ECEN474/704: (Analog) VLSI Circuit Design
Spring 2018

Lecture 14: Feedback & Stability

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Announcements

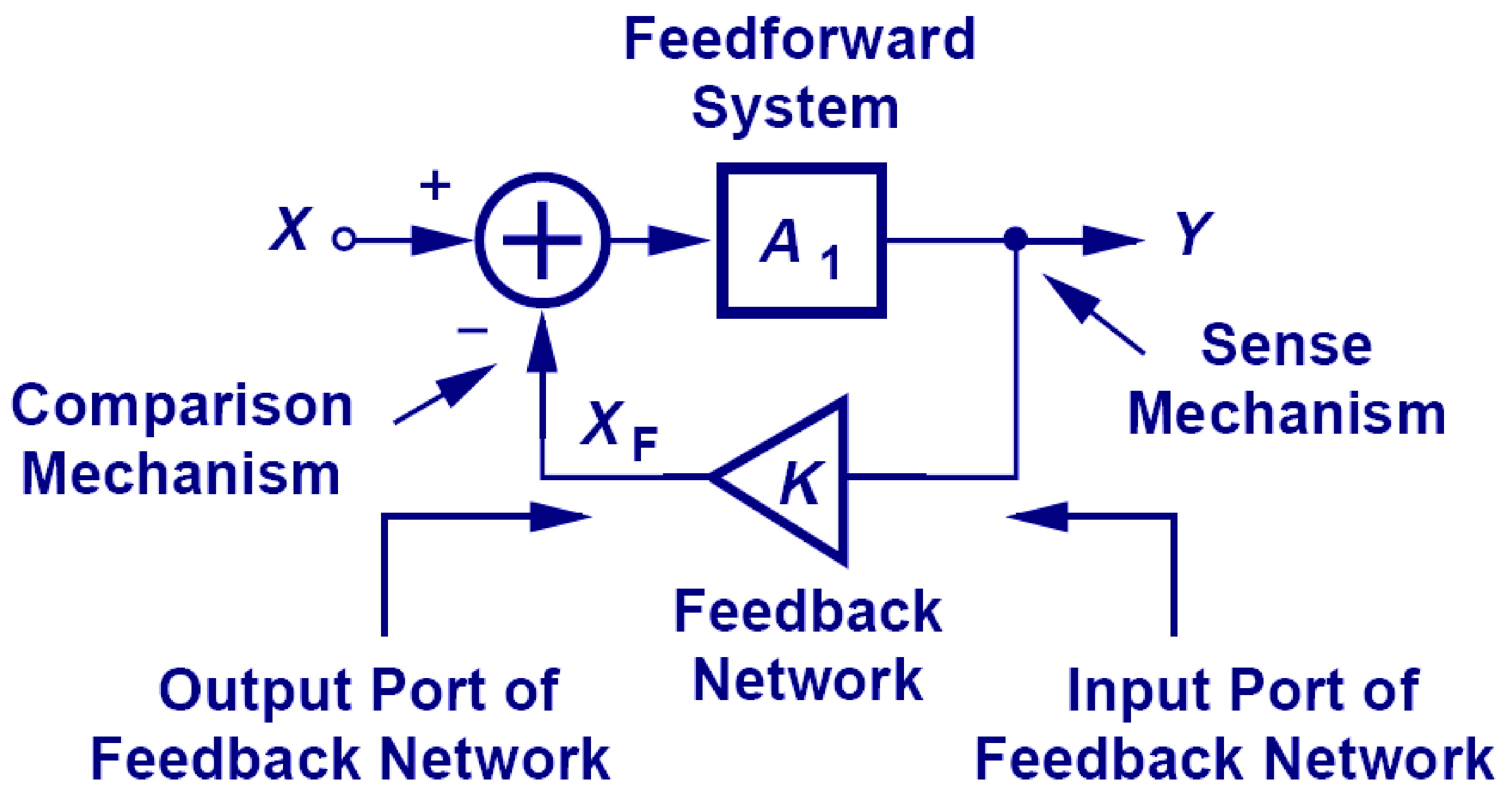
- Exam2 is on Apr. 10
  - 11:10-12:35PM (10 extra minutes)
  - Closed book w/ one standard note sheet
  - 8.5”x11” front & back
  - Bring your calculator
  - Covers material through lecture 11
  - Previous years’ Exam 2s are posted on the website for reference
- Project description is posted on website
  - Preliminary Report (HW4) due on Apr. 17

Announcements & Agenda

- Feedback in Opamp Circuits

- Stability Considerations
  - Nyquist Criteria
  - Phase & Gain Margin

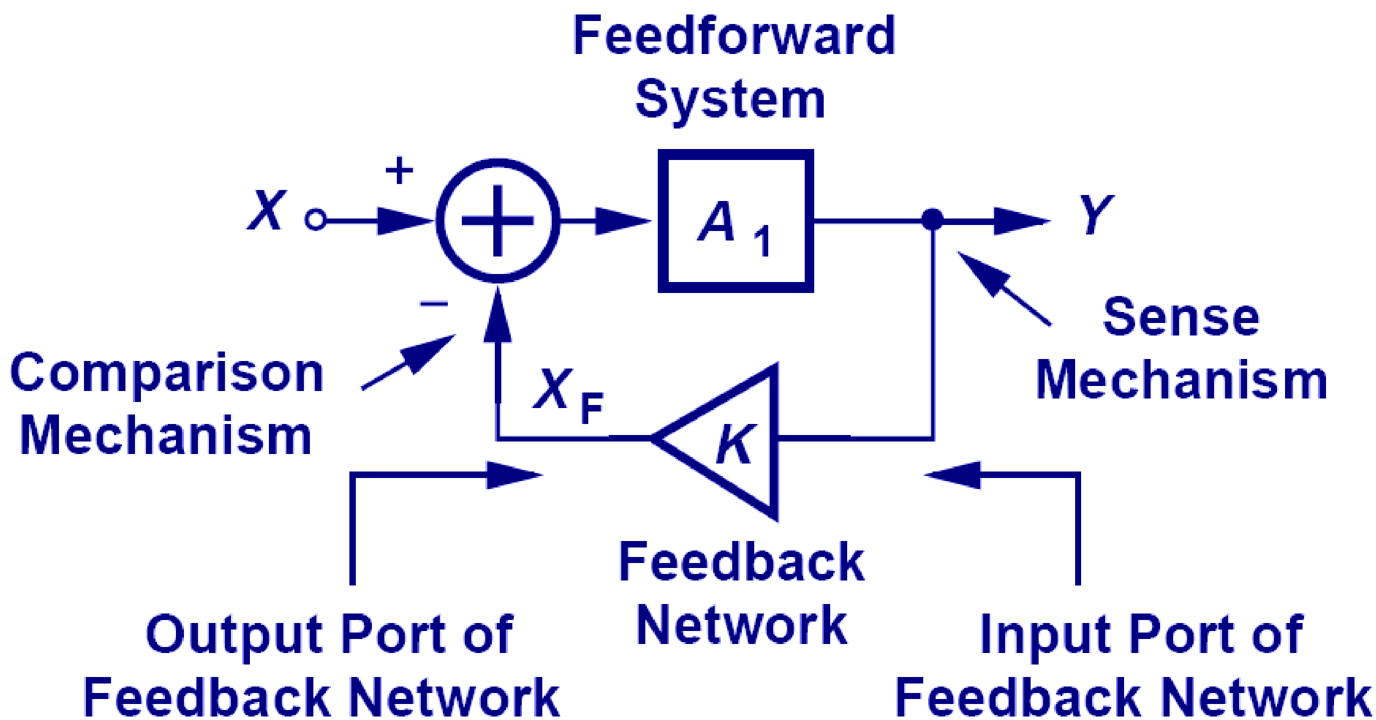
Negative Feedback System



$$\text{Feedback Factor } K = \frac{X_F}{Y}$$

- **A negative feedback system consists of four components: 1) feedforward system, 2) sense mechanism, 3) feedback network, and 4) comparison mechanism.**

Close-loop Transfer Function

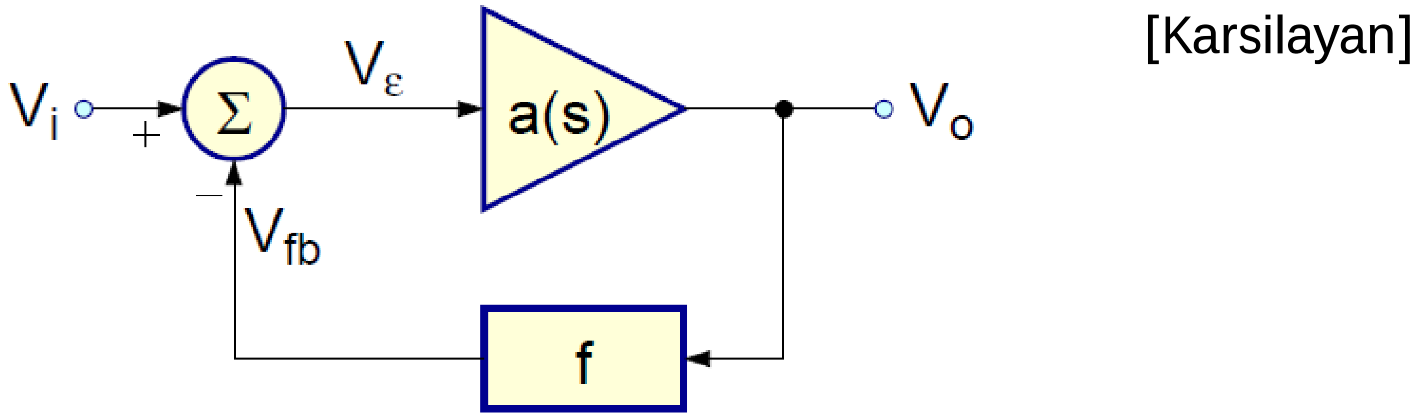


$$Y = (X - X_F)A_1 = (X - YK)A_1$$
$$Y(1 + KA_1) = XA_1$$

Closed-Loop Gain

$$\frac{Y}{X} = \frac{A_1}{1 + KA_1}$$

Feedback Configuration



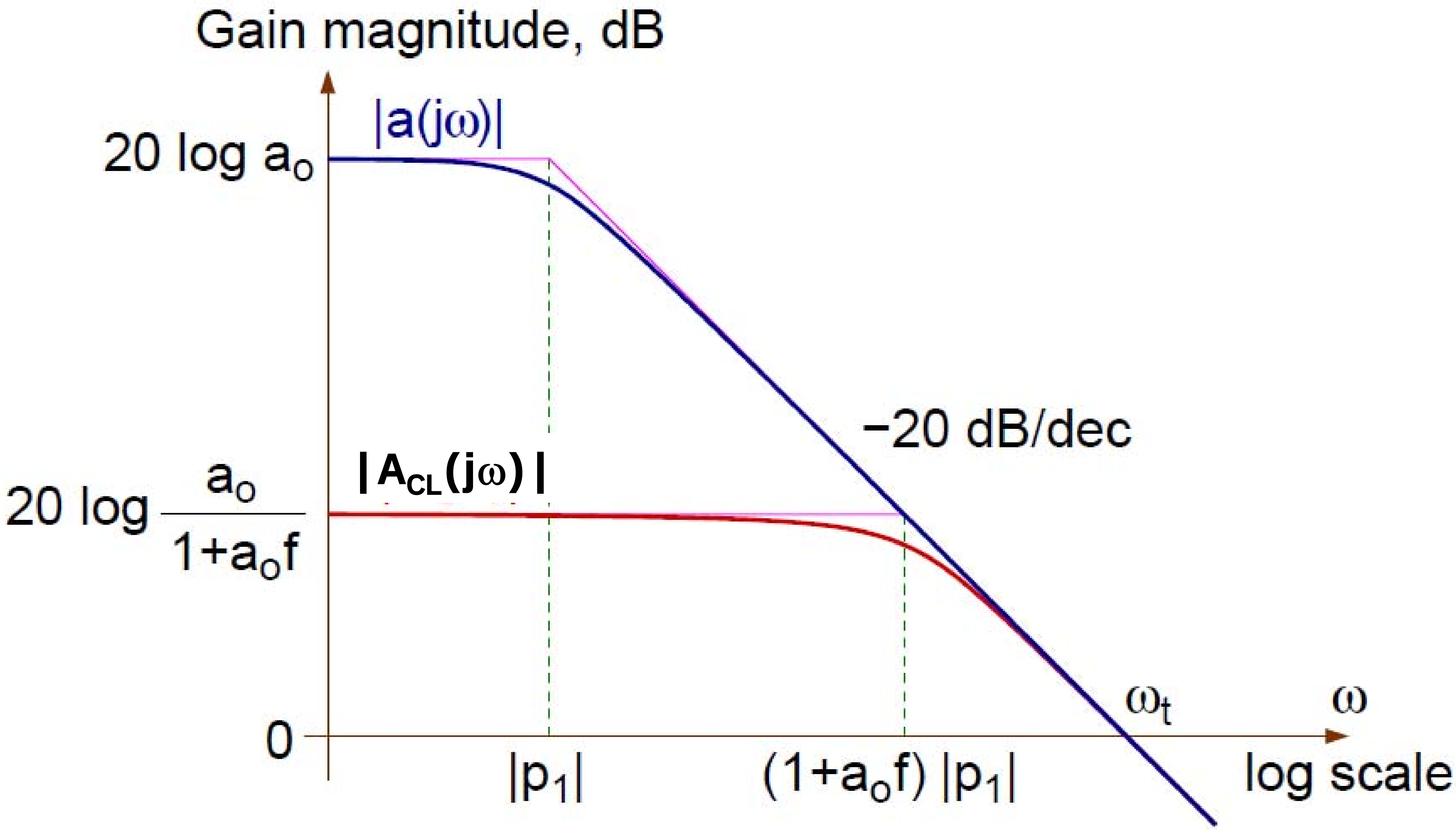
Here f = feedback factor (K in previous slides)

$$a(s) = \frac{V_o}{V_\varepsilon}(s) = \frac{a_o}{1 - \frac{s}{p_1}}$$

$$A_{CL}(s) = \frac{V_o}{V_i}(s) = \frac{a(s)}{1 + a(s)f} = \frac{\frac{a_o}{1 + a_o f}}{1 - \frac{s}{(1 + a_o f)p_1}}$$

Gain-Bandwidth

[Karsilayan]



Instability and the Nyquist Criterion

[Karsilayan]

Transfer function of a 3-pole amplifier:

$$\mathbf{a(s)} = \frac{\mathbf{a_o}}{\left(1 - \frac{s}{p_1}\right)\left(1 - \frac{s}{p_2}\right)\left(1 - \frac{s}{p_3}\right)}$$

Nyquist criterion for stability of the amplifier:

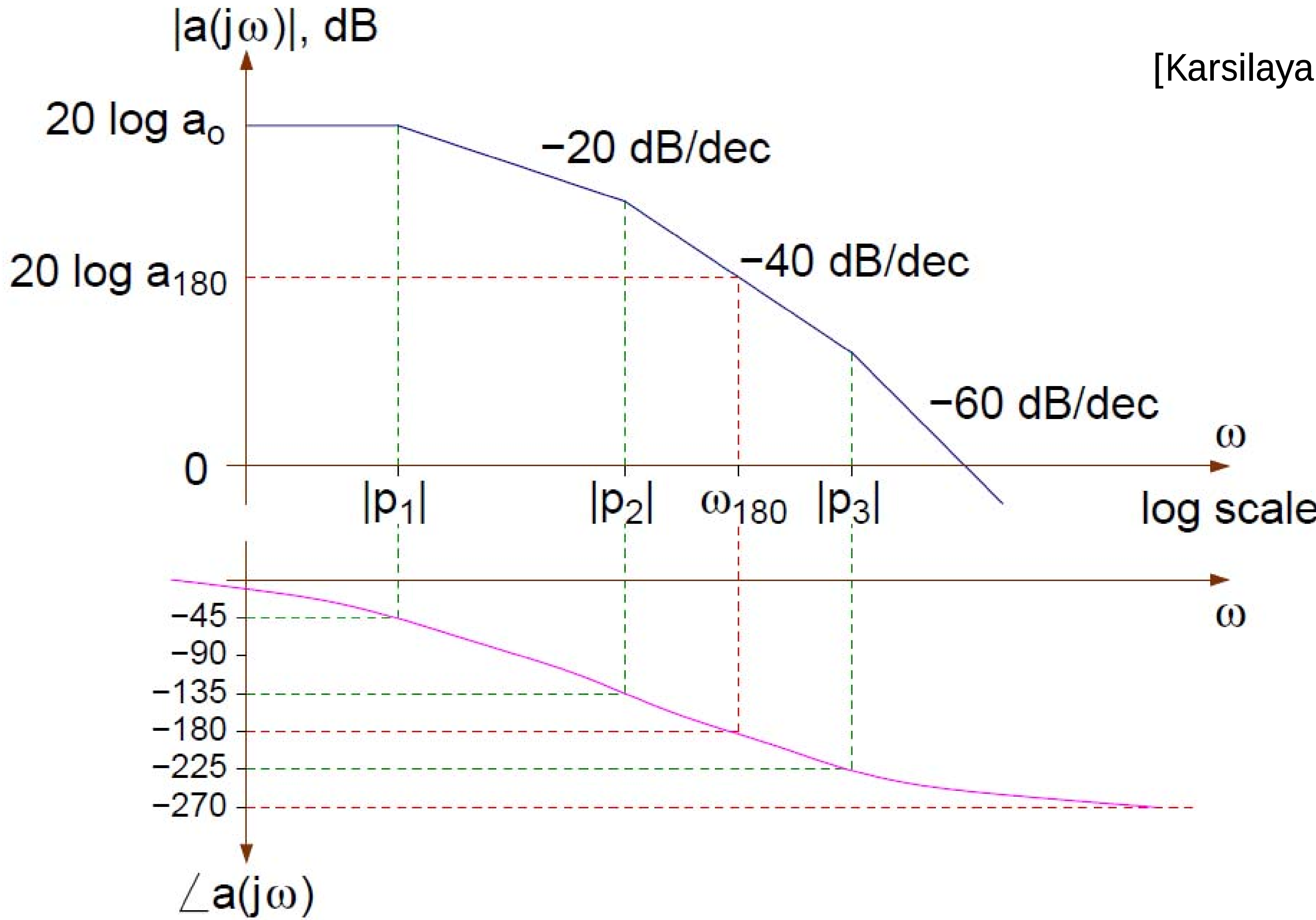
> *Consider a feedback amplifier with a stable* $\mathbf{T(s)}$. *If the Nyquist plot of* $\mathbf{T(j\omega)}$ *encircles the point (-1,0), the feedback amplifier is unstable.*

Recall $T(s)$ is the loop gain

$$T(s) = A(s)K(s) = a(s)f$$

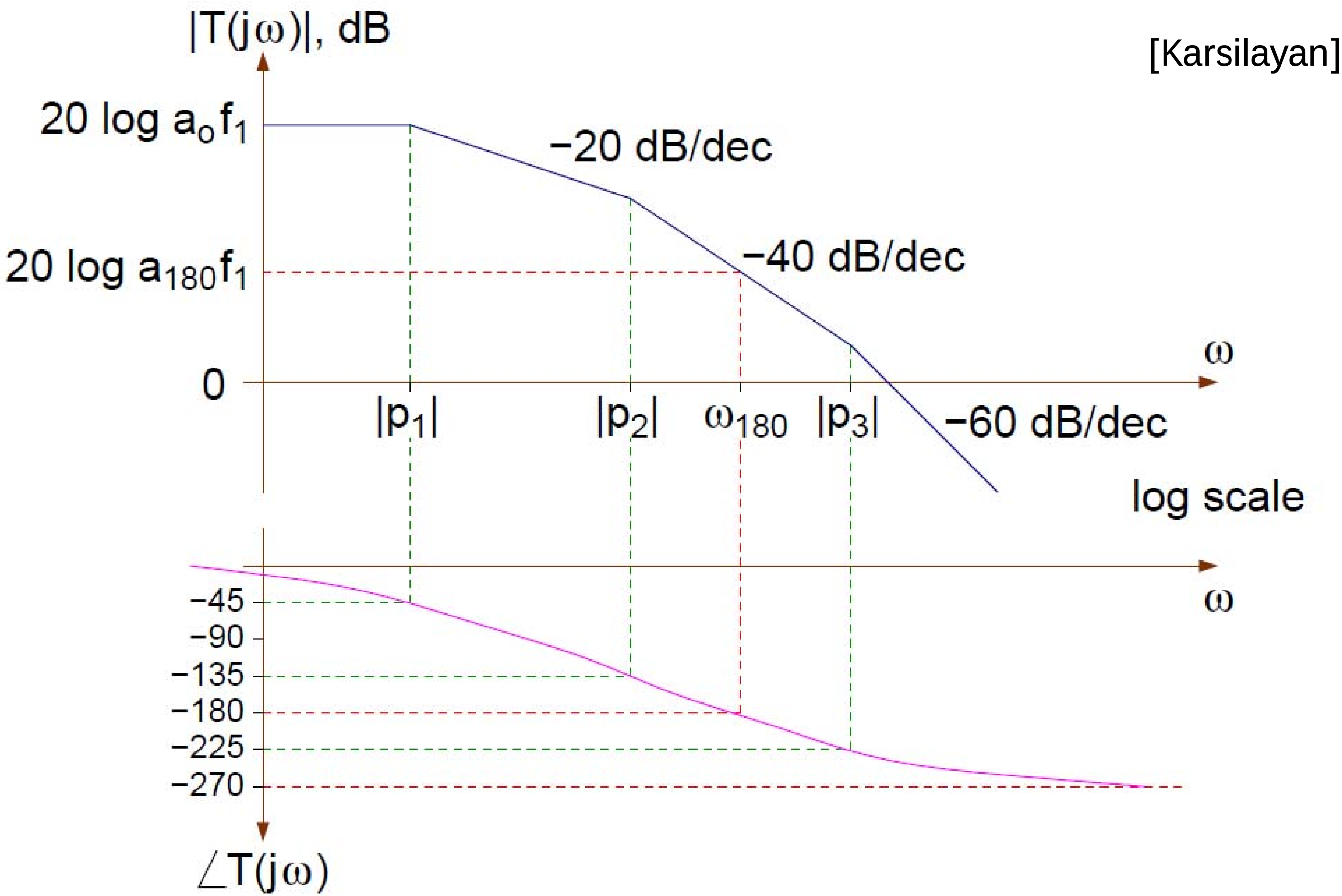
Magnitude & Phase

[Karsilayan]



Magnitude & Phase

$T(s) = a(s)f_1$

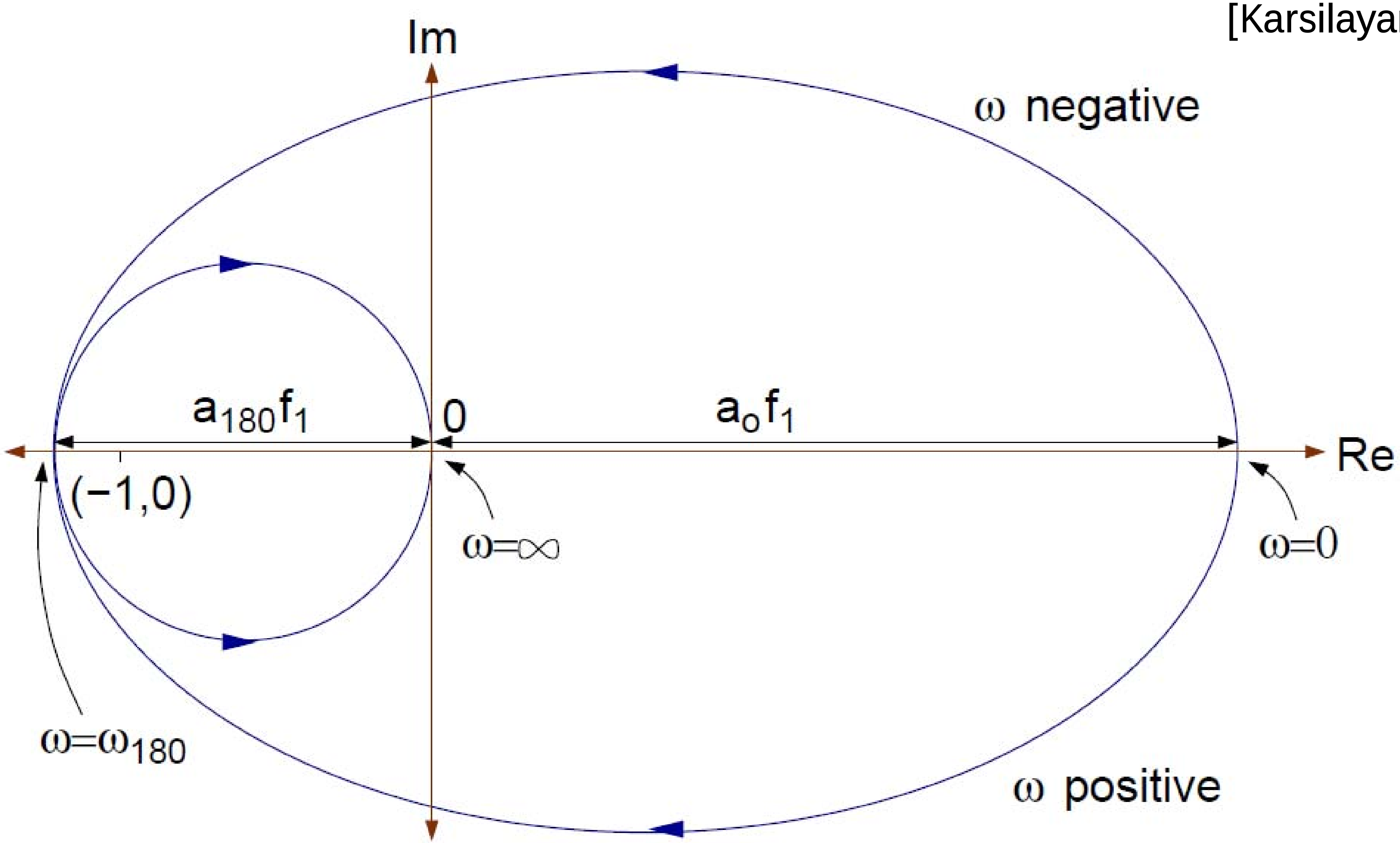


Nyquist Plot

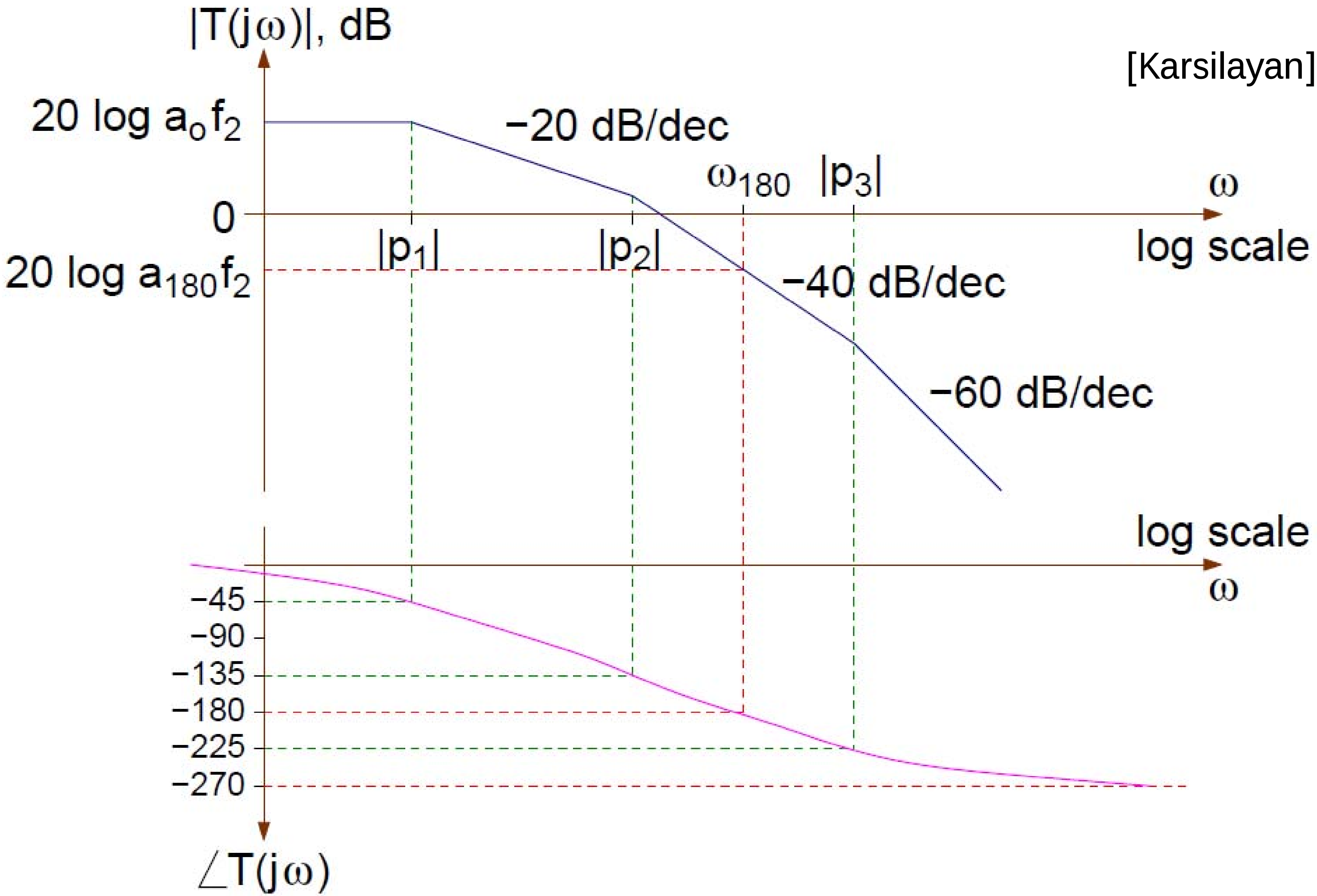
$T(s) = a(s)f_1$

Frequency Sweep of Loop Gain, T(s)

[Karsilayan]



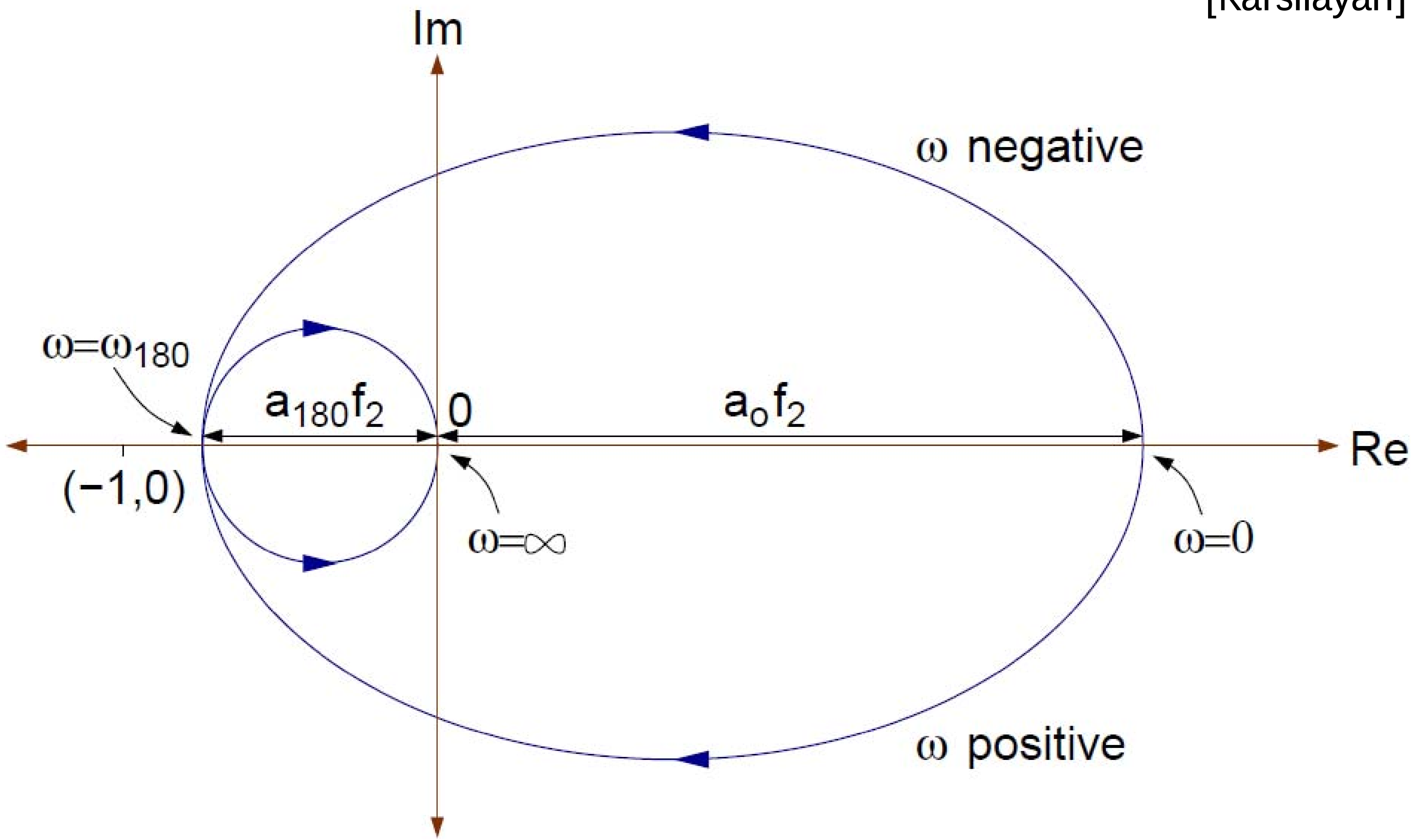
Magnitude & Phase $T(s) = a(s)f_2$



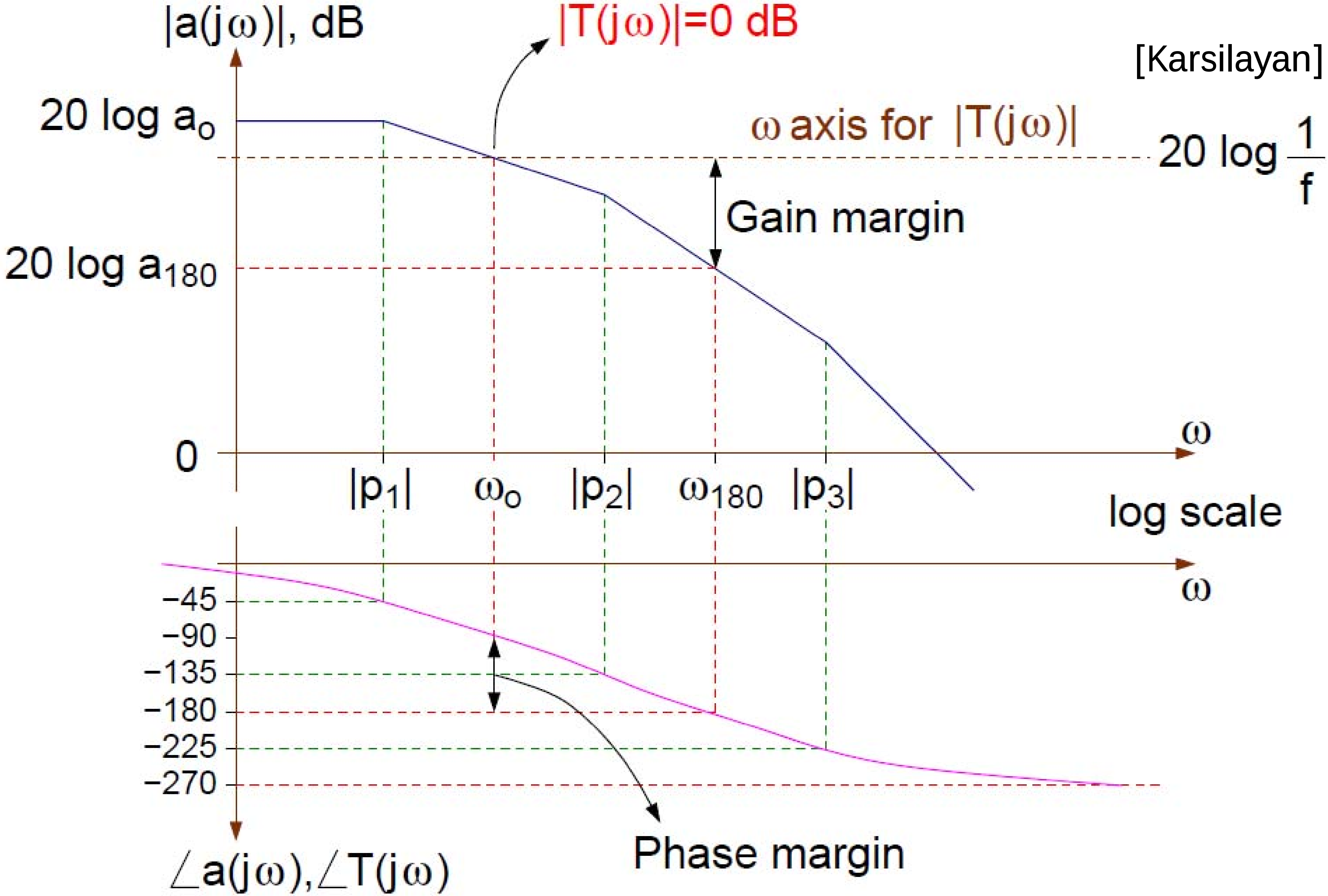
Nyquist Plot

$T(s) = a(s)f_2$

[Karsilayan]



Gain & Phase Margin



Stability Criteria

Nyquist:

[Karsilayan]

$$|T(j\omega_{180})| = a_{180}f < 1 \quad \Rightarrow \quad \text{Stable}$$

Gain Margin (**GM**):

$$GM = 20\log\frac{1}{|T(j\omega_{180})|} = -20\log|T(j\omega_{180})|$$

$$GM > 0 \quad \Rightarrow \quad \text{Stable}$$

Phase Margin (**PM**):

$$PM = 180^\circ + \angle T(j\omega_o)$$

$$PM > 0 \quad \Rightarrow \quad \text{Stable}$$

Phase Margin

[Karsilayan]

$$|T(j\omega_o)| = 1 \;\Rightarrow\; |a(j\omega_o)|f = 1 \;\Rightarrow\; |a(j\omega_o)| = \frac{1}{f}$$

$$PM = 45^\circ \;\Rightarrow\; \angle T(j\omega_o) = -135^\circ\,,\; A_{CL}(j\omega_o) = \frac{a(j\omega_o)}{1 + T(j\omega_o)}$$

$$A_{CL}(j\omega_o) = \frac{a(j\omega_o)}{1 + e^{-j135^\circ}} = \frac{a(j\omega_o)}{1 - 0.7 - 0.7j}$$

$$|A_{CL}(j\omega_o)| = \frac{|a(j\omega_o)|}{|0.3 - 0.7j|} = \frac{1}{0.76f} = \frac{1.3}{f}$$

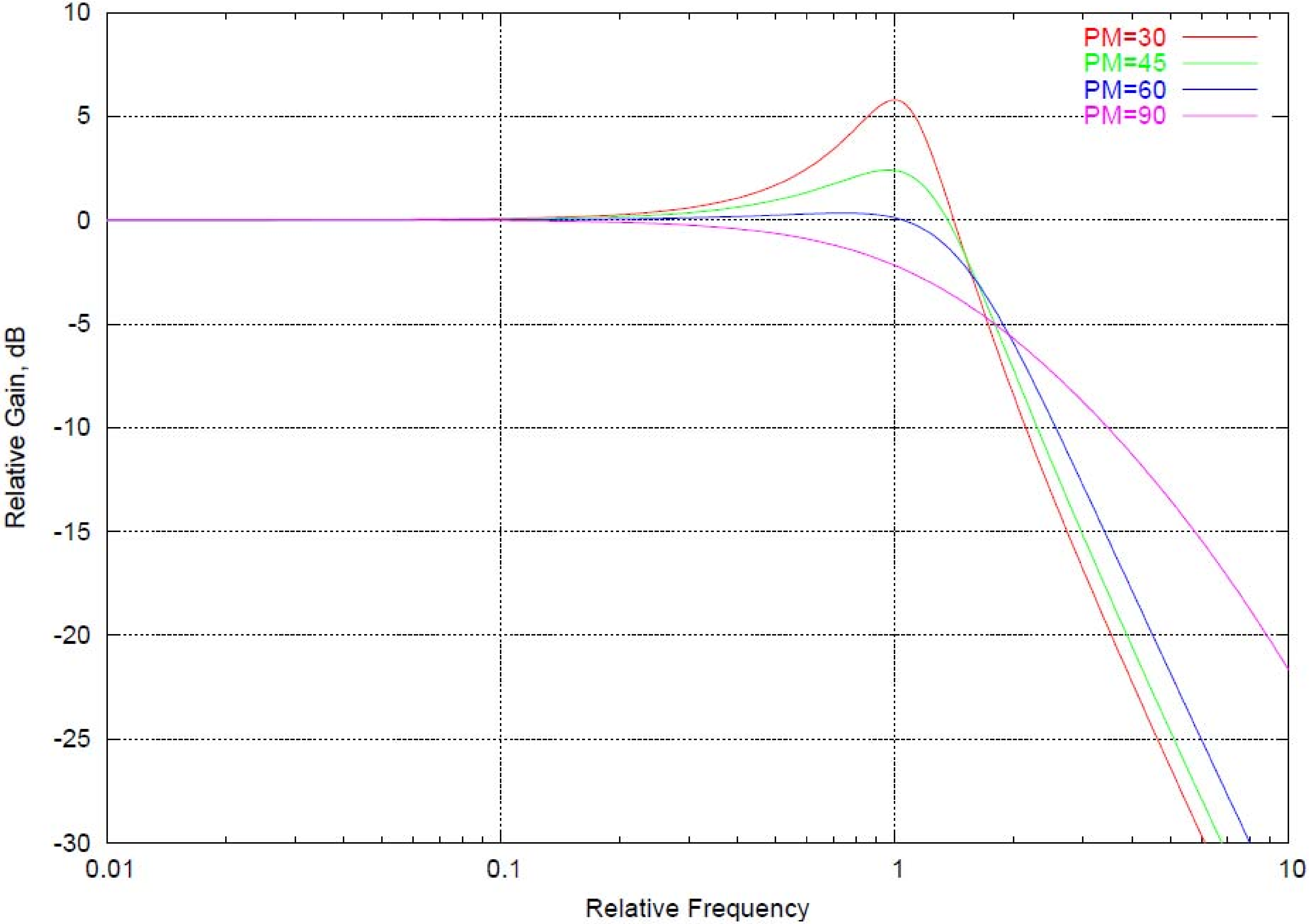
$$PM = 30^\circ \;\Rightarrow\; \angle T(j\omega_o) = -150^\circ\,,\; |A_{CL}(j\omega_o)| = 1.92/f$$

$$PM = 60^\circ \;\Rightarrow\; \angle T(j\omega_o) = -120^\circ\,,\; |A_{CL}(j\omega_o)| = 1/f$$

$$PM = 90^\circ \;\Rightarrow\; \angle T(j\omega_o) = -90^\circ\,,\; |A_{CL}(j\omega_o)| = 0.7/f$$

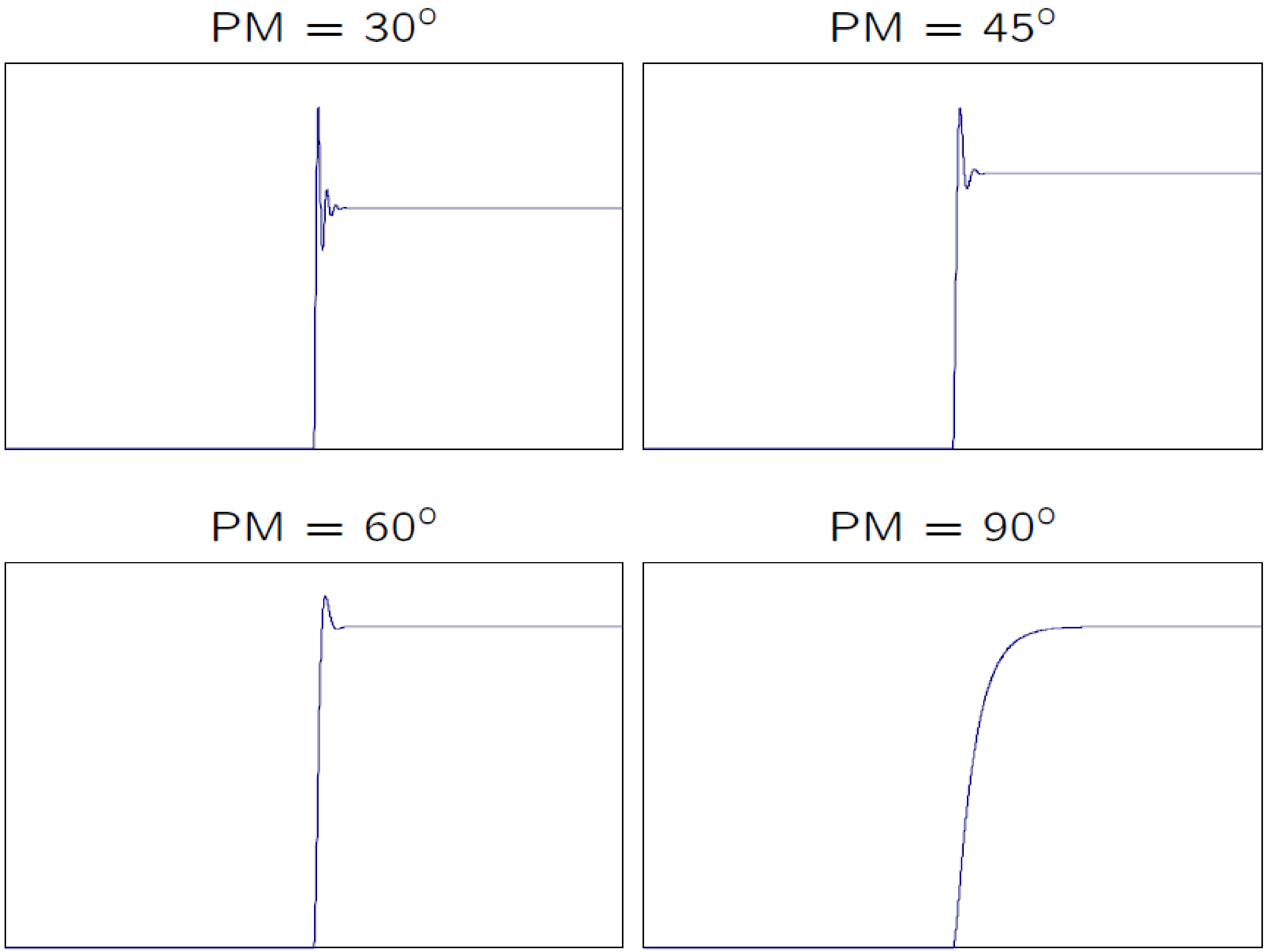
Closed-Loop Frequency Response

[Karsilayan]



Closed-Loop Step Response

[Karsilayan]



Next Time

- Common-Mode Feedback Techniques