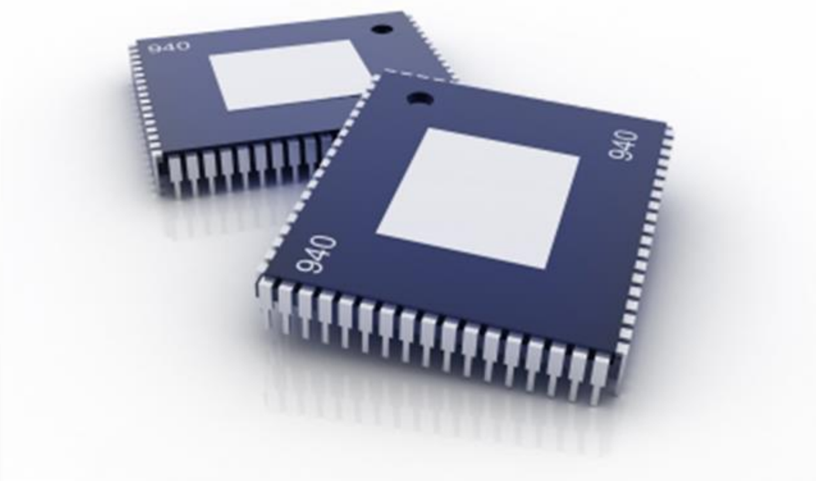


LECTURE 4

Soo-Won Kim

swkim@korea.ac.kr

5. Feedback Amplifiers

5.1 Ideal Model of negative Feedback

5.2 Dynamic Response of Feedback Amplifier

5.3 First- and Second-Order Feedback Systems

5.4 Common Feedback Amplifiers

Close-loop Transfer Function

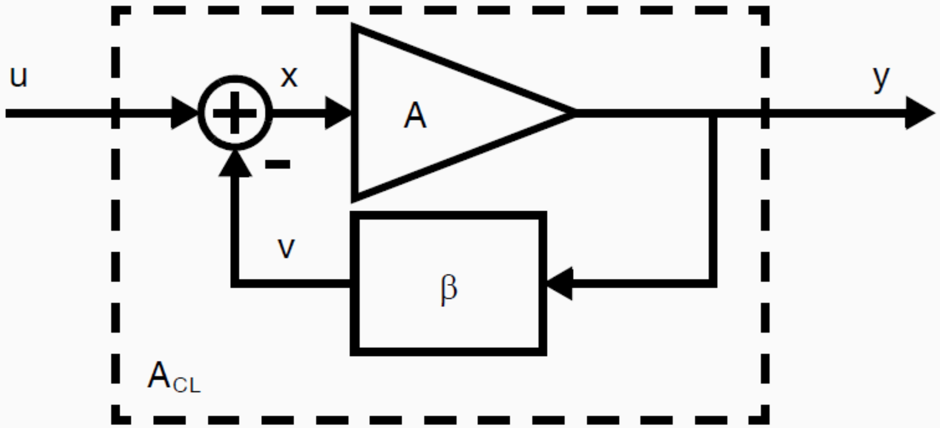


Fig. 5.1 Ideal model of a negativefeedback system.

$$v = \beta y$$

$$y = (u - \beta y)A$$

$$A_{CL} = \frac{y}{u} = \frac{A}{1 + A\beta}$$

$$\approx \frac{1}{\beta} \quad (\text{For } A\beta >> 1)$$

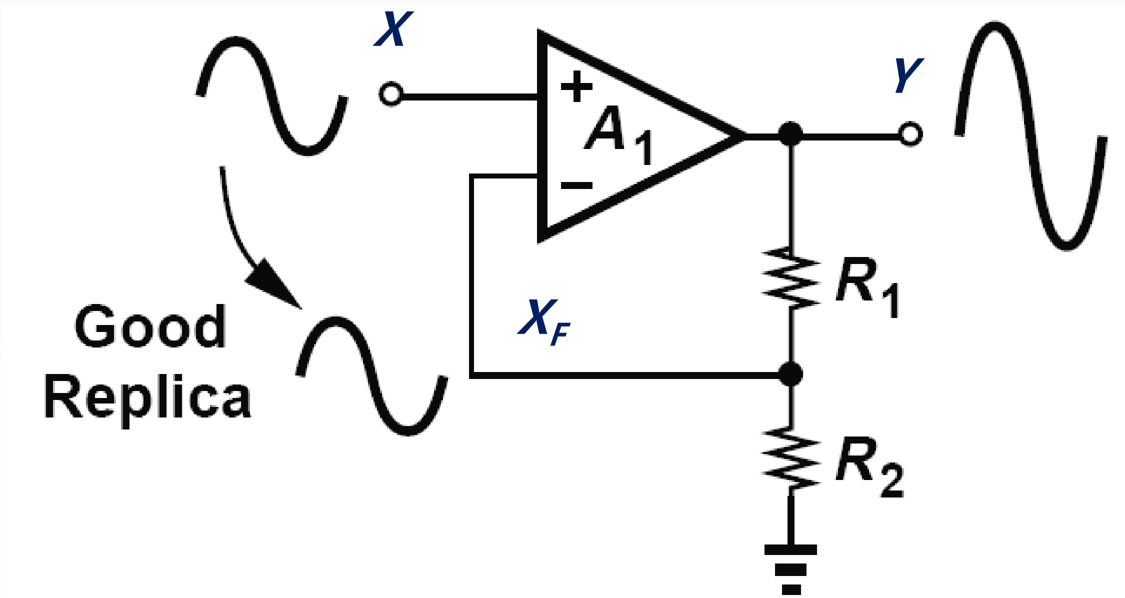
Merits of Negative Feedback

1. Better-defined, lower gain
2. Bandwidth enhancement
3. Modification of I/O Impedances
4. Linearization

Demerits of Negative Feedback

1. Stability issue

Transfer function of negative feedback



$$\frac{Y}{X} = \frac{A_1}{1 + \frac{R_2}{R_1 + R_2} A_1}$$

$\frac{R_2}{R_1+R_2}A_1 \rightarrow KA_1$

For $KA_1 >> 1$

$$\frac{Y}{X} \approx 1 + \frac{R_1}{R_2}$$

Gain Desensitization

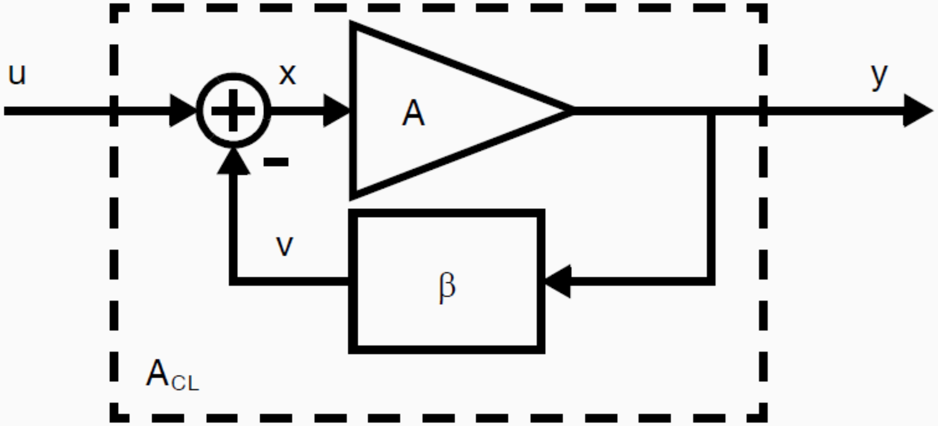


Fig. 5.1 Ideal model of a negativefeedback system.

ex) CS stage

$$A = -g_m(R_D \,||\, r_O)$$

$$A_{CL} = \frac{y}{u} = \frac{A}{1+A\beta} \xrightarrow{A\beta >> 1} A_{CL} = \frac{y}{u} \approx \frac{1}{\beta}$$

A large loop gain is needed to create a precise gain, one that does not depend on A

Bandwidth Enhancement

Open Loop

$$A(s) = \frac{A_0}{1 + \frac{s}{\omega_0}}$$

Open loop gain (@low freq.): A_0

Open-loop Bandwidth: ω_0

Negative Feedback →

$$\frac{Y}{X}(s) = \frac{A(s)}{1 + KA(s)}$$

Closed Loop

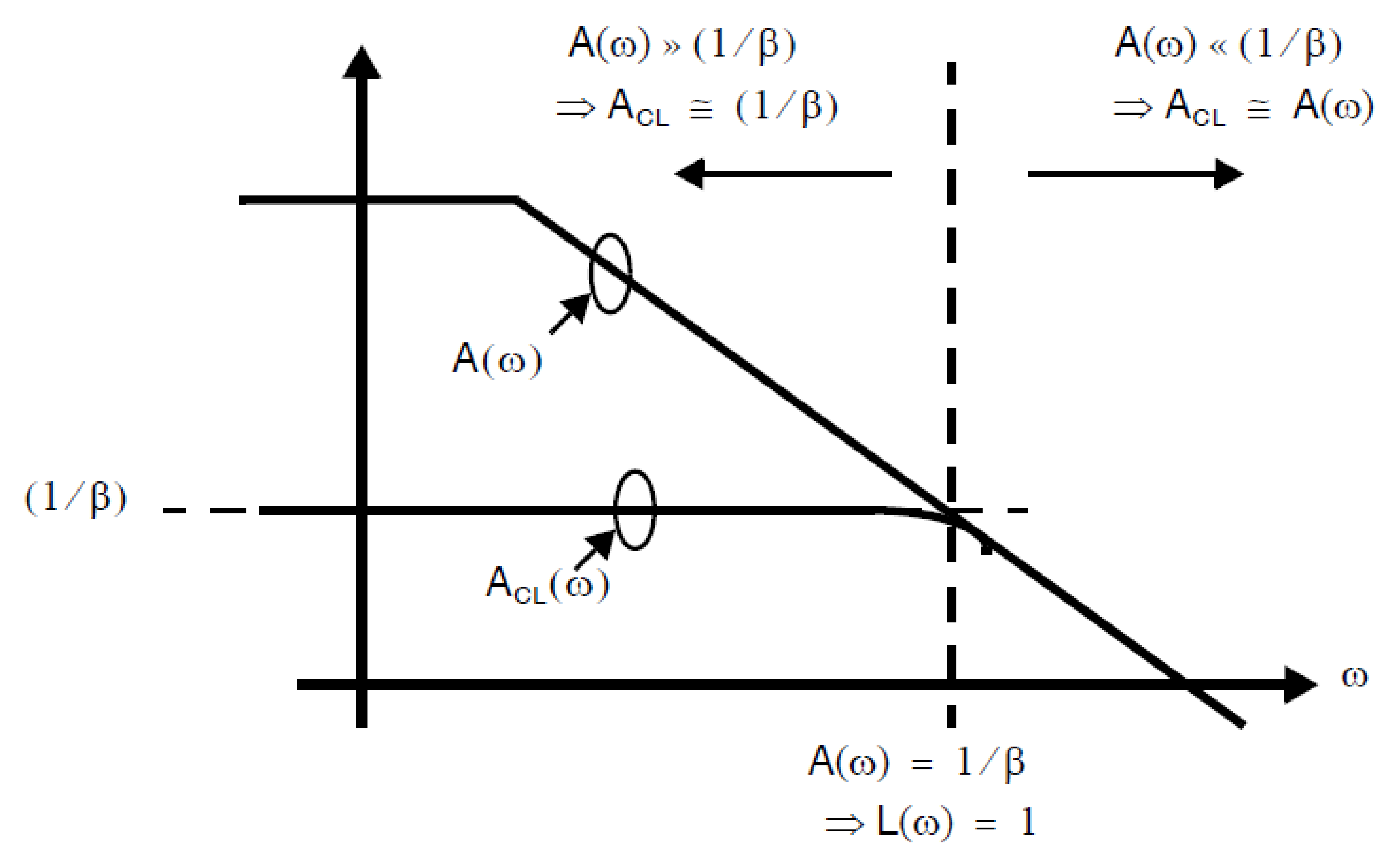
$$\frac{Y}{X}(s) = \frac{\frac{A_0}{1+KA_0}}{1 + \frac{s}{(1+KA_0)\omega_0}}$$

Closed-loop Gain (@low freq): $\frac{A_0}{1+KA_0}$

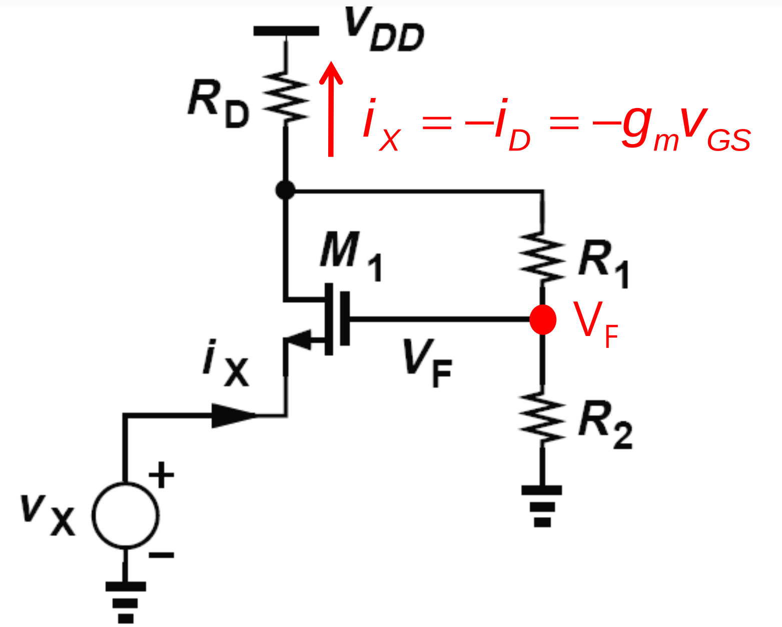
Closed-loop Bandwidth: $(1+KA_0)\omega_0$

Although negative feedback lowers the gain by $(1+KA_0)$, it also extends the bandwidth by the same amount.

Bandwidth Enhancement



Modification of I/O Impedances



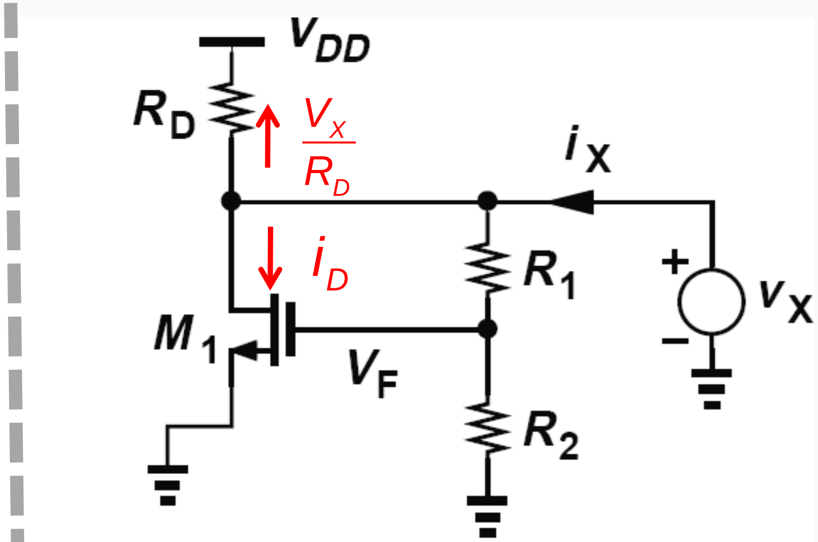
$$v_{GS} = v_F - v_X$$

$$= i_X R_D \cdot \frac{R_2}{R_1 + R_2} - v_X$$

$$i_X = -g_m v_{GS}$$

$$= -g_m \left(i_X R_D \cdot \frac{R_2}{R_1 + R_2} - v_X \right)$$

$$R_{in,closed} = \frac{1}{g_m} \left(1 + \frac{R_2}{R_1 + R_2} g_m R_D \right)$$

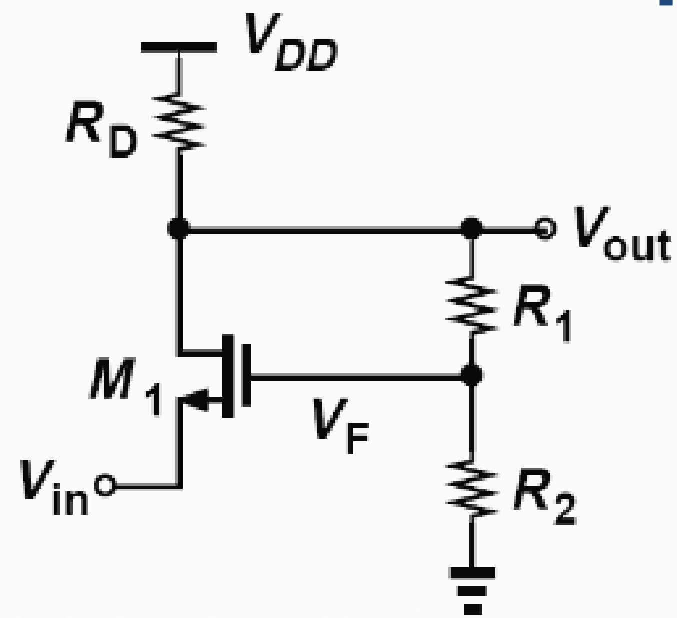


$$v_{GS} = \frac{R_2}{R_1 + R_2} \cdot v_X, \quad i_D = g_m v_{GS} = i_X - \frac{v_X}{R_D}$$

$$g_m \left(\frac{R_2}{R_1 + R_2} \cdot v_X \right) = i_X - \frac{v_X}{R_D}$$

$$R_{out,closed} = \frac{R_D}{1 + \frac{R_2}{R_1 + R_2} g_m R_D}$$

Modification of I/O Impedances



Assume $R_1 + R_2 = R_D$

Open loop

$$R_{in,open} = \frac{1}{g_m}$$

$$R_{out,open} = R_D$$

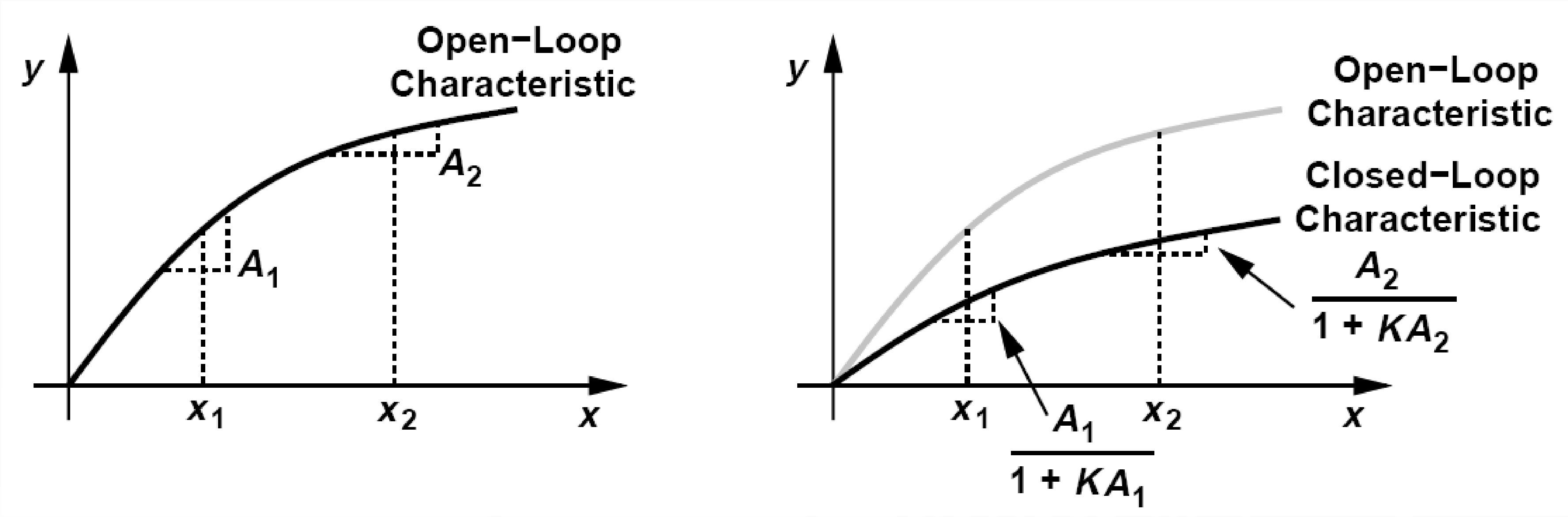
Closed loop

$$R_{in,closed} = \frac{1}{g_m}\left(1 + \frac{R_2}{R_1 + R_2} g_m R_D\right)$$

$$R_{out,closed} = \frac{R_D}{1 + \frac{R_2}{R_1 + R_2} g_m R_D}$$

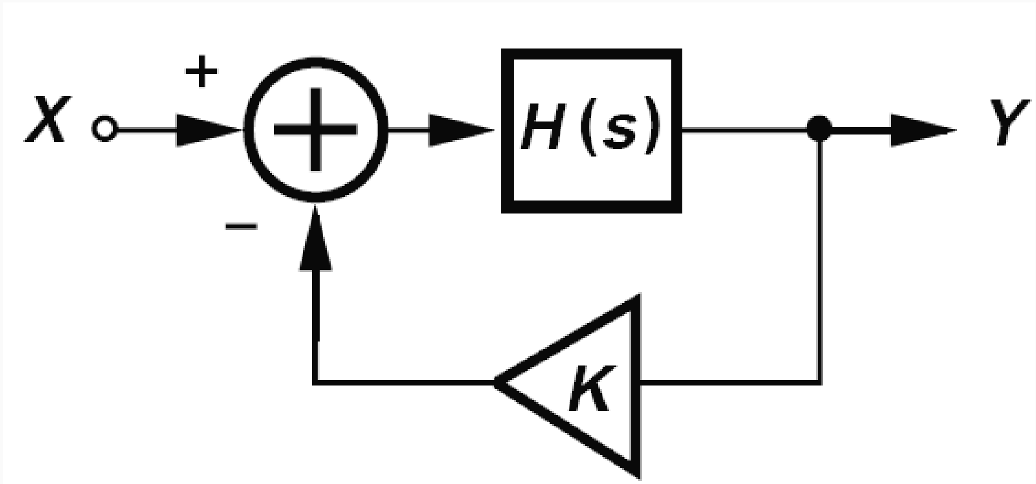
More ideal amp

Linearization



Closed-loop characteristic is more linear than open-loop characteristic

Instability of a Negative Feedback Loop



$$\frac{Y}{X}(s) = \frac{H(s)}{1+KH(s)} \xrightarrow[@\,\omega_1]{KH(j\omega_1) = -1} \frac{Y}{X}(s) \to \infty$$

Small Noise Component at ω_1	Infinite Gain →	The System Oscillates at ω_1

❖Condition for Oscillation

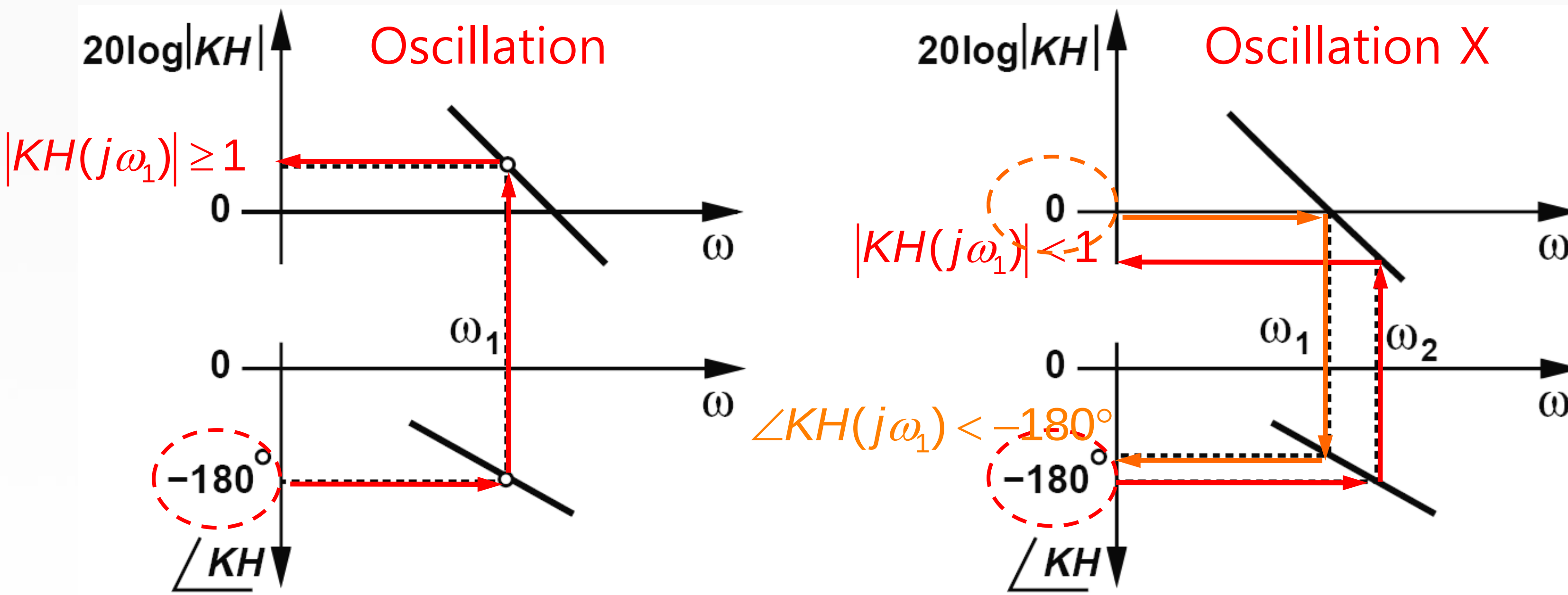
$$KH(j\omega_1) = -1 \Rightarrow \begin{cases} |KH(j\omega_1)| = 1 \\ \angle KH(j\omega_1) = -180 \end{cases}$$

Condition for Oscillation

❖ Condition for Oscillation

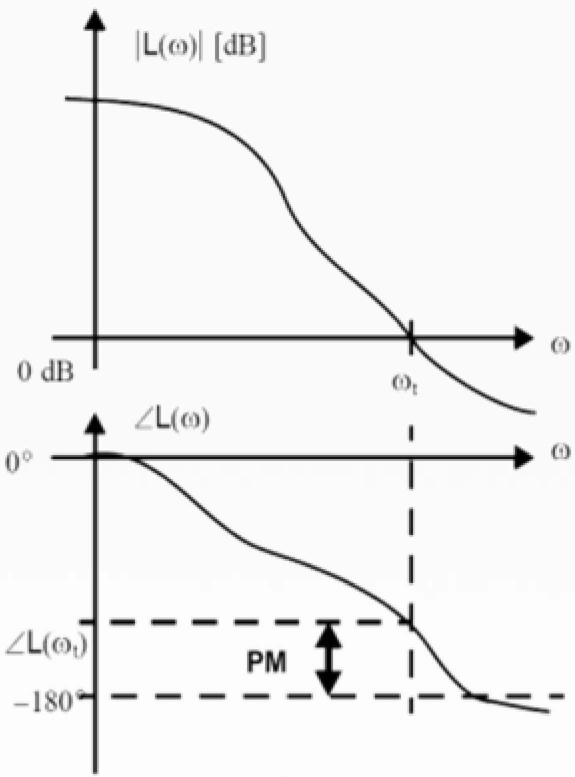
$$\angle KH(j\omega_1) = -180$$

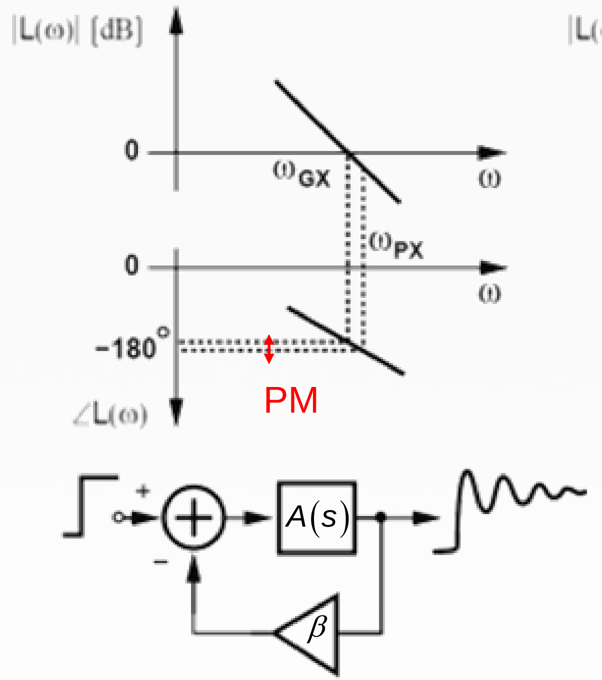
$$|KH(j\omega_1)| \geq 1$$



Phase Margin

Phase Margin = $\angle L(\omega_{GX}) + 180°$





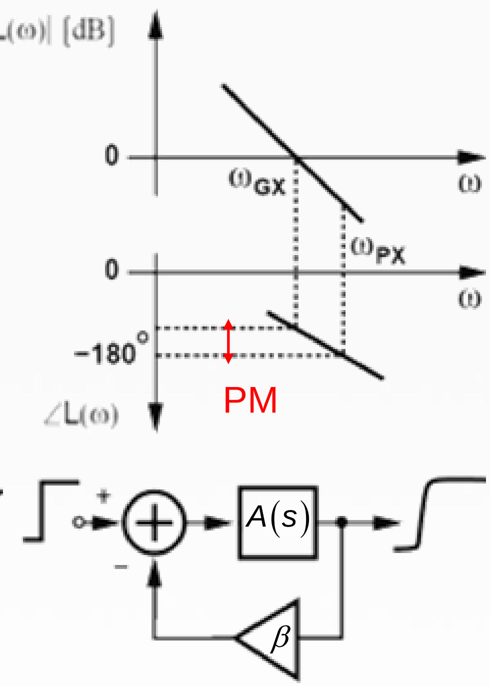


Fig. 5.4 The relationship between bode plot

More stable

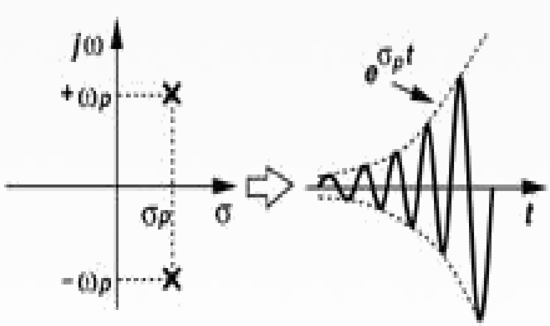
Time Domain Response

$$H(j\omega) = \frac{1}{as^2 + bs + 1}$$

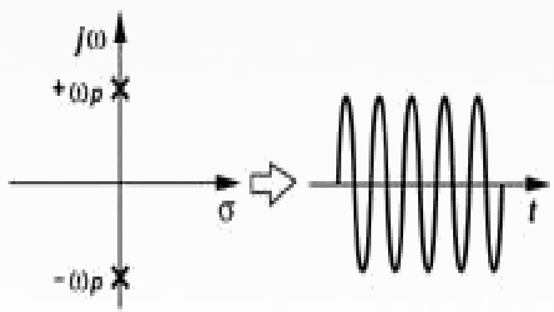
$S_p = \pm jw_p + \sigma_p$: Pole frequency

$e^{(jw_p + \sigma_p)t}$: Inverse Laplace transform

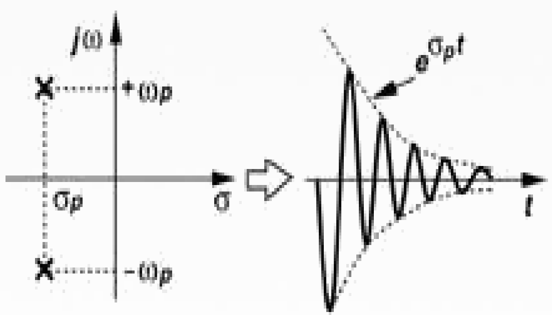
$$e^{(jw_p + \sigma_p)t} = e^{\sigma_p t}\left(\cos w_p t + j \sin w_p t\right)$$



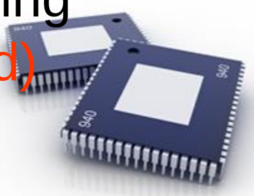
Poles on the RHP
Unstable
(no good)



Poles on the jω axis
Oscillatory
(no good)

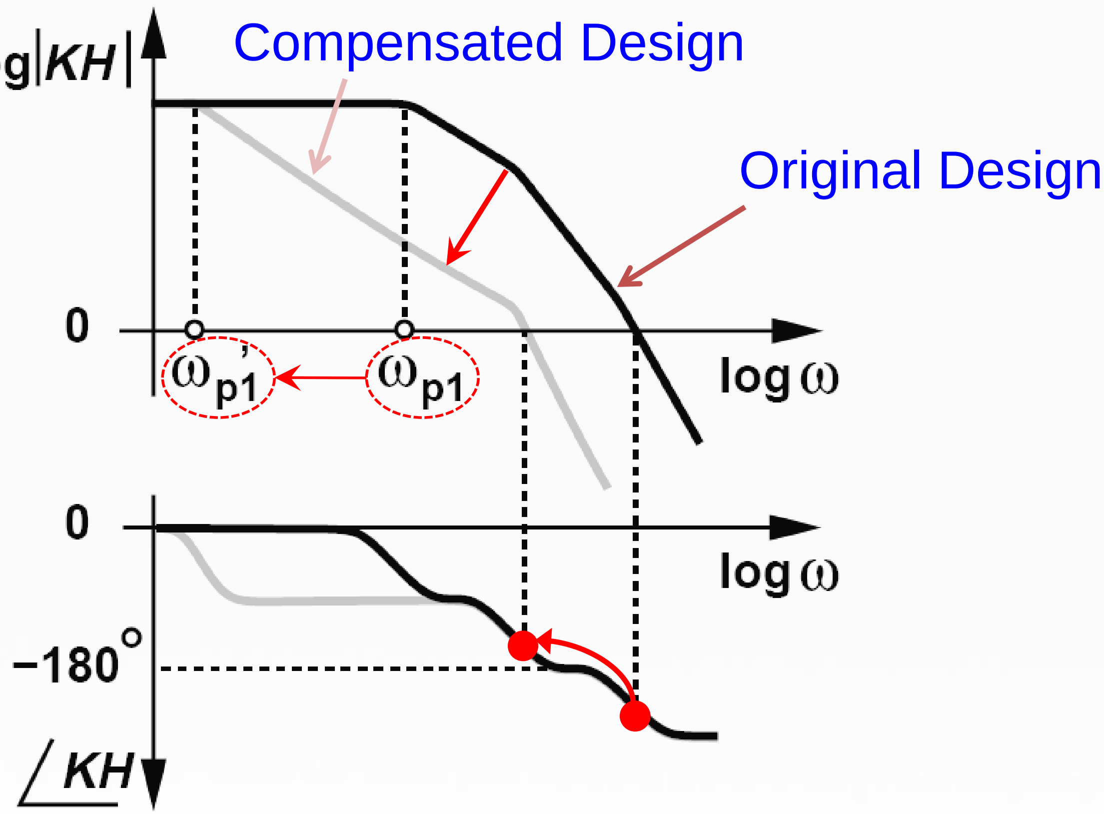


Poles on the LHP
Decaying
(good)



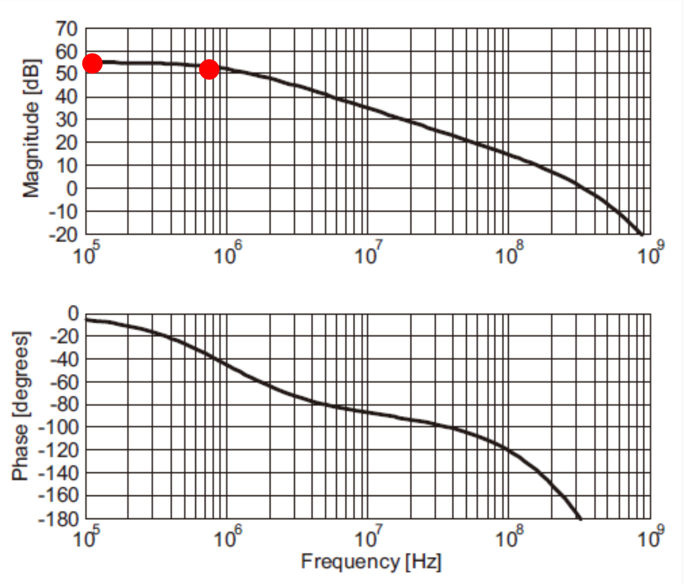
Example of Feedback System

Frequency Compensation

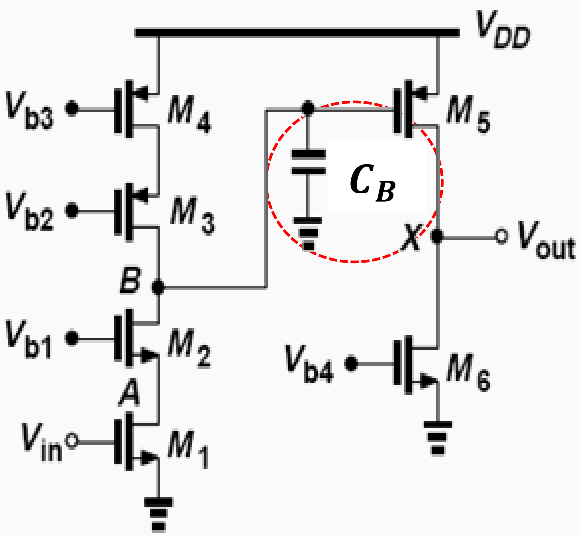


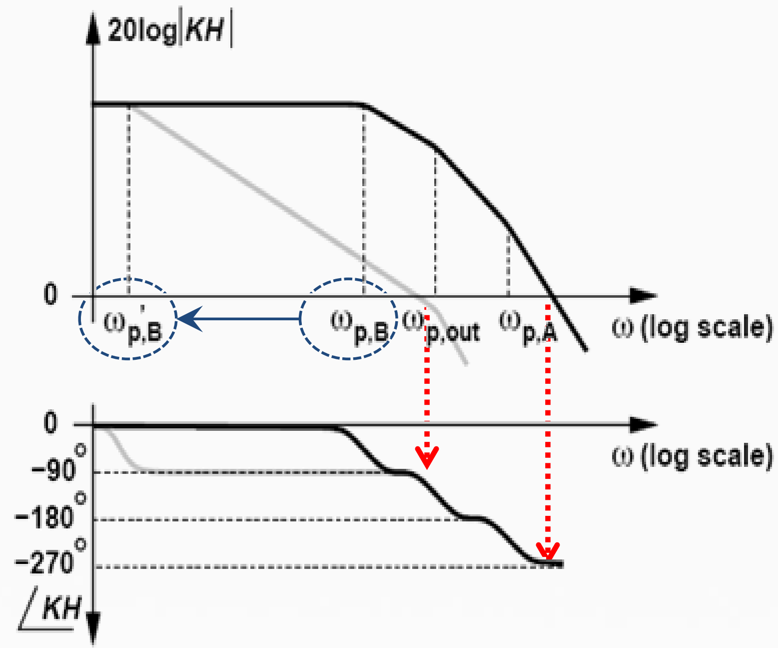
Decreasing ω_{GX} ⇨ Phase margin increase

Example of Frequency Response



Frequency Compensation Example



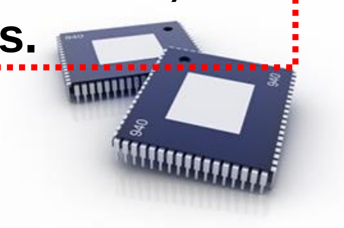


$$\omega_{p,B} \approx \frac{1}{[(g_{m2}r_{o2}r_{o1}) \,||\, (g_{m3}r_{o3}r_{o4})]C_B} \uparrow$$

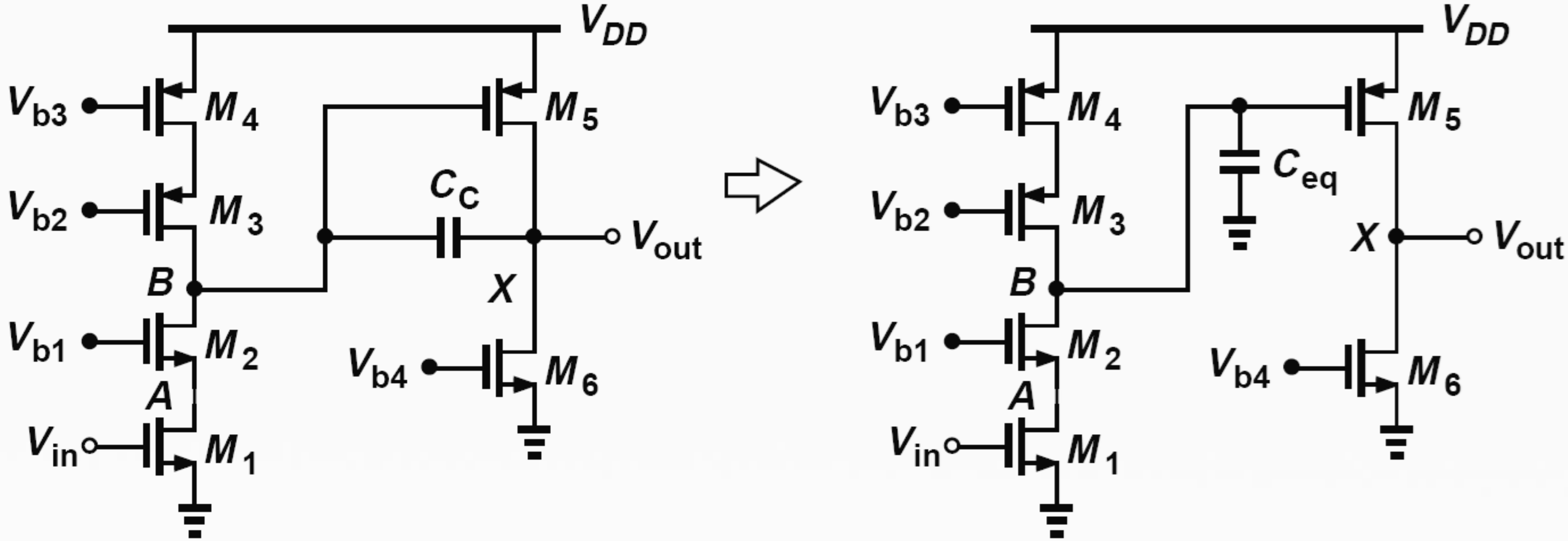
$$\omega_{p,out} = \frac{1}{(r_{o5} \,||\, r_{o6})C_{out}}$$

$$\omega_{p,A} \approx \frac{g_{m2}}{C_A}$$

C_{comp} is added to lower the dominant pole so that ω_{GX} occurs at a lower frequency than before, which means phase margin increases.



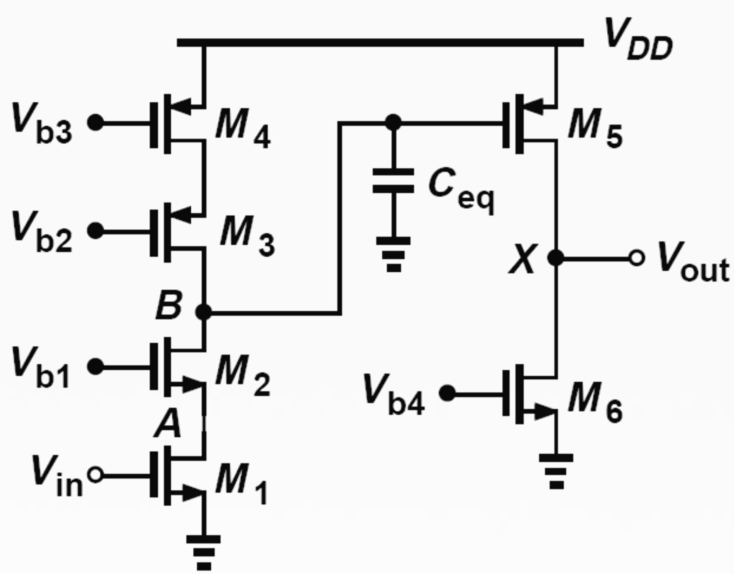
Miller Compensation

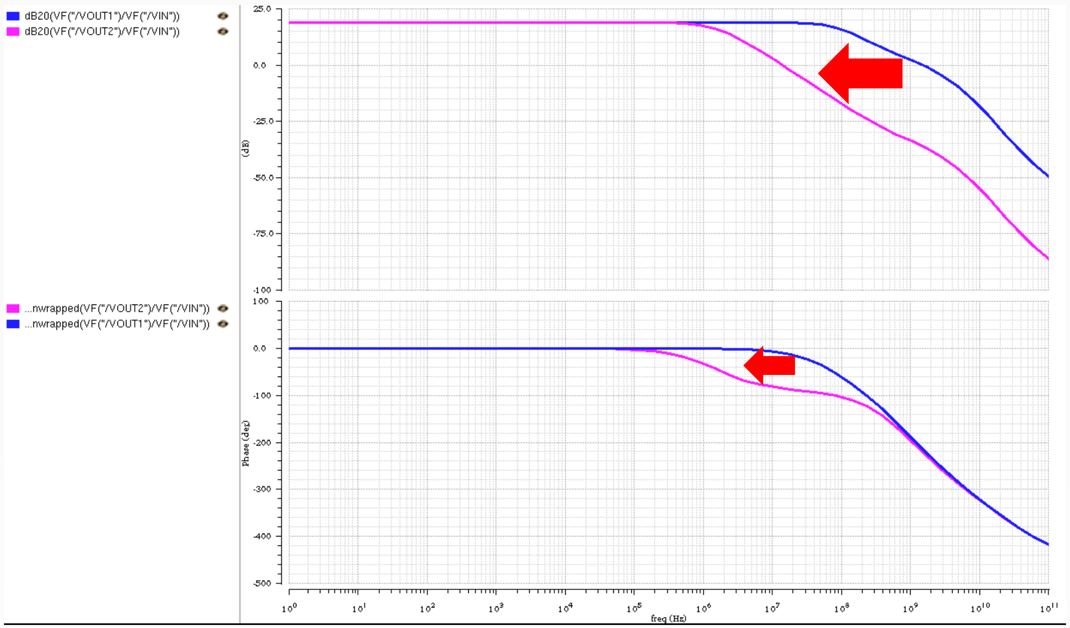


$$C_{eq} = [1 + g_{m5}(r_{O5} \,||\, r_{O6})]C_c$$

To save chip area, Miller multiplication of a smaller capacitance creates an equivalent effect.

Simulation





: Compensation

: No Compensation