Automatic Control (2)

By

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Lecture (4)

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Course Title: Automatic Control (2)

Course Code: EEC 415

Prerequisites: EEC224 Signals and Systems

Study Hours: 3 Cr. hrs.

= [2 Lect. + 0 Tut + 3 Lab]

Assessment:

Final Exam: 40%.

Midterm: 30%.

Quizzes: 10%.

Home assignments and Reports: 10%.

MATLAB Mini Project: 10%.

Textbook:

1- K. Ogata, Modern Control Engineering, Pearson, 5th. Ed., 2009.
2- Nise, N. S. "Control System Engineering", 7th edition, John Wiley & Sons Ltd., UK, 2016.
3- F. Golnaraghi and B. C. Kuo, "Automatic control Systems", 10th ed., John Wiley & Sons, Inc. 2017.
4- Andrea Bacciotti, "Stability and Control of Linear Systems" Volume 185, Springer, 2019.

Course Description

- Compensation in control systems, lead, lag, and lead-lag phase compensation in frequency domain,
- State model of linear systems using physical variables, state space representation using phase variables, state space representation, using canonical variables, properties of transition matrix and solution of state equation,
- Poles, zeros, eigen values and stability in multivariable system,
- Introduction to nonlinear control systems, describing function method, nature and stability of limit cycle.

Analysis & Design of Control Systems using Frequency Response

Controller

Input: $A\sin\omega t$

Output: $\hat{A}\sin(\omega t+\phi)$

$\hat{A}/A$ is the normalized amplitude ratio (*AR*)

ϕ is the phase angle, response angle (*RA*)

AR and ϕ are functions of *ω*

Assume *G(s)* known and let

$$s = j\omega \qquad G(j\omega) = K_1 + K_2 j$$

$$|G| = AR = \sqrt{K_1^2 + K_2^2}$$

$$\phi = \angle G = \arctan\frac{K_2}{K_1}$$

Ideal PID Controller.

$$G_c(s) = K_c\left(1 + \frac{1}{\tau_I s} + \tau_D s\right)$$

Series PID Controller. The simplest version of the series PID controller is

$$G_c(s) = K_c\left(\frac{\tau_I s + 1}{\tau_I s}\right)(\tau_D s + 1)$$

Series PID Controller with a Derivative Filter. The series controller with a derivative filter was described in Chapter 8

$$G_c(s) = K_c\left(\frac{\tau_I s + 1}{\tau_I s}\right)\left(\frac{\tau_D s + 1}{\alpha\tau_D s + 1}\right)$$

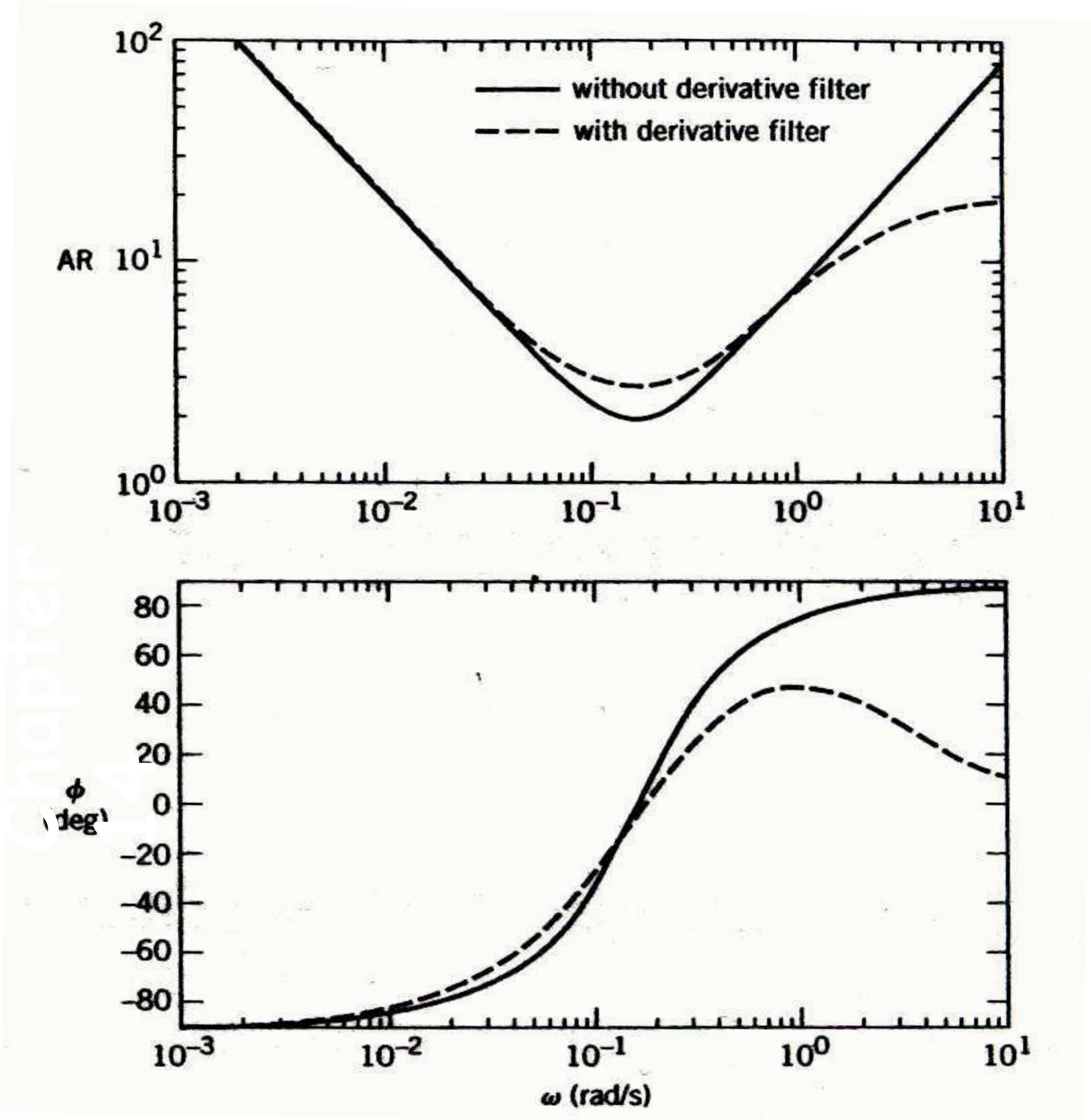


Figure Bode plots of ideal parallel PID controller and series PID controller with derivative filter (α = 1).

Ideal parallel:

$$G_c(s) = 2\left(1 + \frac{1}{10s} + 4s\right)$$

Series with Derivative Filter:

$$G_c(s) = 2\left(\frac{10s+1}{10s}\right)\left(\frac{4s+1}{0.4s+1}\right)$$

Advantages of FR Analysis for Controller Design:

1. Applicable to dynamic model of any order (including non-polynomials).
2. Designer can specify desired closed-loop response characteristics.
3. Information on stability and sensitivity/robustness is provided.

Disadvantage:

The approach tends to be iterative and hence time-consuming

-- interactive computer graphics desirable (MATLAB)

Bode Plot Overview

Technique for estimating a complicated transfer function (several poles and zeroes) quickly

$$H(\omega) = G_0(j\omega)^K \frac{(1 + j\omega\tau_{z1})(1 + j\omega\tau_{z2})\cdots(1 + j\omega\tau_{zn})}{(1 + j\omega\tau_{p2})(1 + j\omega\tau_{p2})\cdots(1 + j\omega\tau_{pm})}$$

Break frequencies :

$$\omega_i = \frac{1}{\tau_i}$$

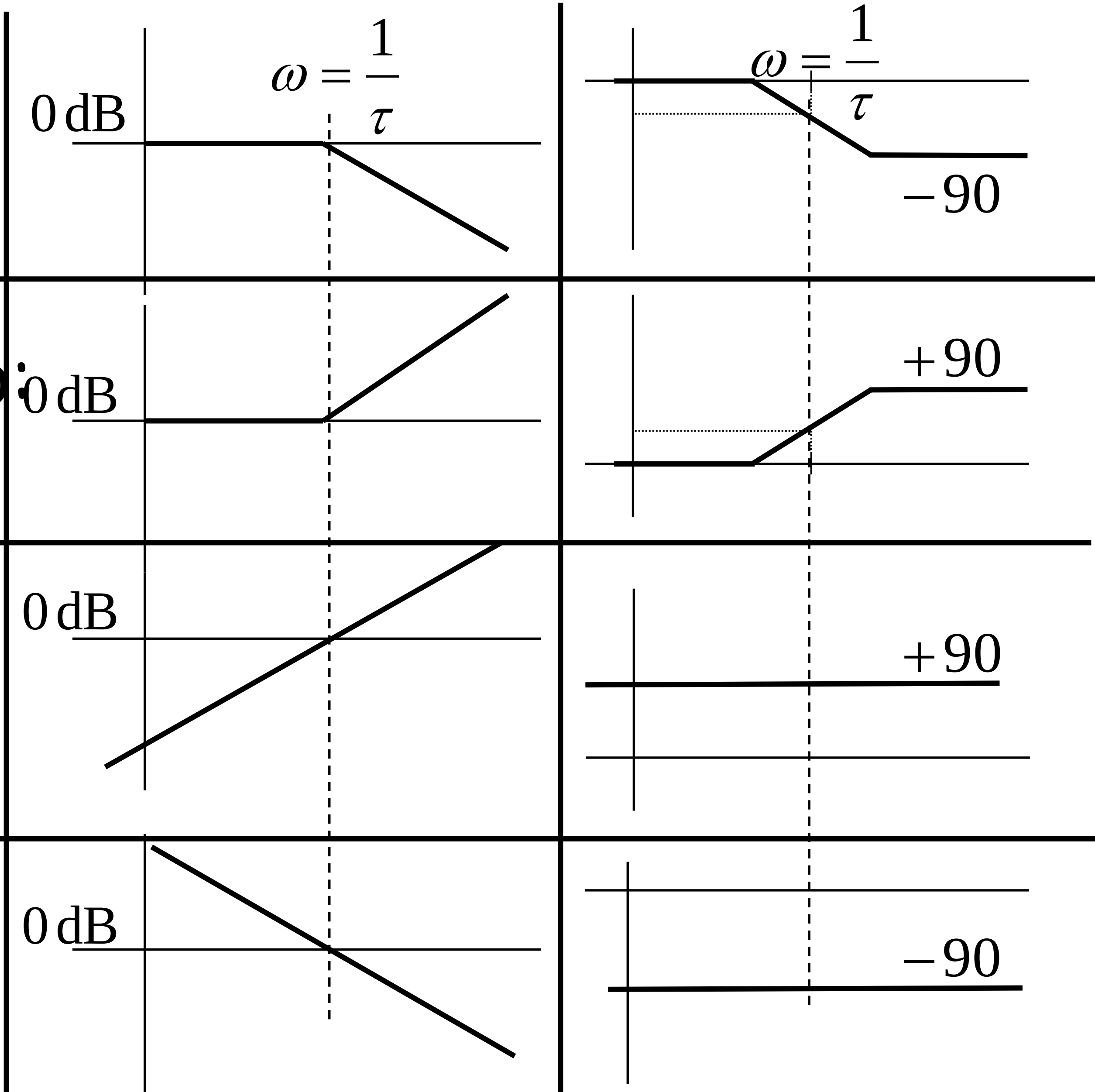
Summary of Individual Factors

Simple Pole: $\frac{1}{1+j\omega\tau}$

Simple Zero: $1+j\omega\tau$

DC Zero: $j\omega\tau$

DC Pole: $\frac{1}{j\omega\tau}$



Example

Consider the following transfer function

$$H(j\omega) = \frac{10^{-5} j\omega(1 + j\omega\tau_2)}{(1 + j\omega\tau_1)(1 + j\omega\tau_3)}$$

$\tau_1 = 100\text{ns}$

$\tau_2 = 10\text{ns}$

$\tau_3 = 100\text{ps}$

Break frequencies: invert time constants

$\omega_1 = 10\text{Mrad/s}$ $\omega_2 = 100\text{Mrad/s}$ $\omega_3 = 10\text{Grad/s}$

$$H(j\omega) = \frac{\frac{j\omega}{10^5}(1 + j\frac{\omega}{\omega_2})}{(1 + j\frac{\omega}{\omega_1})(1 + j\frac{\omega}{\omega_3})}$$

Breaking Down the Magnitude

Recall log of products is sum of logs

$$\left|H(j\omega)\right|_{\mathrm{dB}} = 20\log\left|\frac{\frac{j\omega}{10^5}(1+j\frac{\omega}{\omega_2})}{(1+j\frac{\omega}{\omega_1})(1+j\frac{\omega}{\omega_3})}\right|$$

$$= 20\log\left|\frac{j\omega}{10^5}\right| + 20\log\left|1+j\frac{\omega}{\omega_2}\right|$$

$$-20\log\left|1+j\frac{\omega}{\omega_1}\right| - 20\log\left|1+j\frac{\omega}{\omega_3}\right|$$

Let's plot each factor separately and add them graphically

Breaking Down the Phase

Since $\angle a \cdot b = \angle a + \angle b$

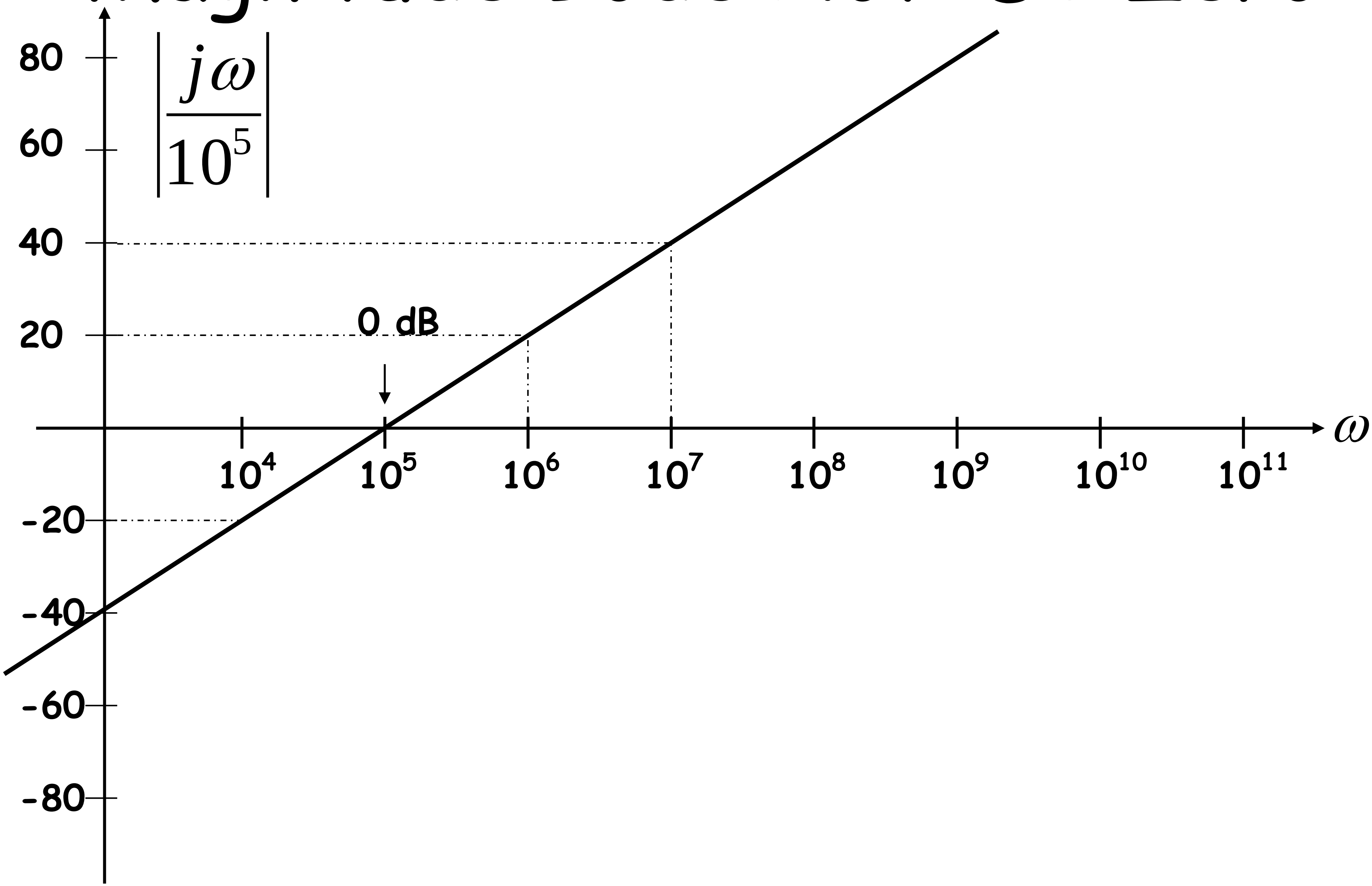
$$\angle H(j\omega) = \angle \frac{10^{-5}\, j\omega(1 + j\omega\tau_2)}{(1 + j\omega\tau_1)(1 + j\omega\tau_3)}$$

$$\angle H(j\omega) = \angle \frac{j\omega}{10^5} + \angle 1 + j\frac{\omega}{\omega_2}$$

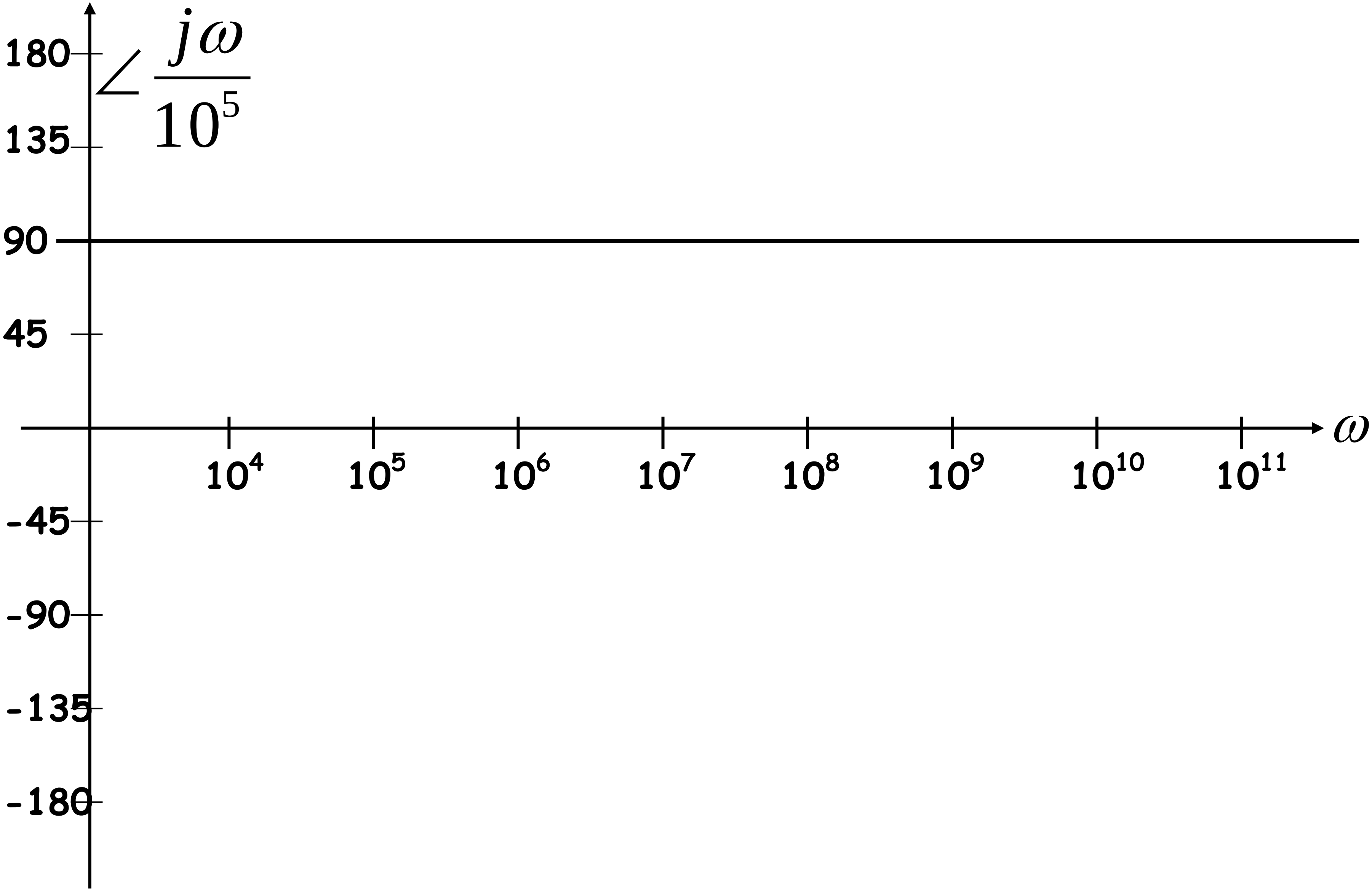
$$- \angle 1 + j\frac{\omega}{\omega_1} - \angle 1 + j\frac{\omega}{\omega_3}$$

Let's plot each factor separately and add them graphically

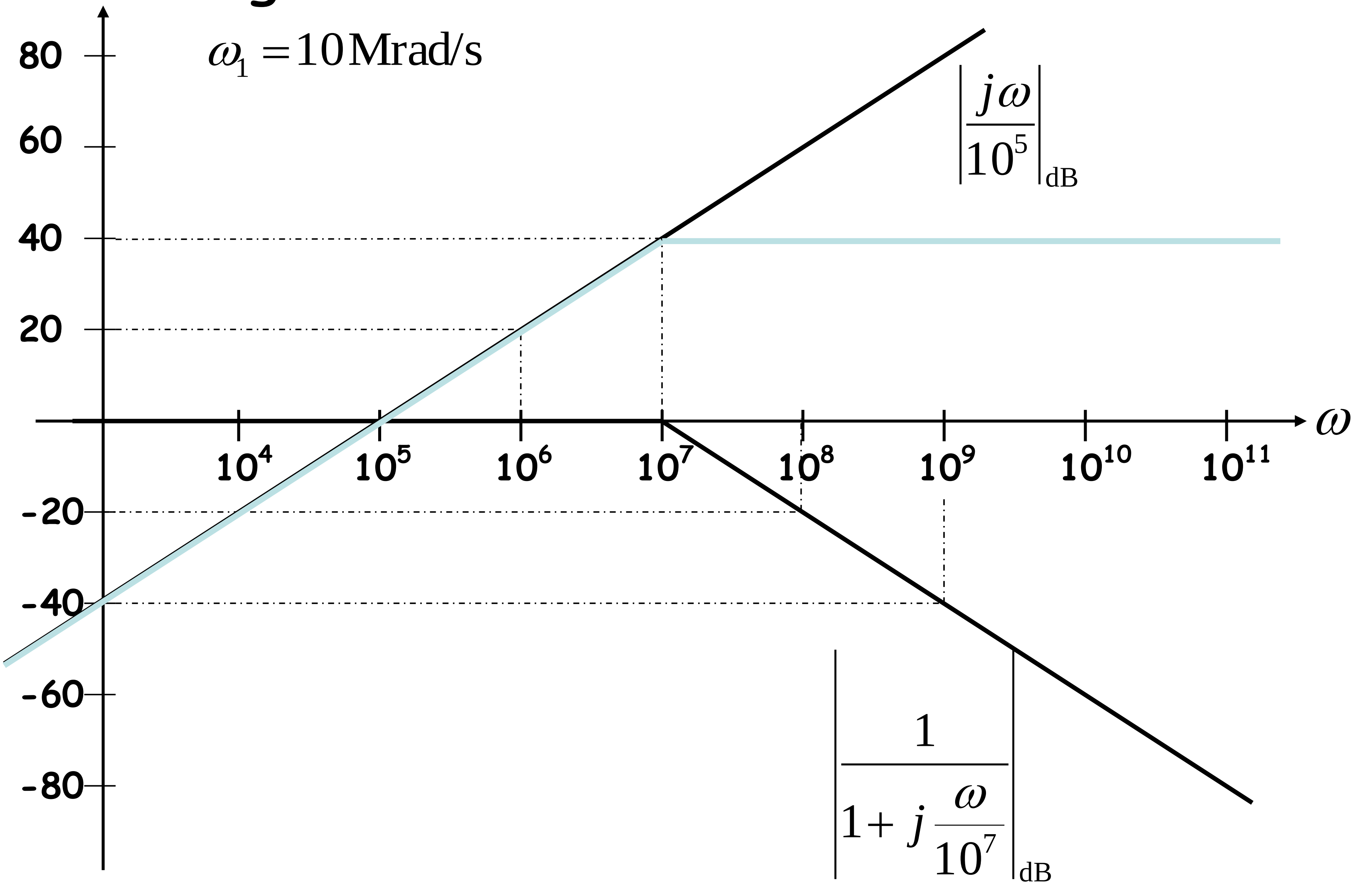
Magnitude Bode Plot: DC Zero



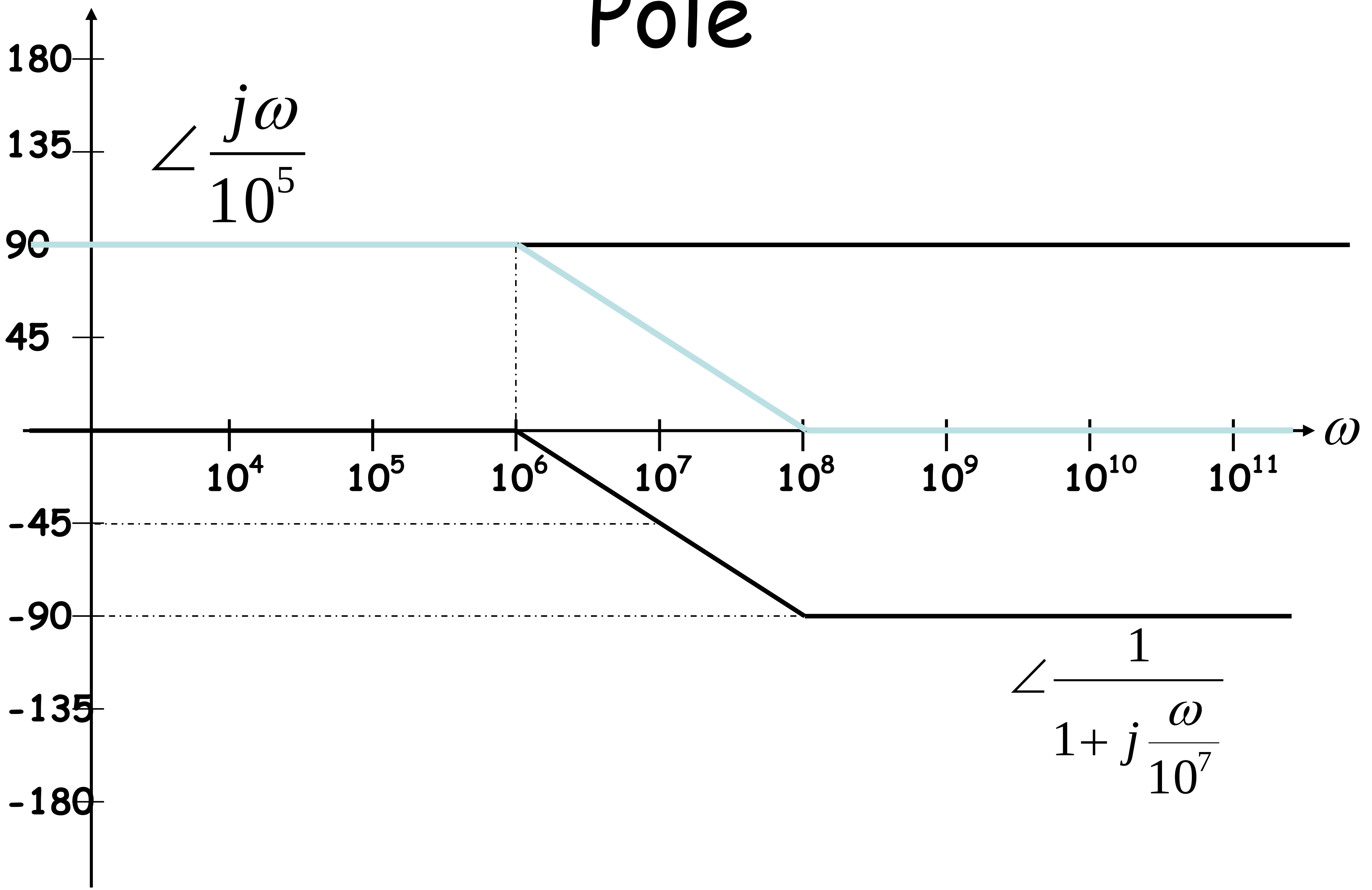
Phase Bode Plot: DC Zero



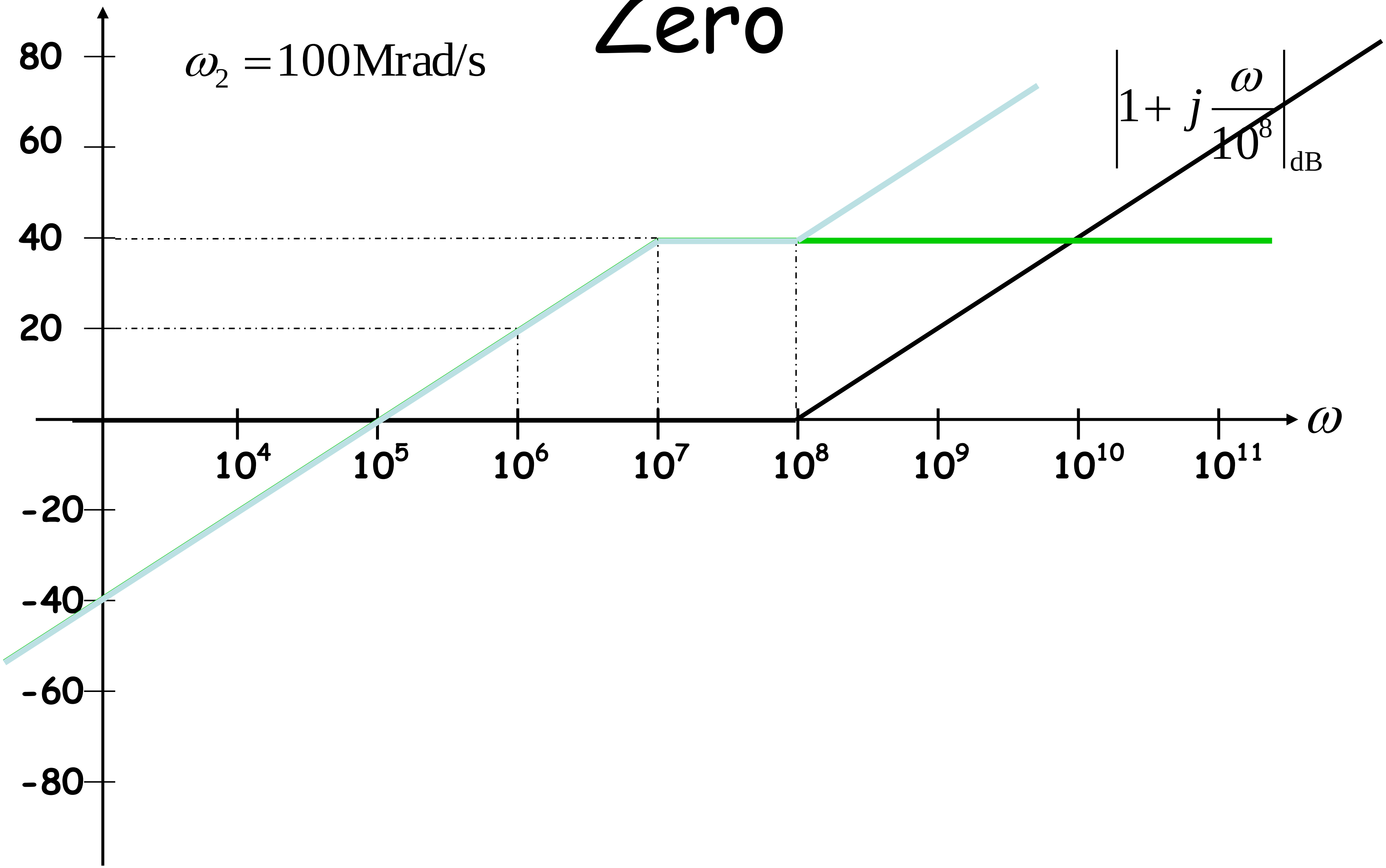
Magnitude Bode Plot: Add First Pole



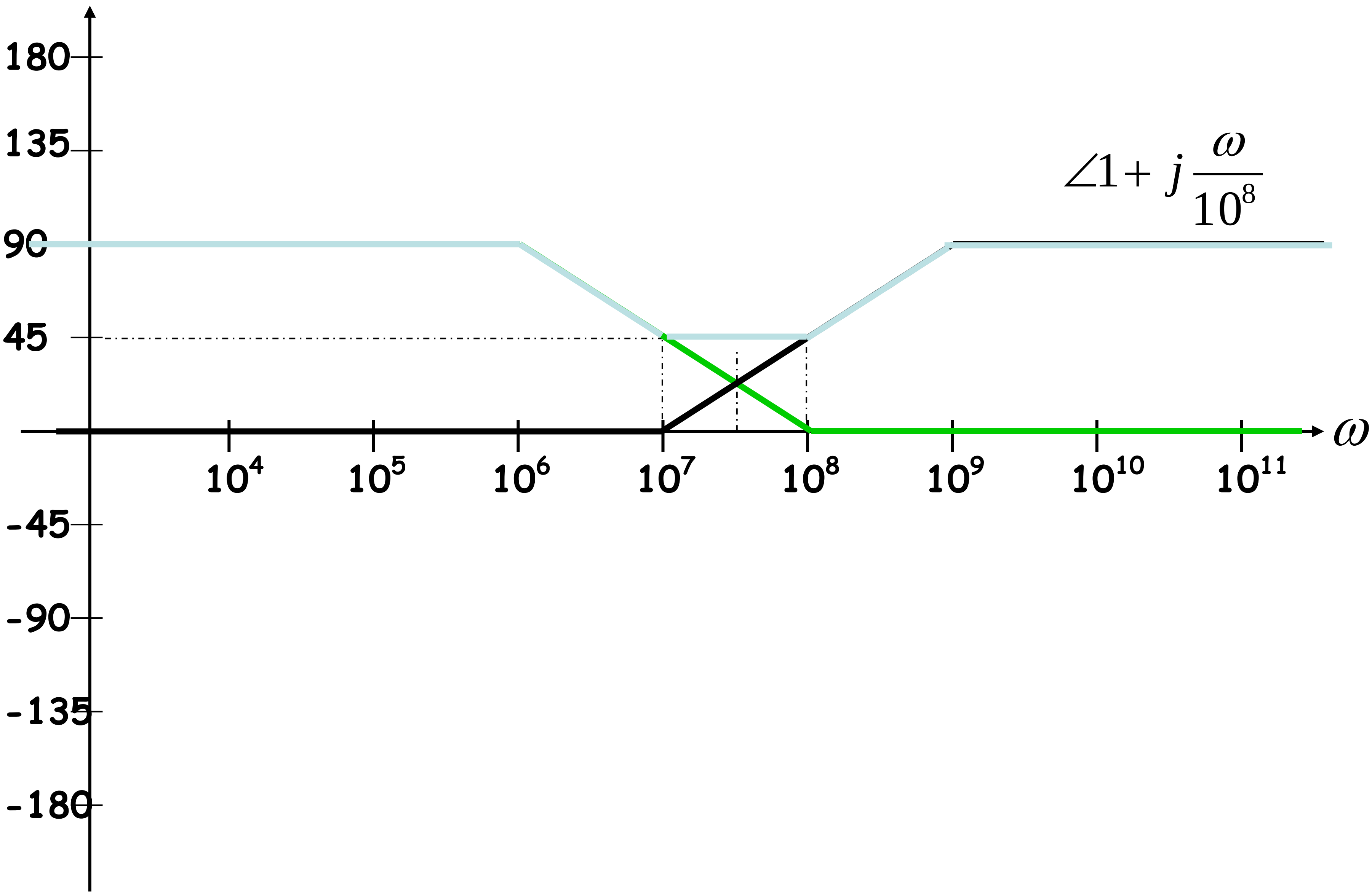
Phase Bode Plot: Add First Pole



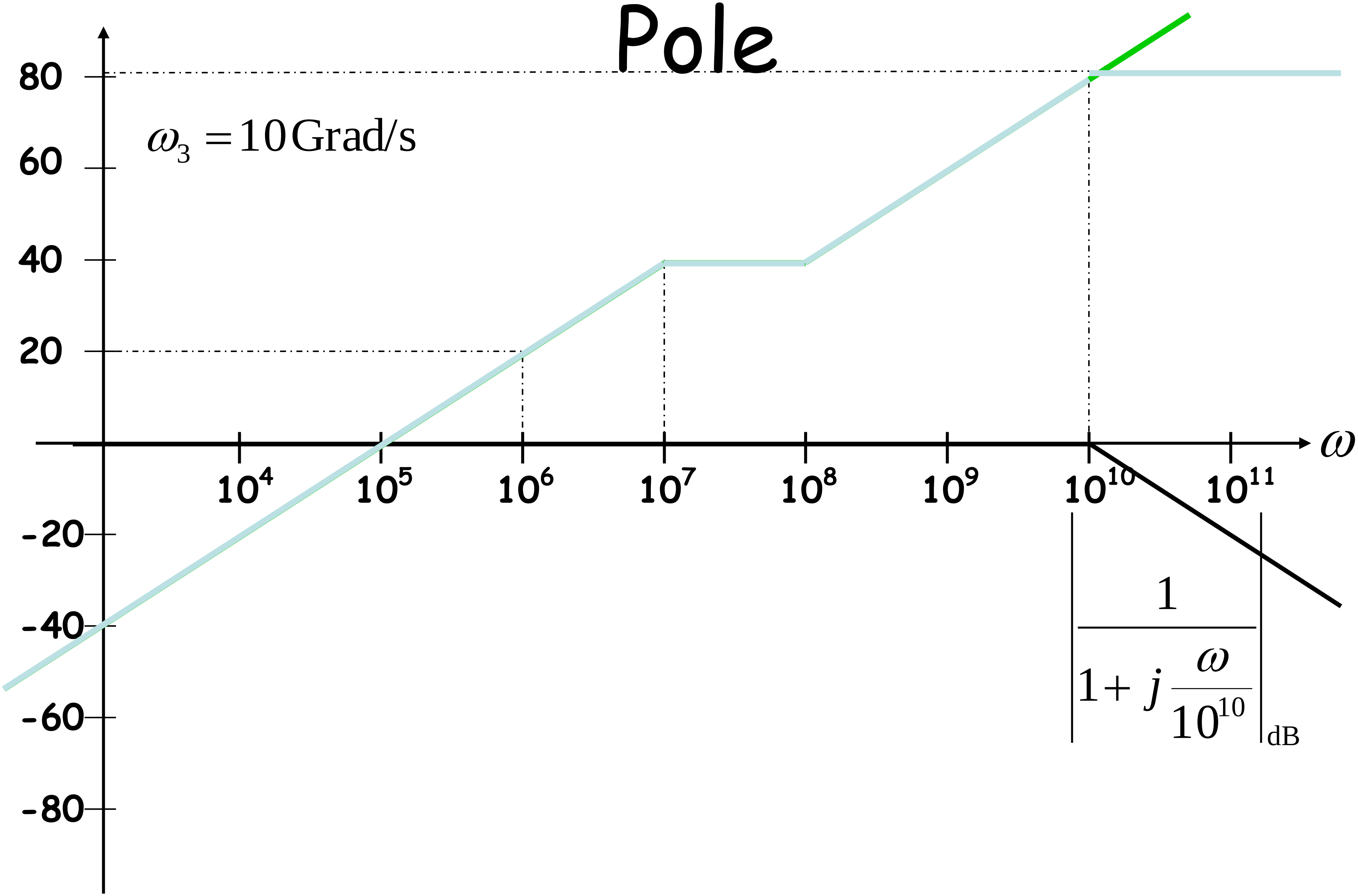
Magnitude Bode Plot: Add 2nd Zero



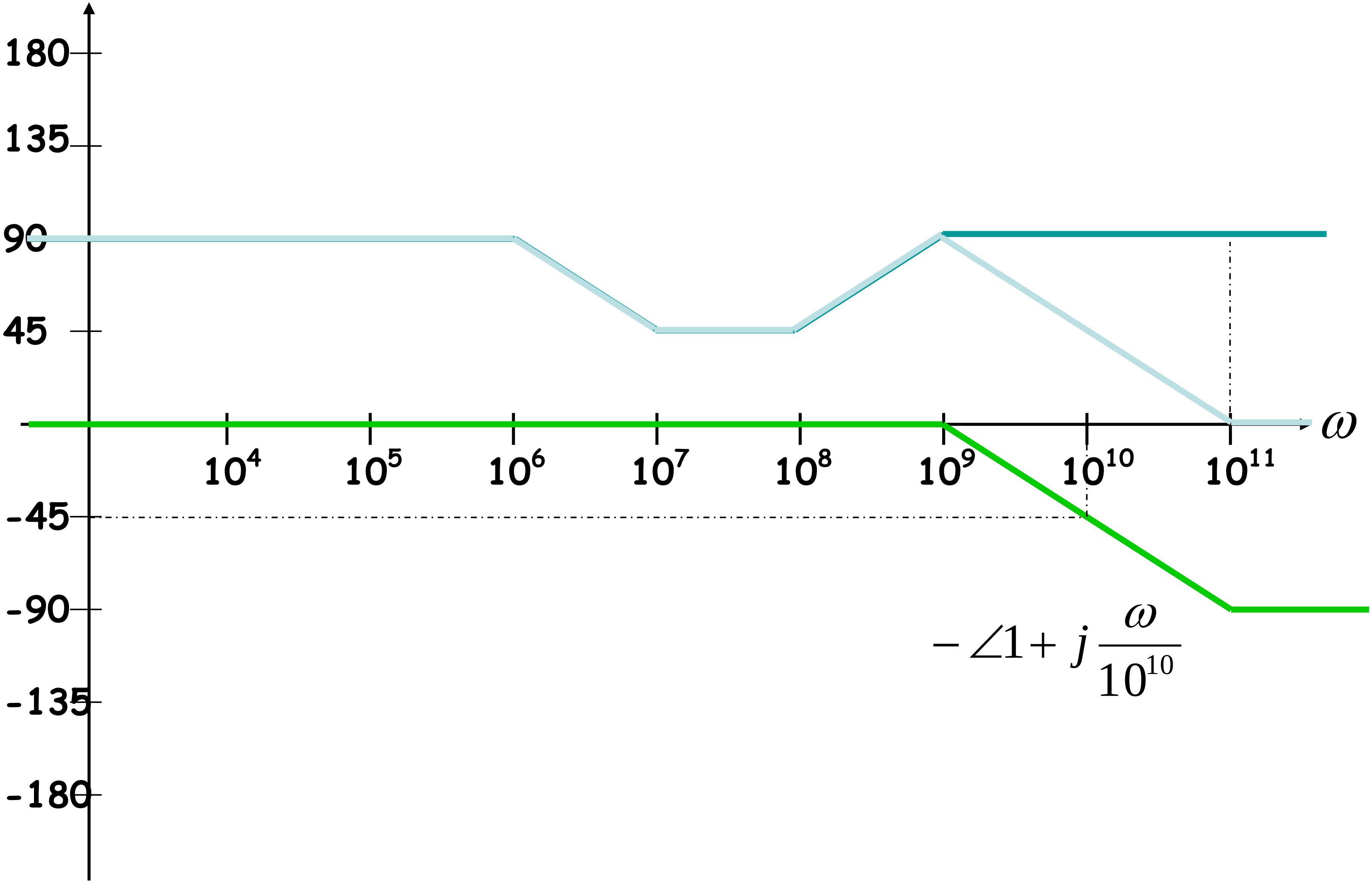
Phase Bode Plot: Add 2nd Zero



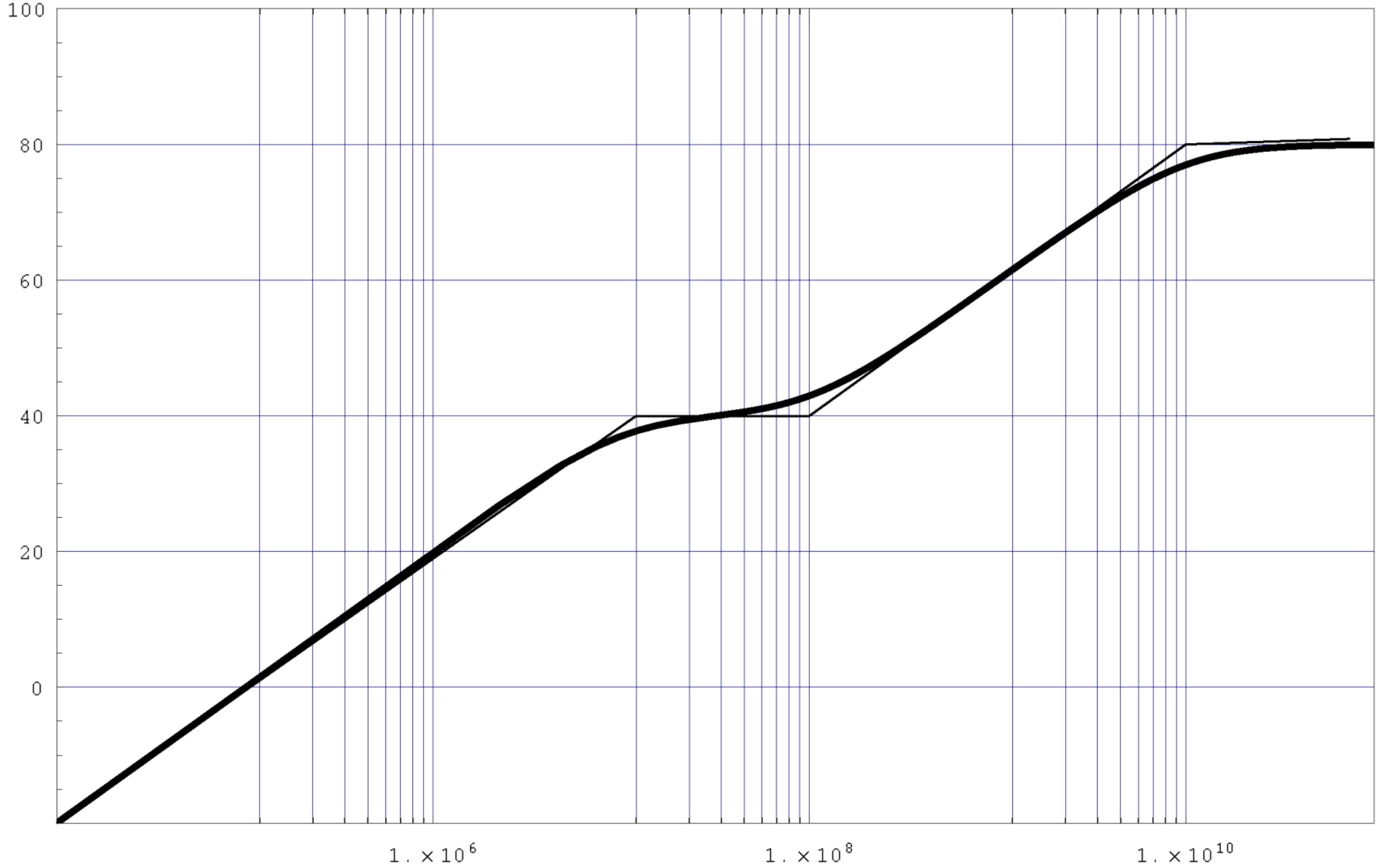
Magnitude Bode Plot: Add 2nd Pole



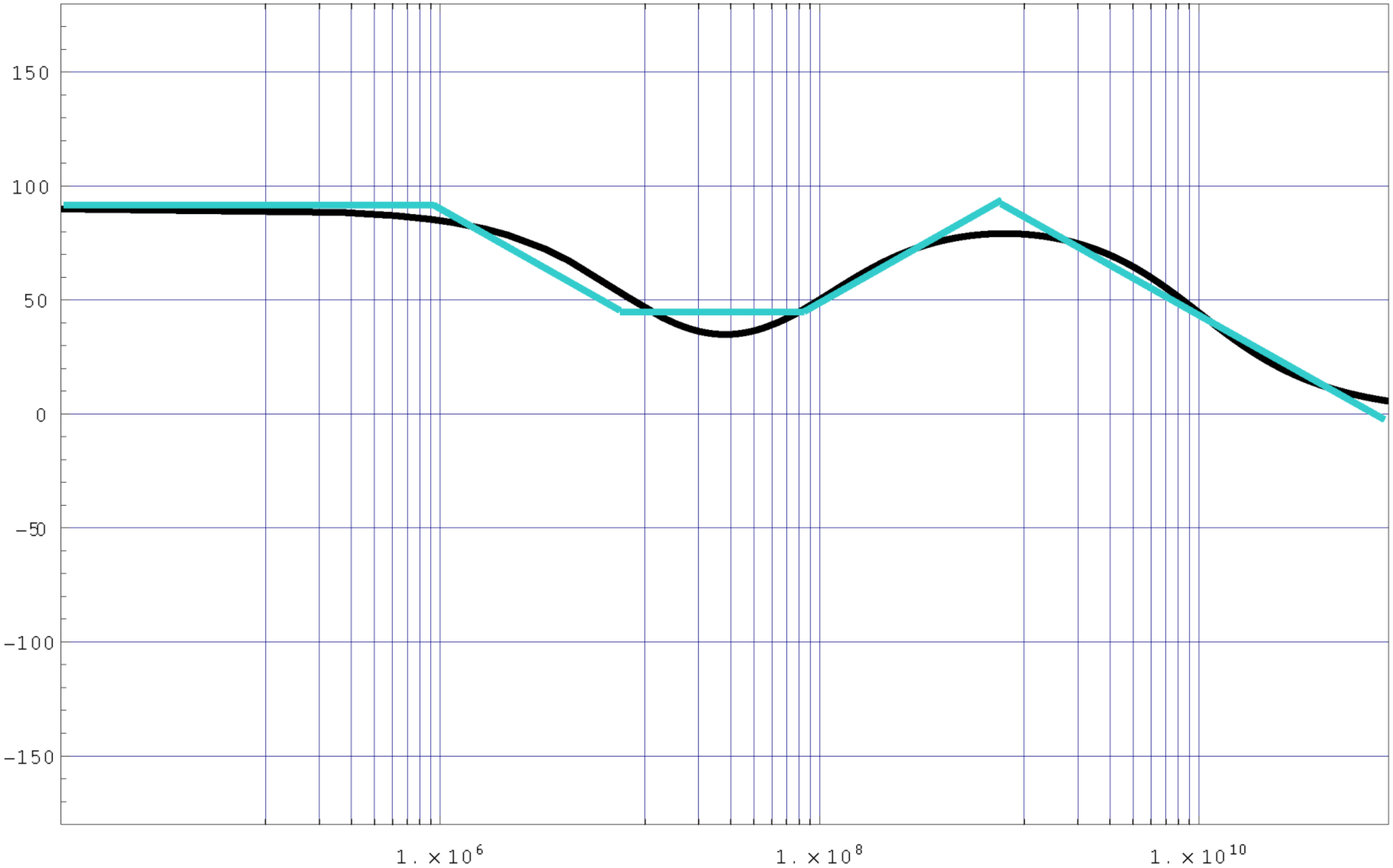
Phase Bode Plot: Add 2^{nd} Pole



Comparison to "Actual" Mag Plot



Comparison to "Actual" Phase Plot



With Our Best Wishes

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Course Staff

Thank You For Your Attention

Mohamed Ahmed Ebrahim