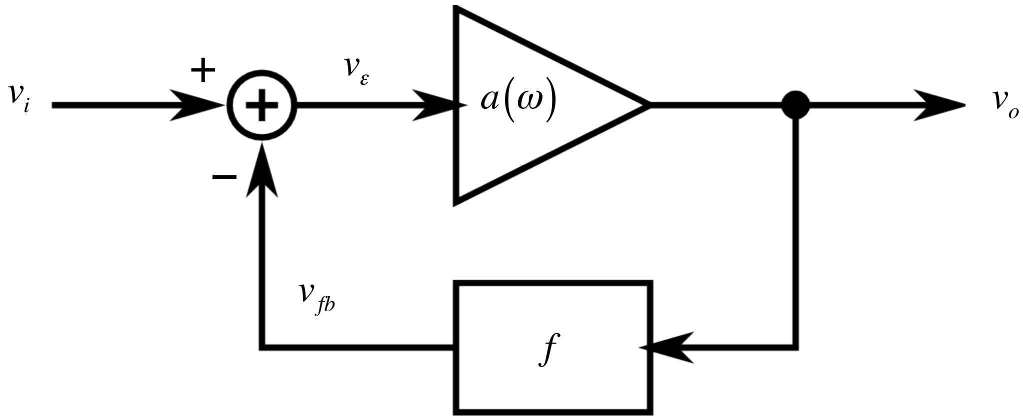
EEE 51: Second Semester 2017 - 2018

Lecture 21

Feedback Frequency Response

Pole and Zero Locations



$$a(s) = \frac{N(s)}{D(s)}$$

$$A_{CL}(s) = \frac{\dfrac{N(s)}{D(s)}}{1 + \dfrac{N(s)}{D(s)} f} = \frac{N(s)}{D(s) + N(s) \cdot f}$$

Zeros of a(s)

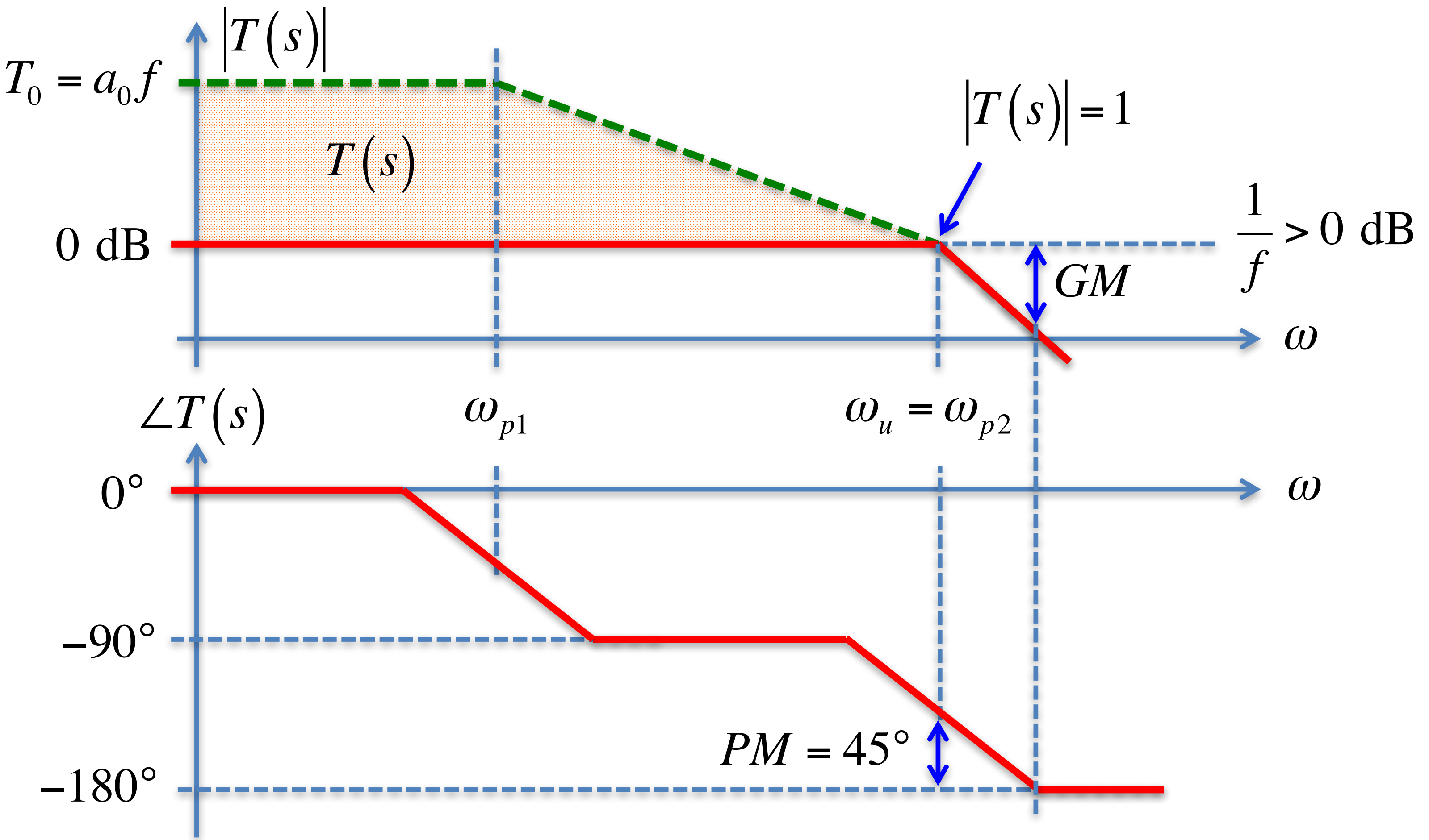
Poles of a(s)

Compensation

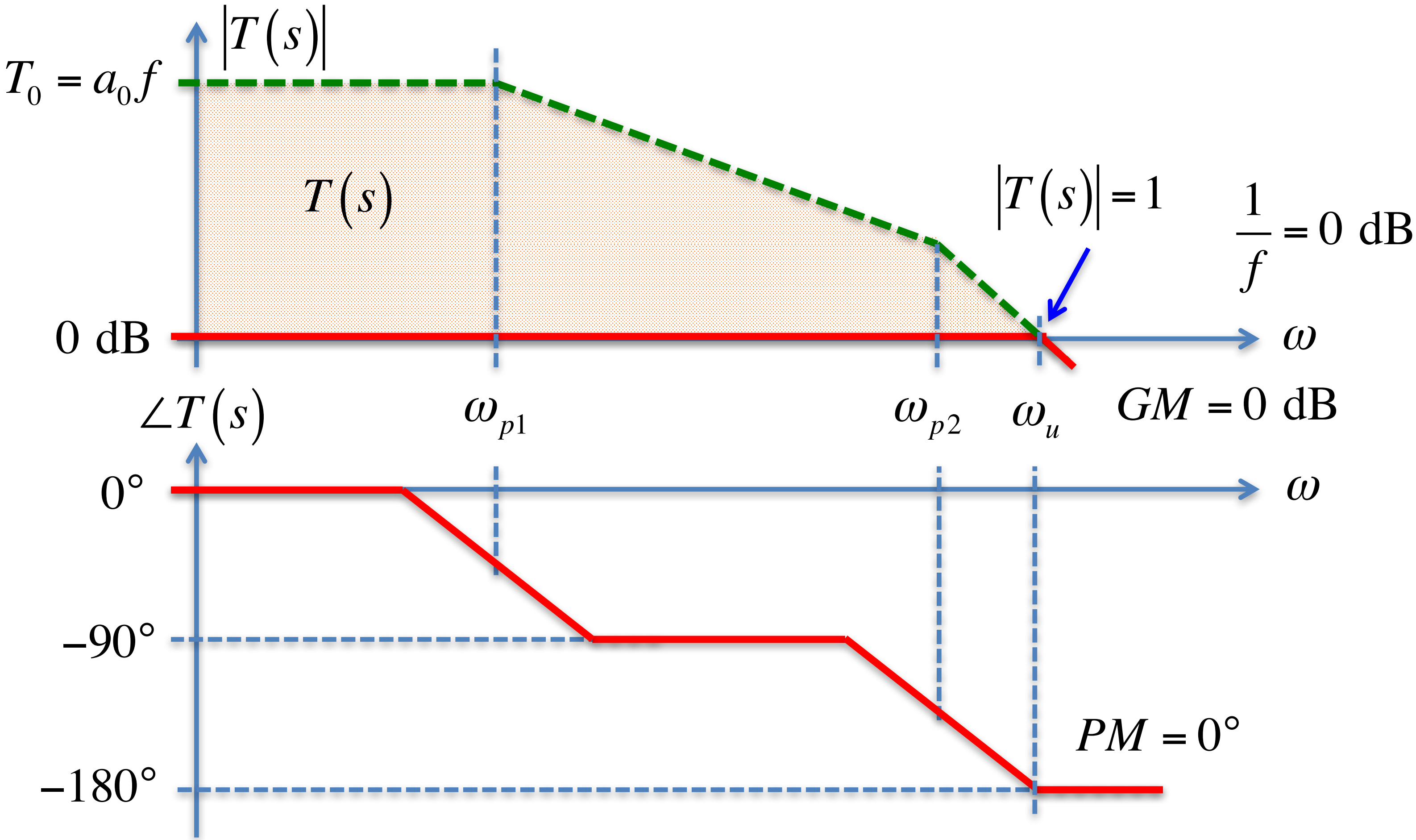
- A method where an amplifier is modified so that it is stable

- Main Idea:
  - At the frequency ω_{180} where loop gain phase is equal to -180°, make sure that $|T(\omega_{180})| < 1$

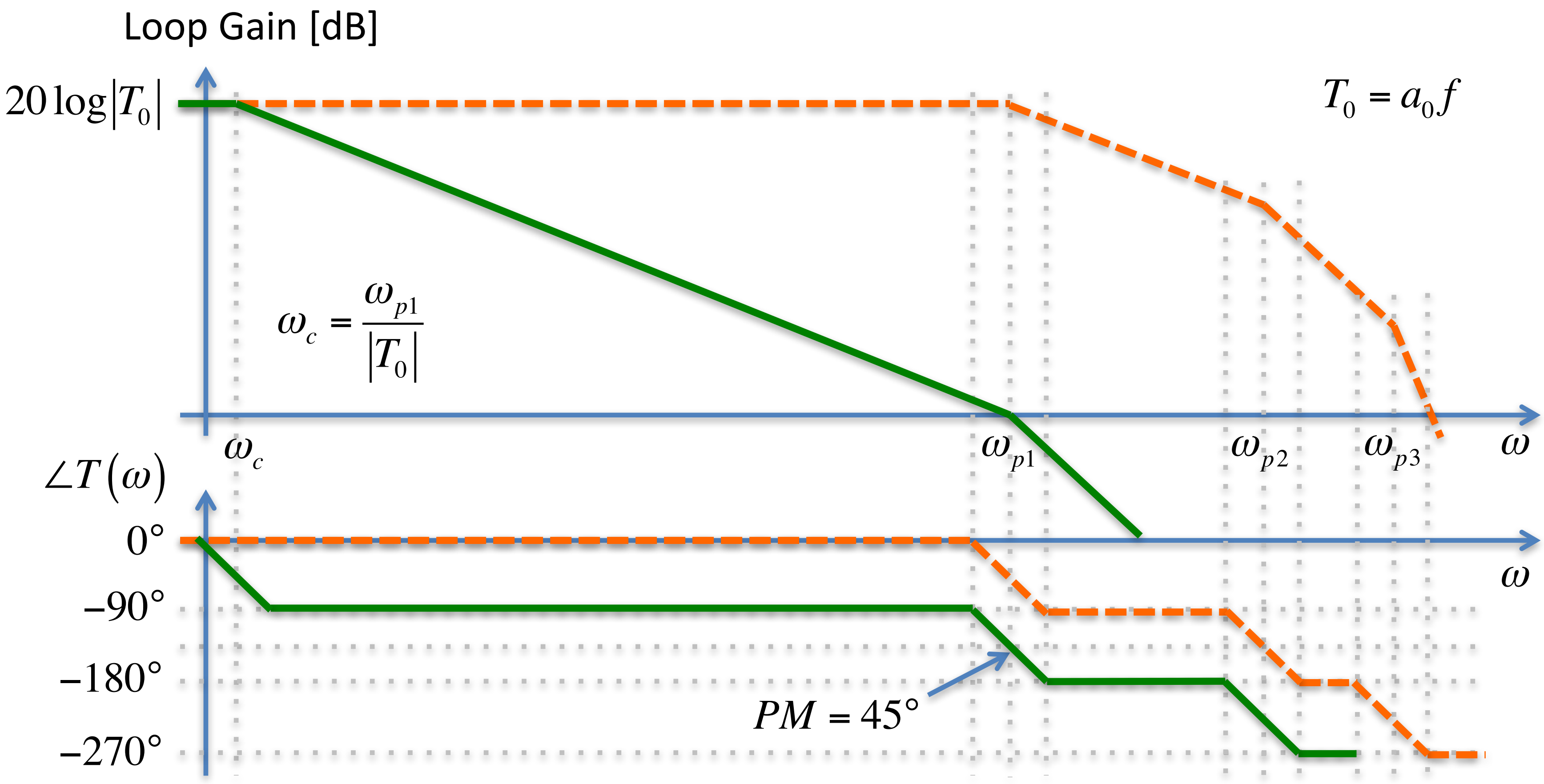
- Alternate:
  - At $|T(\omega_u)| = 1$, make the loop gain phase less than -180°



$|T(s)|$
$T_0 = a_0 f$
$T(s)$
$|T(s)| = 1$
0 dB
$\frac{1}{f} > 0$ dB
GM
ω
$\angle T(s)$
ω_{p1}
$\omega_u = \omega_{p2}$
$0°$
ω
$-90°$
$PM = 45°$
$-180°$


$|T(s)|$
$T_0 = a_0 f$
$T(s)$
$|T(s)| = 1$
$\frac{1}{f} = 0$ dB
0 dB
ω
$\angle T(s)$
ω_{p1}
ω_{p2}
ω_u
$GM = 0$ dB
$0°$
ω
$-90°$
$PM = 0°$
$-180°$

Narrowbanding: Adding a Dominant Pole



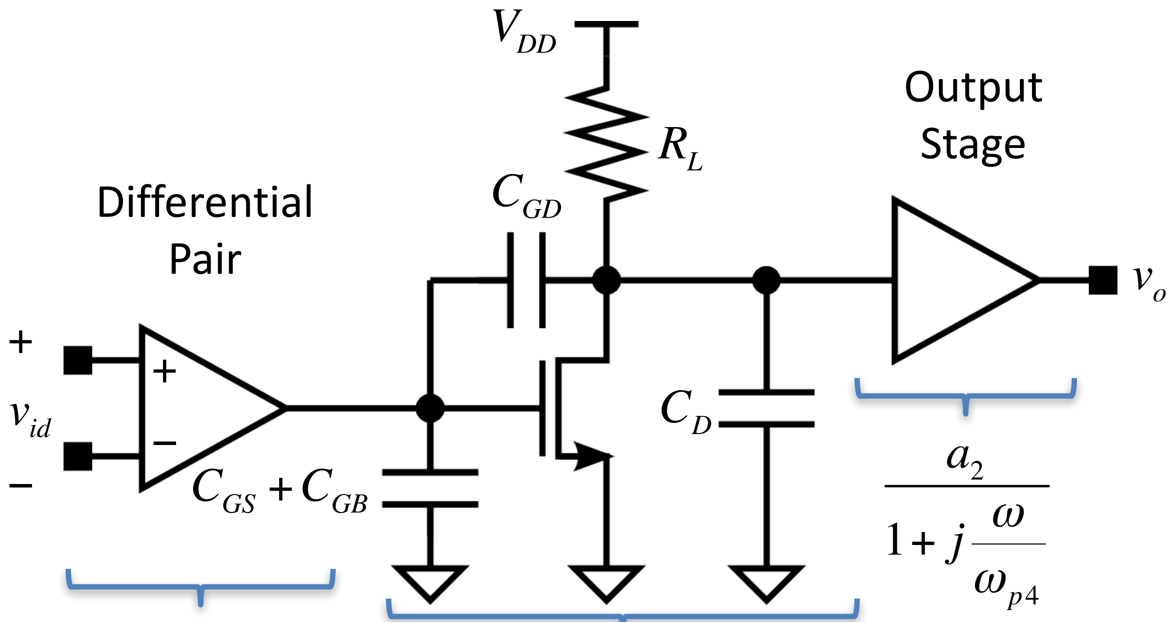
Narrowbanding

- In order to get a phase margin of 45°
  - Add a compensation pole at

$$\omega_c = \frac{\omega_{p1}}{|T_0|} = \frac{\omega_{p1}}{|a_0 f|}$$

- Example: f_{p1} = 1 MHz, $|a_0 f| = 10^4$
  - f_c = 100 Hz
  - -90° phase shift from the new compensation pole
  - -45° from the original (and now second) pole

Pole Splitting



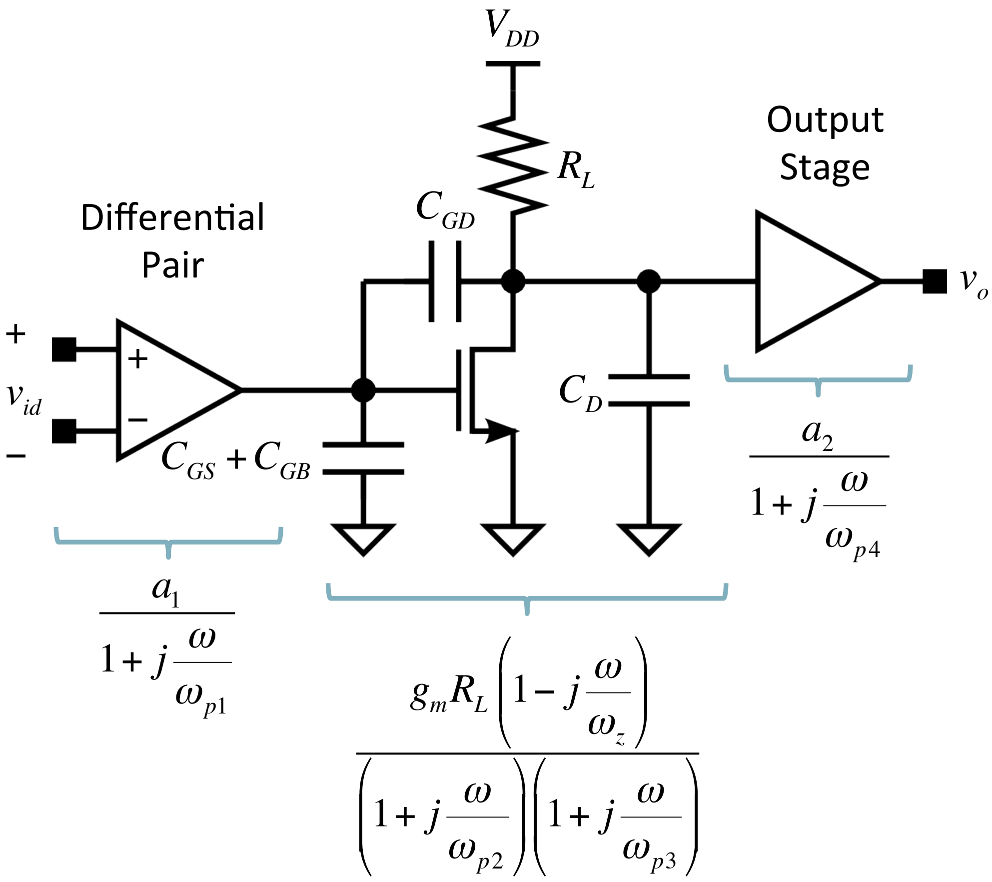
$$\frac{a_1}{1 + j\dfrac{\omega}{\omega_{p1}}}$$

$$\frac{g_m R_L \left(1 - j\dfrac{\omega}{\omega_z}\right)}{\left(1 + j\dfrac{\omega}{\omega_{p2}}\right)\left(1 + j\dfrac{\omega}{\omega_{p3}}\right)}$$

$$\frac{a_2}{1 + j\dfrac{\omega}{\omega_{p4}}}$$

Can we use an existing pole instead of creating a new one?

Pole Splitting



Assume $\omega_{p4} >> \omega_{p1}$:

$$\omega_{p2} = \frac{1}{R_{o,diff} C_{GS}}$$

$$\omega_{p3} = \frac{1}{R_L C_D}$$

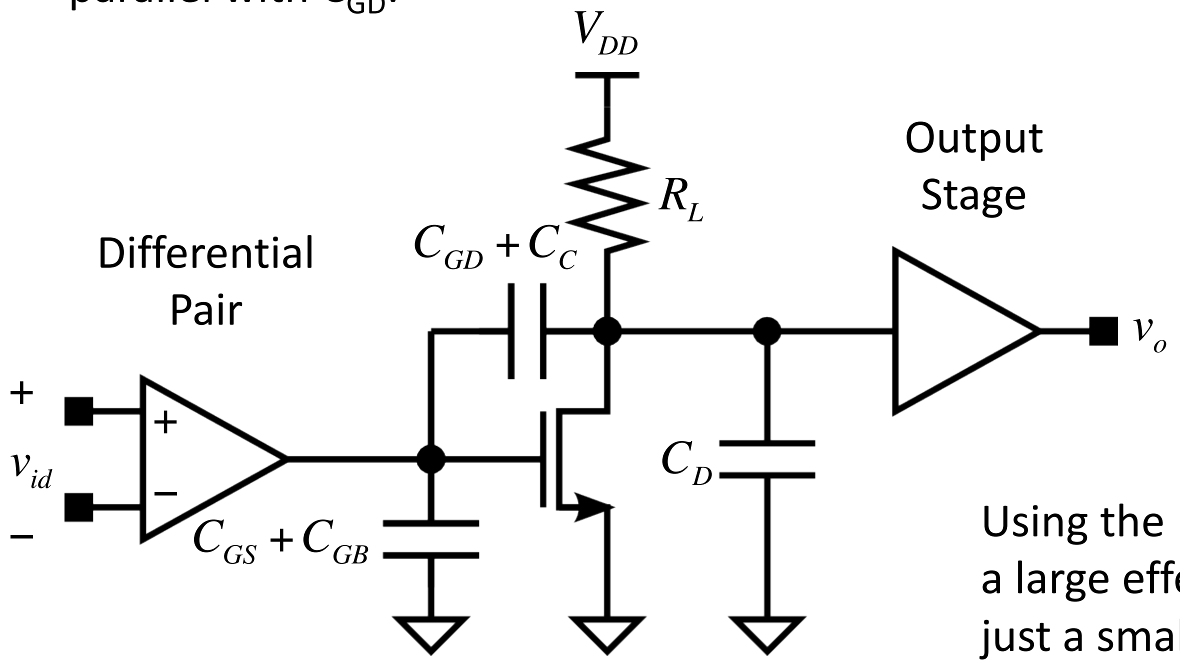
$$\omega_z = \frac{g_m}{C_{GD}}$$

Since there are 4 poles, we must make sure that the amplifier is stable

Can we do this by just making one of the existing poles the dominant pole?

Pole Splitting

Add a compensation capacitance C_C in parallel with C_{GD}:



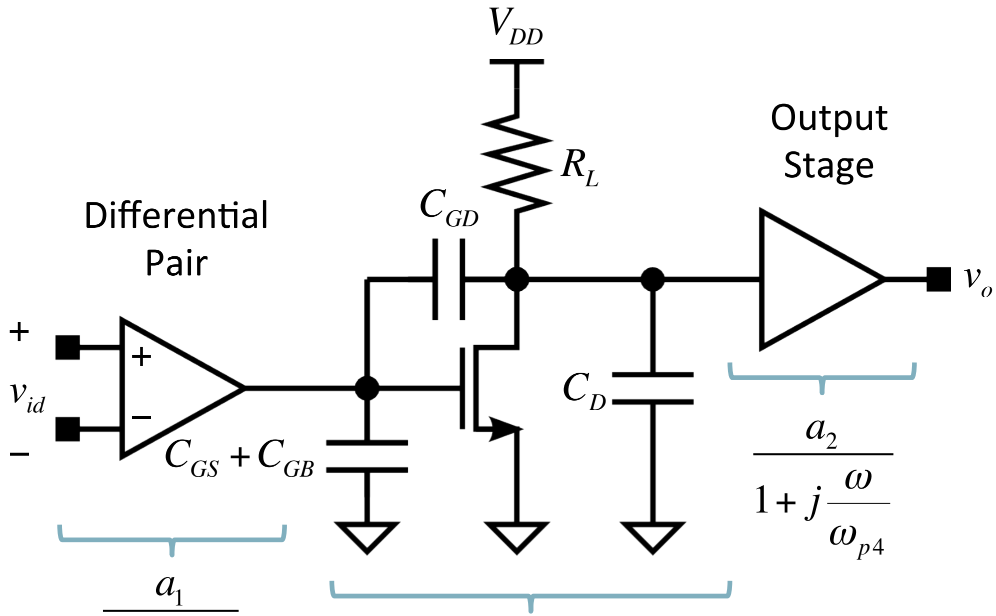
$$\omega_{p2} = \frac{1}{R_{o,diff}\left(1+g_m R_L\right)C_C}$$

$$\omega_{p3} = \frac{g_m}{C_{GS}+C_D}$$

$$\omega_z = \frac{g_m}{C_C}$$

Using the Miller effect, we can add a large effective capacitance using just a small physical capacitance

Example:



$$\frac{a_1}{1+j\frac{\omega}{\omega_{p1}}}$$

$$\frac{g_m R_L\left(1-j\frac{\omega}{\omega_z}\right)}{\left(1+j\frac{\omega}{\omega_{p2}}\right)\left(1+j\frac{\omega}{\omega_{p3}}\right)}$$

$$R_{o,diff}=10\text{M}\Omega$$

$$R_L=5\text{M}\Omega$$

$$C_{GS}=C_D=0.1\text{pF}$$

$$g_m=10^{-3}\text{S}$$

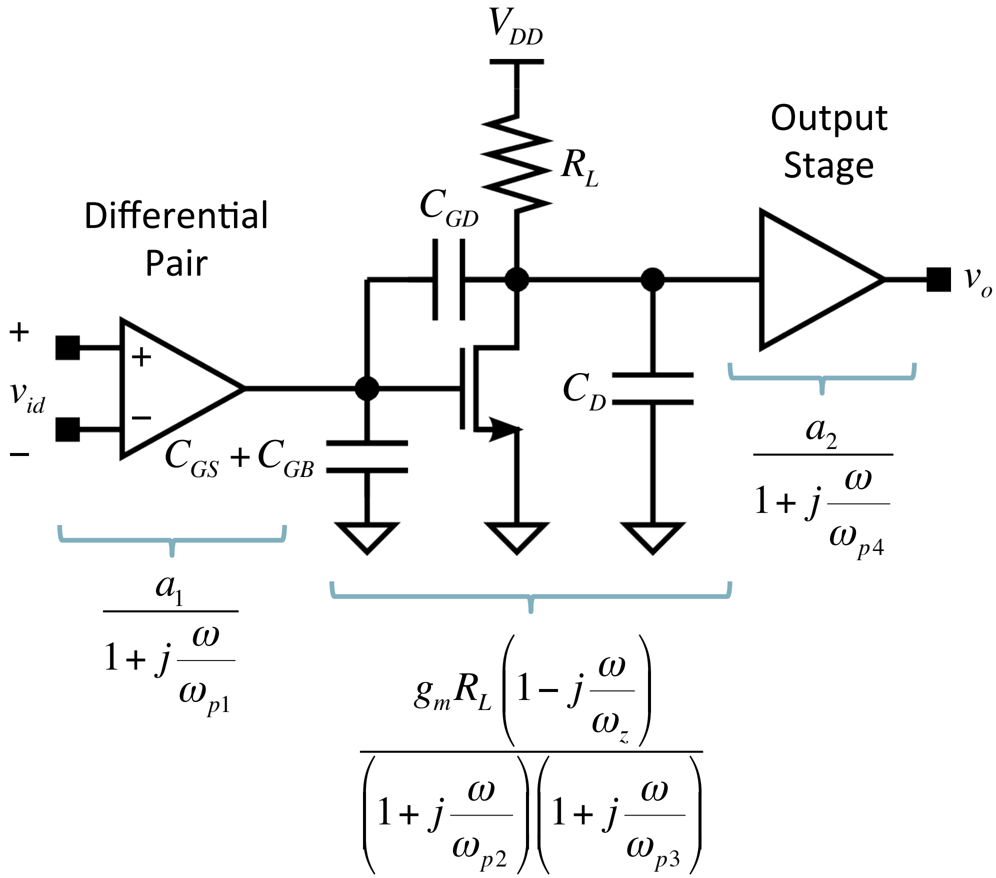
$$\omega_{p1}=10\frac{\text{Mrad}}{\text{s}}$$

$$\omega_{p4}=100\frac{\text{Mrad}}{\text{s}}$$

$$a_1=10^3$$

$$a_2=1$$

Before Compensation and with $C_{GD} = 0$:

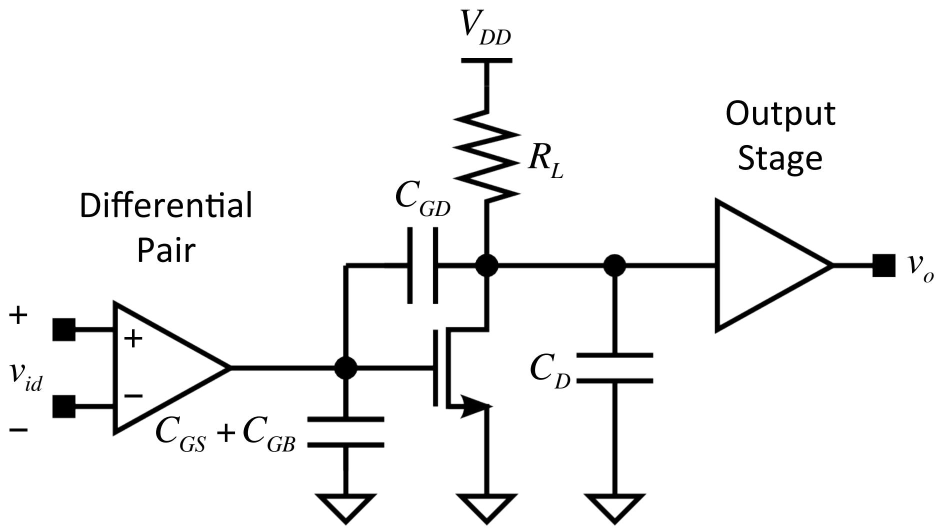


$$\omega_{p2} = \frac{1}{R_{o,diff} C_{GS}} = 1\frac{\mathrm{Mrad}}{\mathrm{s}}$$

$$\omega_{p3} = \frac{1}{R_L C_D} = 2\frac{\mathrm{Mrad}}{\mathrm{s}}$$

$$\omega_z = \frac{g_m}{C_{GD}} \rightarrow \infty$$

Before Compensation and with C_{GD} = 0:



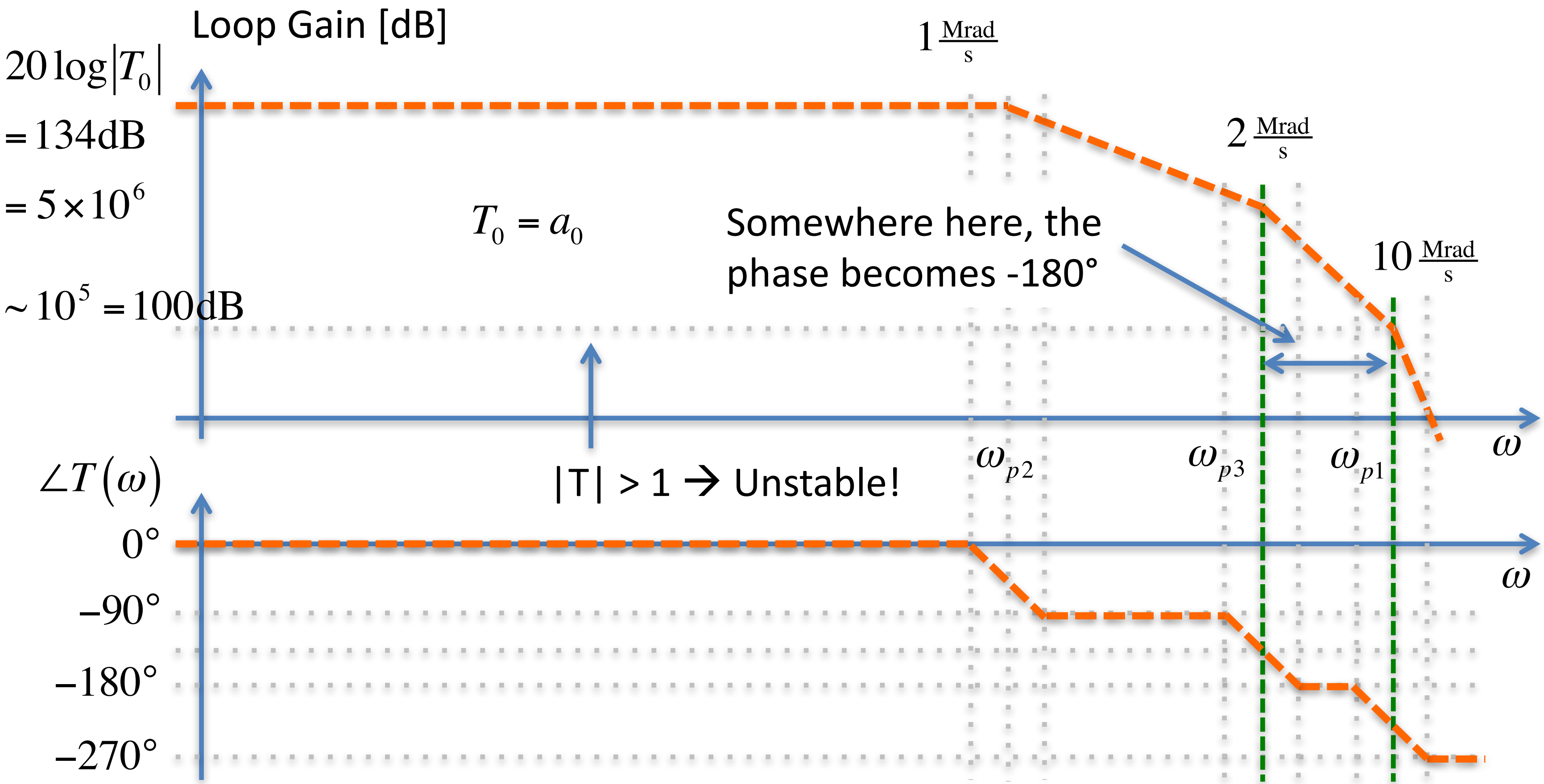
$$\omega_{p2} = \frac{1}{R_{o,diff}C_{GS}} = 1\frac{\text{Mrad}}{\text{s}}$$

$$\omega_{p3} = \frac{1}{R_L C_D} = 2\frac{\text{Mrad}}{\text{s}}$$

$$\omega_z = \frac{g_m}{C_{GD}} \to \infty$$

$$a(\omega) = \frac{10^3 \cdot \left(10^{-3} \cdot 5\times 10^6\right)\cdot 1}{\left(1+j\dfrac{\omega}{10\times 10^6}\right)\left(1+j\dfrac{\omega}{1\times 10^6}\right)\left(1+j\dfrac{\omega}{2\times 10^6}\right)\left(1+j\dfrac{\omega}{100\times 10^6}\right)}$$

Before Compensation (use f = 1):



Compensate for f = 1 and PM = 45°

We want:

$$\omega_{p2} = \frac{\omega_{p1}}{T_0} = \frac{10\times10^6}{5\times10^6} = 2\,\frac{\text{rad}}{\text{s}}$$

For $C_C >> C_{GS}$, C_D and C_{GD}

$$\omega_{p2} = \frac{1}{R_{o,diff}\left(1+g_mR_L\right)C_C}$$

$$C_C = \frac{1}{R_{o,diff}\left(1+g_mR_L\right)\omega_{p2}} = \frac{T_0}{R_{o,diff}\left(1+g_mR_L\right)\omega_{p1}}$$

$$= \frac{1}{10\times10^6\cdot\left(5\times10^3\right)\cdot2} = 10\text{pF}$$

Thus,

$$\omega_{p3} = \frac{g_m}{C_{GS}+C_D} = \frac{10^{-3}}{0.2\times10^{-12}}$$

$$= 5\,\frac{\text{Grad}}{\text{s}}$$

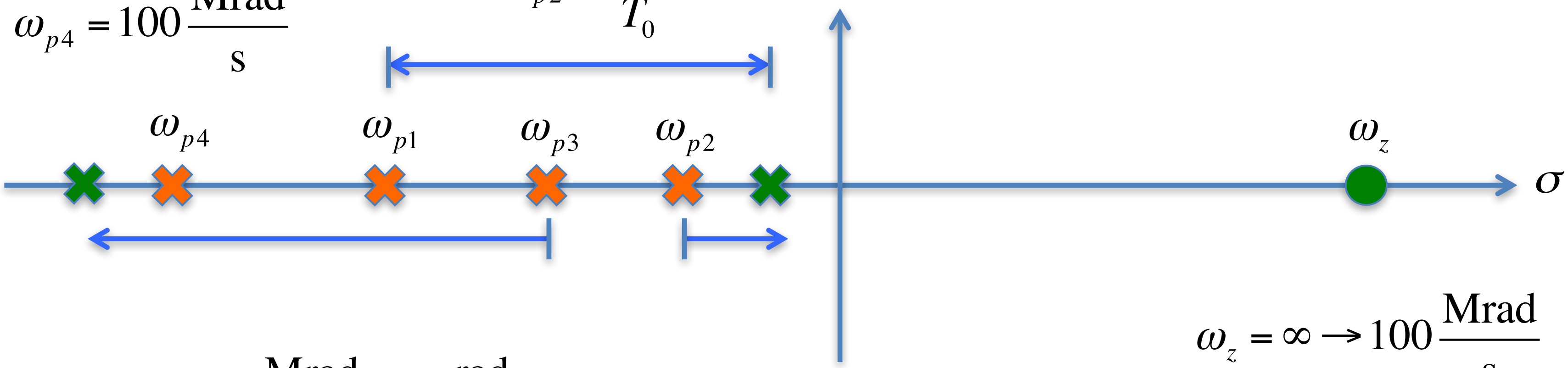
$$\omega_z = \frac{g_m}{C_C} = \frac{10^{-3}}{10\times10^{-12}} = 100\,\frac{\text{Mrad}}{\text{s}}$$

Compensate for f = 1 and PM = 45°

$$\omega_{p1} = 10\,\frac{\text{Mrad}}{\text{s}}$$

$$\omega_{p4} = 100\,\frac{\text{Mrad}}{\text{s}}$$

$$\omega_{p2} = \frac{\omega_{p1}}{T_0}$$



$$\omega_z = \infty \rightarrow 100\,\frac{\text{Mrad}}{\text{s}}$$

$$\omega_{p2} = 1\,\frac{\text{Mrad}}{\text{s}} \rightarrow 2\,\frac{\text{rad}}{\text{s}}$$

$$\omega_{p3} = 2\,\frac{\text{Mrad}}{\text{s}} \rightarrow 5\,\frac{\text{Grad}}{\text{s}}$$

Next Meeting

- Feedback Amplifier Step Response
- Introduction to Oscillators