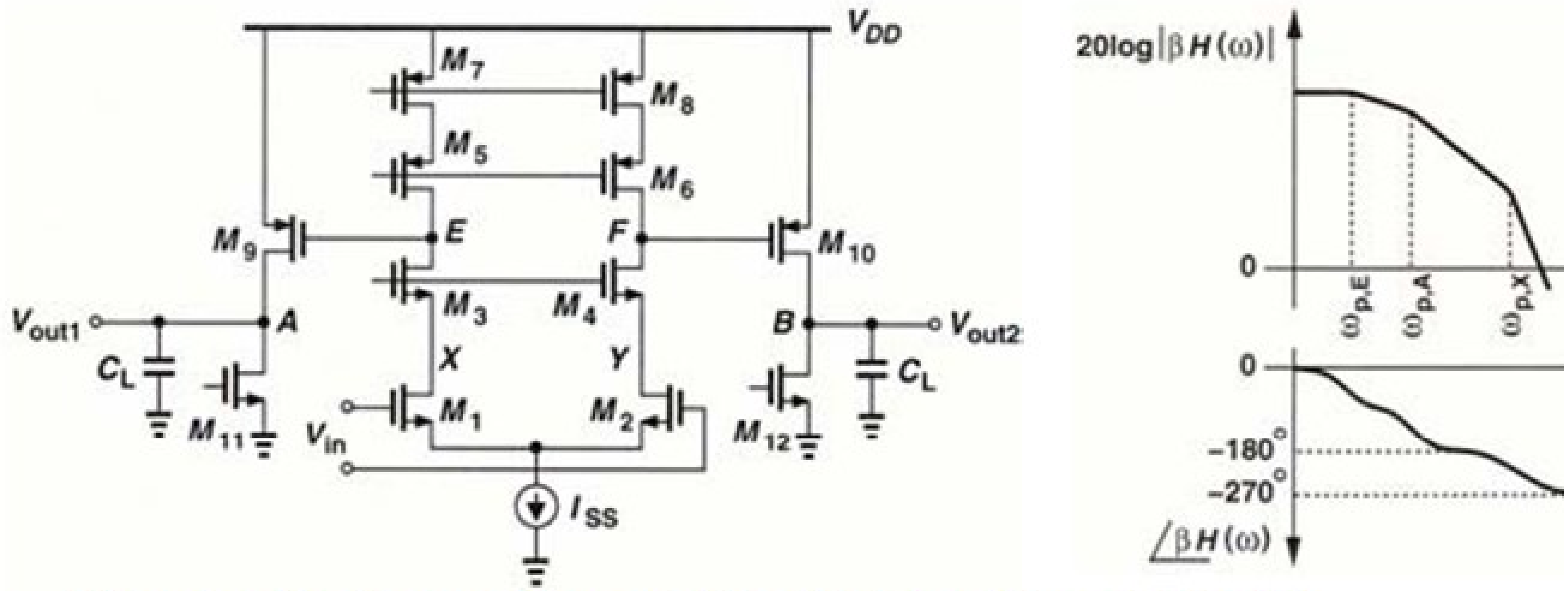
  Discussion:

  - This approach retains the low frequency gain and the output swings but it reduces the bandwidth by forcing the gain to fall at lower frequencies

Moving GX



Compensation of two-stage op amps

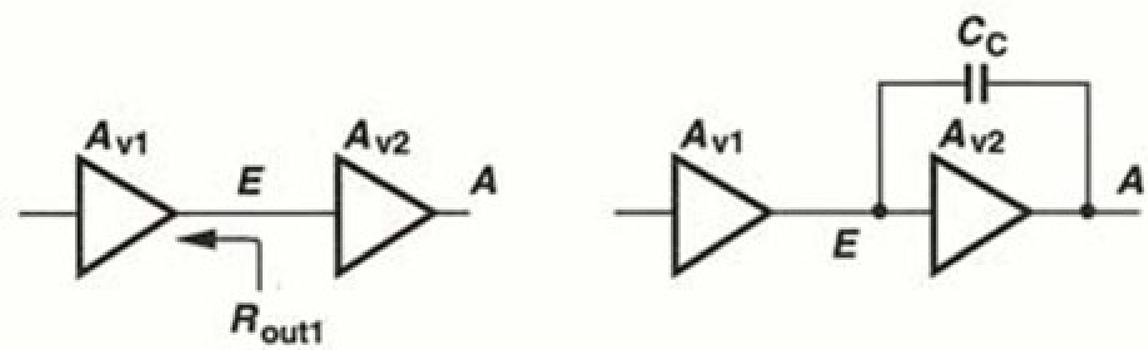


- We identify three poles at X(or Y), E(or F) and A(or B).

  A pole at X(or Y) lies at relatively high frequencies. Since the resistance seen at E is quite high, even the capacitances of M can create a pole relatively close to the origin. At node A, the resistance is lower but the value of C_L may be quite high. Cons circuit exhibits *two* dominant poles.

- One of the dominant poles must be moved toward the origin s

Miller compensation of a two-stage op amp



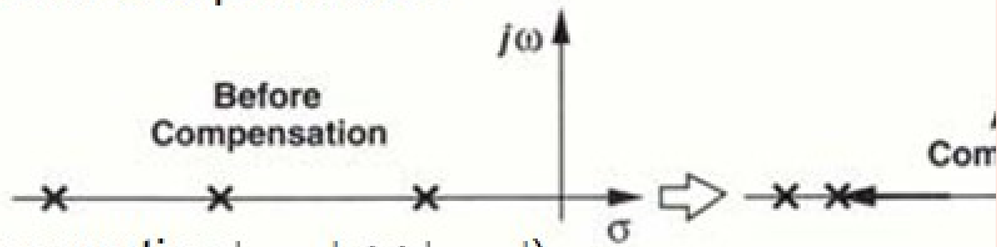
(a) (b)

- In a two-stage amp as shown in Fig.(a), the first stage exhibits a impedance and the second stage provides a moderate gain, the providing a suitable environment for Miller multiplication of capa

- In Fig.(b), we create a large capacitance at *E*, the pole is $\omega_{p,E} = \frac{\ }{R}$
  As a result, a low-frequency pole can be established with a mod capacitor value, saving considerable chip area.

Miller compensation of a two-stage op amp (cont'd)

- Pole splitting as a result of Miller compensation.



- Discussion
- Two poles: (based on the assumption $|\omega_{p,1}| << |\omega_{p,2}|$)

Simplified circuit of a two-s

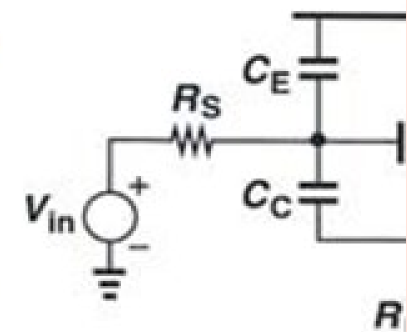
$$\omega_{p1} \approx \frac{1}{R_S[(1+g_{m9}R_L)(C_C+C_{GD9})+C_E]+R_L(C_C+C_{GD9}+C_L)}$$

R_S = the output resistance

$$\omega_{p2} \approx \frac{R_S[(1+g_{m9}R_L)(C_C+C_{GD9})+C_E]+R_L(C_C+C_{GD9}+C_L)}{R_S R_L[(C_C+C_{GD9})C_E+(C_C+C_{GD9})C_L+C_E C_L]}$$

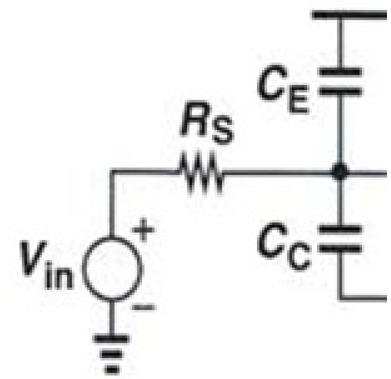
$R_L = r_{o9} \| r_{o11}$

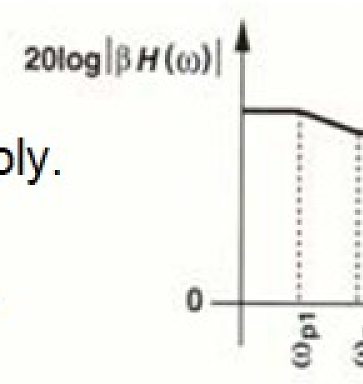
- For $C_C = 0$ and relatively large C_L, $\omega_{p,2} \approx 1/(R_L C_L)$. For $C_C \neq 0$ and $C_C + C_{GD9} >> C_E$, $\omega_{p,2} \approx g_{m9}/(C_E + C_L)$. Typically $C_E << C_L$, we conclude that Miller compensation increases the magnitude of the output



Miller compensation of a two-stage op amp (cont'd)

- Effect of right half plane zero
  - ☐ The circuit contains a right-half-plane zero at $\omega_z = g_{m9}/(C_C + C_{GD9})$ because $C_C + C_{GD9}$ forms a "parasitic" signal path from the input to the output.
  - ☐ A zero in the right hand plane contributes more phase shift, thus moving the phase crossover toward the origin. Furthermore, from Bode approximations, the zero slows down the drop of the magnitude, thereby pushing the gain crossover away from the origin. As a result, the stability degrades considerably.

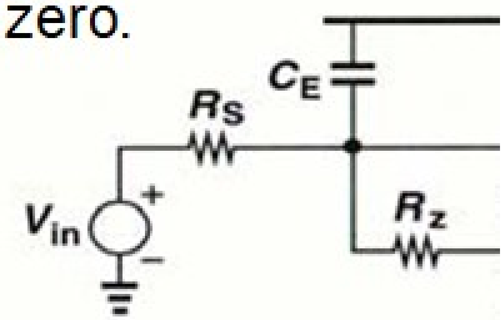




  - ☐ For two-stage op amps, typically $|\omega_{p1}| < |\omega_z| < |\omega_{p2}|$, the zero introduces significant phase shift while

Miller compensation of a two-stage op amp (cont'd

- Addition of R_z to move the right hand plane zero.



- ☐ The zero is given by .
  If $R_z \geq g_{m9}^{-1}$, then $\omega_z \leq 0$.

- ☐ We may move the zero well into the left plane so as to canc
  nondominant pole. That is

$$\frac{1}{C_C(g_{m9}^{-1}-R_z)} = \frac{-g_{m9}}{C_L+C_E} \Rightarrow R_z = \frac{C_L+C_E+C_C}{g_{m9}C_C} \approx \frac{C_L+C_C}{g_{m9}C_C}$$, because $C_E << C$

  - Drawbacks:

    1. It is difficult to guarantee the relationship of the abov

Miller compensation of a two-stage op amp (cont'd)

- Generation of V_b for proper temperature and process tracking.

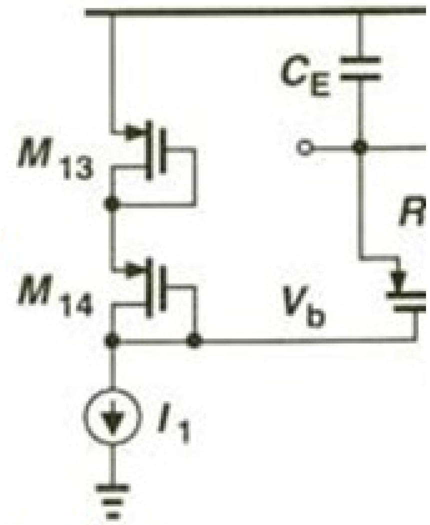
  ☐ If I_1 is chosen with respect to I_{D9} such that

  $V_{GS13} = V_{GS9}$, then $V_{GS15} = V_{GS14}$.

  Since $g_{m14} = \mu_p C_{ox}(W/L)_{14}(V_{GS14} - V_{TH14})$

  and $R_{on15} = [\mu_p C_{ox}(W/L)_{15}(V_{GS15} - V_{TH15})]^{-1}$,

  we have $R_{on15} = \dfrac{(W/L)_{14}}{g_{m14}(W/L)_{15}}$



  For pole-zero cancellation to occur, $\dfrac{(W/L)_{14}}{g_{m14}(W/L)_{15}} = \dfrac{C_L + C_C}{g_{m9} C_C}$

  and hence $(W/L)_{14} = \sqrt{(W/L)_{14}(W/L)_{15}} \sqrt{\dfrac{I_{D9}}{\ldots}} \dfrac{C_C}{\ldots}$

Miller compensation of a two-stage op amp (cont'd)

- Method of defining g_{m9} with respect to R_S.

Goal: $R_z = \dfrac{C_L + C_C}{g_{m9} C_C}$ ....(A)

☐ The technique incorporates M_{b1}-M_{b4} along with R_S to generate $I_b \propto R_S^{-2}$

Thus, $g_{m9} \propto \sqrt{I_{D9}} \propto \sqrt{I_{D11}} \propto R_S^{-1}$