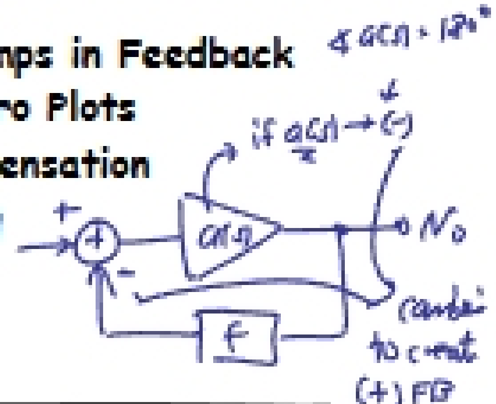
- **Announcements:**
  - Evening lecture today, 7 p.m., in 289 Cory
  - You should be finished with a draft design of your op amp project by now
- **Today:**
  - Stability of Op Amps in Feedback
  - Review of Pole/Zero Plots
  - Methods for Compensation
    - Narrowbanding
    - Pole-Splitting



Last Time –

$\boxed{\text{Stability of FB Ckt. Using a Single Pole Op Amp}}$

For a single pole op amp: $a(s) = \frac{a_o}{1-\frac{s}{p_1}} \equiv$ op amp transfer function

Thus: closed loop Xfer Fcn

$$A(s) = \frac{a(s)}{1+a(s)f} = \frac{a_o}{1+a_o f}\cdot\frac{1}{1-\frac{s}{p_1(1+a_o f)}}$$

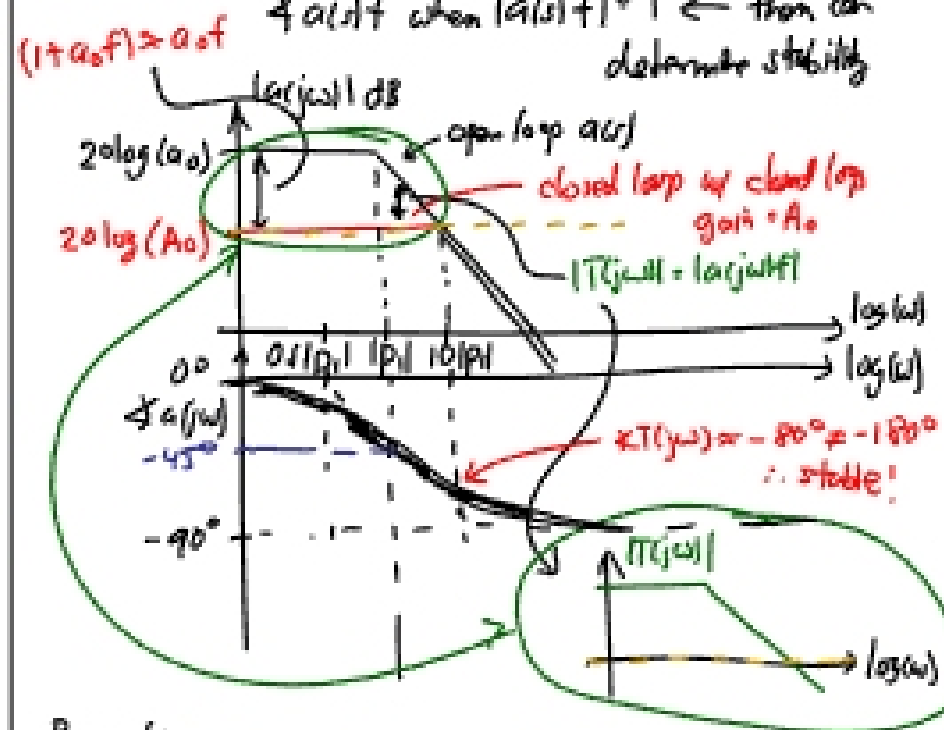
much higher 3dB freq.

A_o = closed loop dc gain → $(1+a_o f) \approx a_o f$ × smaller than a_o $\approx \frac{1}{f}$

$T_o = a_o f$ = loop gain (defined at dc)

$T(s) = a(s) f$ = loop transmission (defined for general frequencies)

Bode Plot: → use to determine $\measuredangle a(s)f$ when $|a(s)f| = 1$ ← then can determine stability



Remarks:

① For the case of a single pole op amp, FB can never reach $\measuredangle T(j\omega) = -180°$! (90° is the limit!)

② Thus, an op amp FB ckt. w/ f = const. and using a single-pole op amp is always stable!

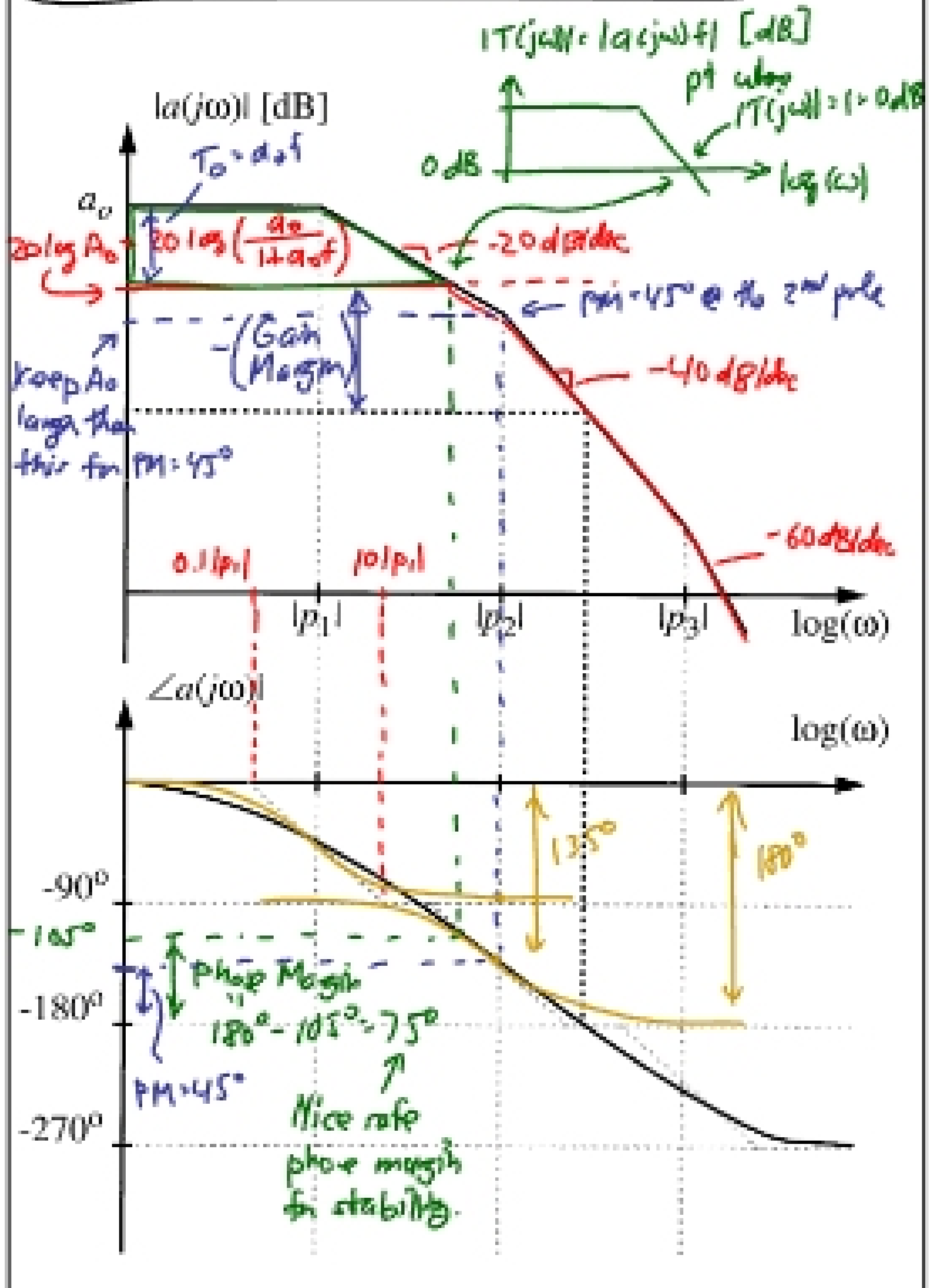
↓

But add a few non-dominant poles → then instability is possible!

since now, $\measuredangle T(j\omega)$ can reach $-180°$!

Can best visualize this via a Bode plot.

Stability of a FB ckt. Using a Multi-Pole Op Amp



For the more general case where $a(s)$ has multiple poles
⇒ $A(s)$ has the same additional poles
⇒ i.e., @ freqs $> |p_1|(1+a_o f)$, the $A(s)$ curve just follows the $a(s)$ curve

$$A(s) \cong \frac{A_o}{\left(1-\frac{s}{p_1(1+a_o f)}\right)\left(1-\frac{s}{p_2}\right)\left(1-\frac{s}{p_3}\right)}$$

makes sense, because @ freqs $> |p_1|(1+a_o f)$, the loop transmission $|T(j\omega)| < 1$ → ∴ there isn't really much FB anymore...

Definition.

Phase Margin = 180° + ($\angle T(j\omega)$ @ the freq. where $|T(j\omega)| = 1$)

⇒ Phase Margin must be > 0° for stability

$\boxed{\text{For Stability: Phase Margin} > 0^\circ}$

⇒ For safety, though, usually design for

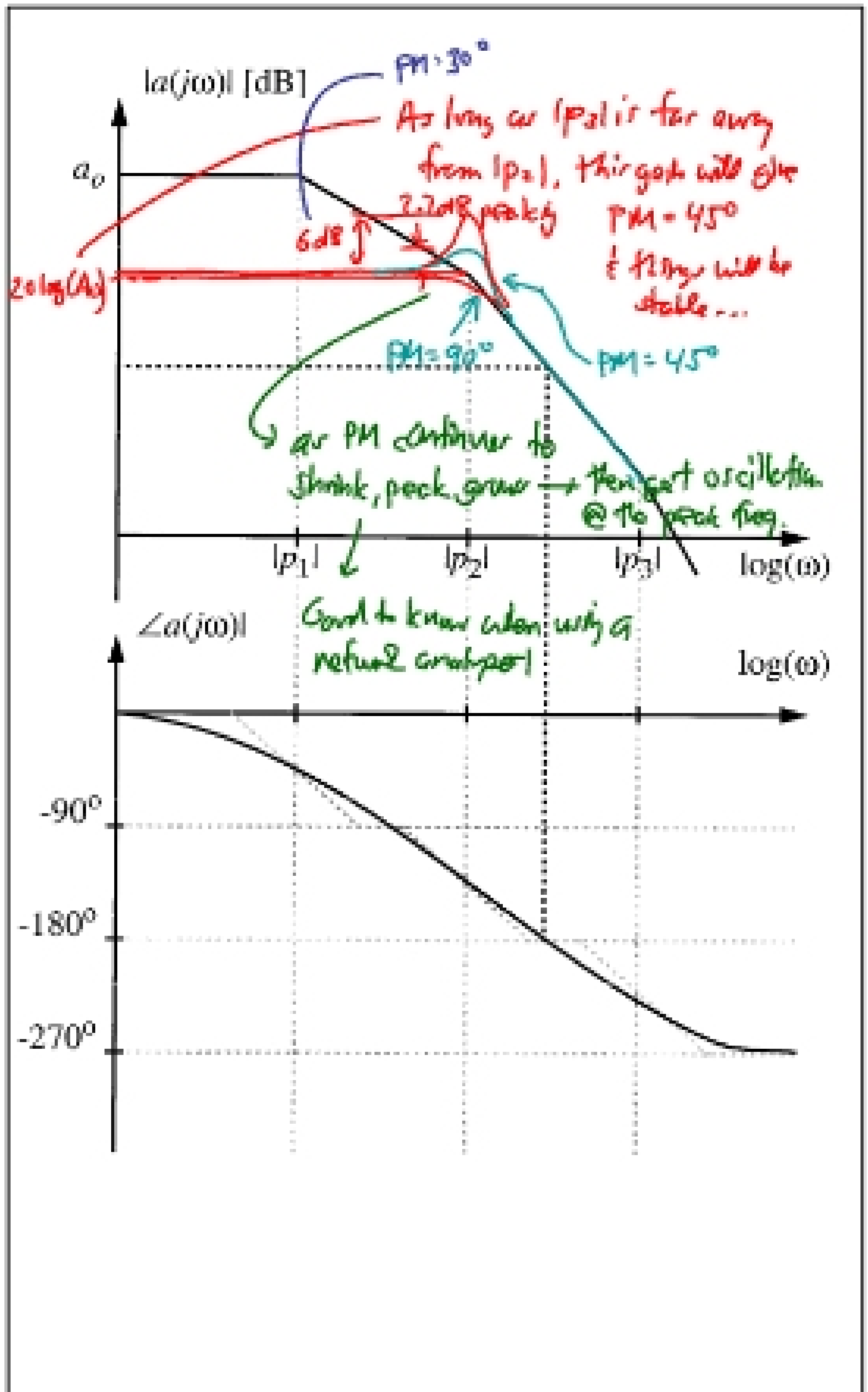
$\boxed{\text{Phase Margin} \geq 45^\circ}$

Design Criterion (for practical design)

Definition.

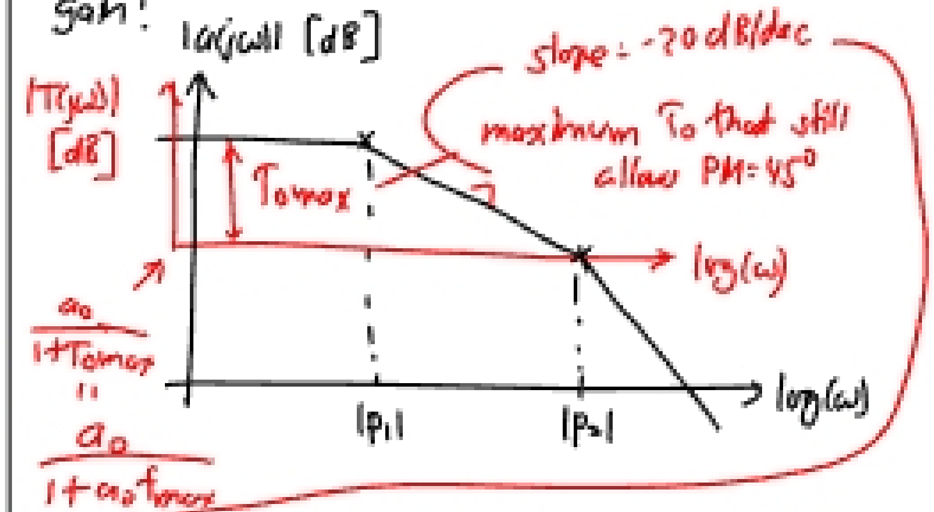
Gain Margin ≡ $|T(j\omega)|$ in dB @ freq. where $\angle T(j\omega) = -180^\circ$

For stability: $\boxed{\text{Gain Margin} < 0\text{dB}}$



Compensation of Op Amps

To compensate, need the distance between p_1 & p_2 to be large enough to encompass the largest desired loop gain!



$$20(\log|p_2| - \log|p_1|) = 20\log(T_{omax})$$

$$\boxed{\frac{|p_2|}{|p_1|} = T_{omax} \rightarrow |p_2| = |p_1| T_{omax}}$$

largest desired (expected) loop gain

provided $|p_3| \gg |p_2|$

Need for stability w/ PM=45° @ all desired closed loop gains

Two Ways to Compensate:

1. Narrowbanding
2. Pole-splitting

Basically, there is a minimum separation between p_1 & p_2 that insures stability.