Welcome to KOM3712 Control Systems Design Spring 2023

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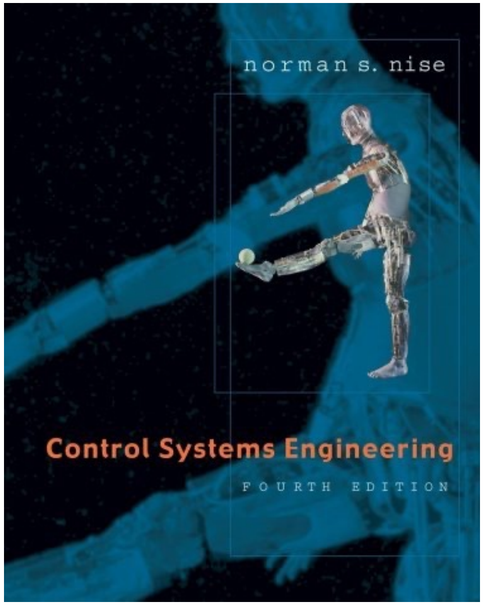
- **Instructor:** Dr. Şeref Naci Engin
- **Assistant:** Ms. Buse Tacal Ucun
- **Office Hours:** Mondays 1:00 – 3:00 pm
  and drop-in based short visits
- **Grading:**
  - Midterm exam : 1 X 30%
  - Assignments/Quizzes : 3 X 10%
  - Final exam : 40%
- **Only individual efforts & submissions allowed!**
- **No tolerance to cheating!**
- **Attendance min. 70%, plus assignments and quizzes**

Textbooks

- **N. S. Nise, Control Systems Engineering, 6th edition, John Wiley & Sons, MA, 2011**.
- G. F. Franklin, J. D. Powell, and A. Emami-Naeini, Feedback Control of Dynamic Systems, 6th edition, Prentice Hall, NJ, 2010
- **K. Ogata, Modern Control Engineering, 5th edition, Prentice Hall, NJ, 2010**
- C.L. Phillips, and J. Parr, Feedback Control Systems, 5th Ed., Prentice-Hall, 2010.
- **F. Golnaraghi and B. C. Kuo, Automatic Control Systems, 9th edition, John Wiley & Sons, NJ, 2010 (This book is available in Turkish by A. Bir, Literatür Yayıncılık)**
- J. J. D'Azzo, C. H. Houpis, and S. N. Sheldon, Linear Control System Analysis and Design with Matlab, 5th edition, Marcel Dekker, 2003



KOM 3712 – Topics by weeks

Week-1	**Recap.** of Control Systems, RL based design for Cascaded and Feedback Controllers, PID tuning by Ziegler-Nichols, issues in PID implementations
Week-2	**Recapture** and Introduction to **Frequency Response Techniques**, Analytical Expressions, Plotting Frequency Response, Bode Plots
Week-3	**Bode** Plots of 2nd Order Systems, Corrections to Second-Order Bode Plots, Bode plots for higher order systems, Nyquist Diagrams
Week-4	**The Nyquist Criterio**n, Applying the Nyquist Criterion to Determine Stability, Sketching the Nyquist Diagram, Stability via the Nyquist Diagram, Range of Gain for Stability via the Nyquist Criterion, Stability via Mapping only the Positive $j\omega$-Axis, Gain Margin (GM) and Phase Margin (PM) via the Nyquist Diagram
Week-5	Stability, Gain Margin, and Phase Margin via Bode Plots, Range of Gain for Stability via Bode Plots, Evaluating GM and PM, Examples
Week-6	Relation Between Closed-Loop Transient and Closed-Loop Frequency Responses, Response Speed and Closed-Loop Frequency Response, Relation Between Closed- and Open-Loop Frequency Responses, **Constant *M* Circles** and **Constant *N* Circles**, Relation Between Closed-Loop Transient and Open-Loop Frequency Responses

KOM 3712 – Topics by weeks, *cont'd…*

Week-7	**Damping Ratio** From ***M* Circles**, Damping Ratio From PM, Response Speed from Open-Loop Frequency Response, Steady-State Error Characteristics (K_p, K_v, K_a) from Frequency Response, Systems with Time Delay, Obtaining Transfer Functions Experimentally
Week-8	Midterm Exam
Week-9	**Design via Frequency Response**, Transient Response via Gain Adjustment, Lag Compensation Design, Lead Compensation Design, Lag-Lead Compensation Design
Week-10	**Design via State Space**, State space representations for dynamic systems, Canonical Forms, Controllability, Observability
Week-11	**Controller Design**, Alternative Approaches to Controller Design, Pole Placement / Assignment, Example Problems, Design of Servo Systems
Week-12	**State Observers**, Design of Regulator and Control Systems with Observers
Week-13	**Steady-State Error Design** via **Integral Control**, Case Study - Antenna Control: Design of Controller and Observer
Week-14	**LQR**: Quadratic Optimal Regulator Systems (Linear Quadratic Optimal Regulator). A brief intro to LQR with examples.

Decibel vs. Gain and Energy

- A logarithmic scale is used when there is a large range of quantities.
- It is based on orders of magnitude, rather than a standard linear scale, so each mark on the decibel scale is the previous mark multiplied by a value.
- On the decibel scale, the quietest audible sound (perceived near total silence) is 0 dB.
- A sound 10 times more powerful is 10 dB.
- A sound 100 times more powerful than near total silence is 20 dB.
- A sound 1,000 times more powerful than near total silence is 30 dB, 40 dB and so on.

Decibel vs. Gain and Energy, cont.'s...

Change in dB in Gain	Change in sound energy	Explanation
3 dB increase	sound energy is doubled	$20 \log x = 3\text{dB} \rightarrow x = \sqrt{2}$ Energy: $x^2 = 2$
3 dB decrease	sound energy is halved	$20 \log x = -3\text{dB} \rightarrow x = 1/\sqrt{2}$ Energy: $x^2 = 1/2$
10 dB increase	sound energy is increased by a factor of 10	$20 \log x = 10\text{dB} \rightarrow x = \sqrt{10}$ Energy: $x^2 = 10$
10 dB decrease	sound energy is decreased by a factor of 10	$20 \log x = -10\text{dB} \rightarrow x = 1/\sqrt{10}$ Energy: $x^2 = 1/10$
20 dB increase	sound energy is increased by a factor of 100	$20 \log x = 20\text{dB} \rightarrow x = 10$ Energy: $x^2 = 100$
20 dB decrease	sound energy is decreased by a factor of 100	$20 \log x = -20\text{dB} \rightarrow x = 1/10$ Energy: $x^2 = 1/100$

Example Problems from the past! - 1 of 2

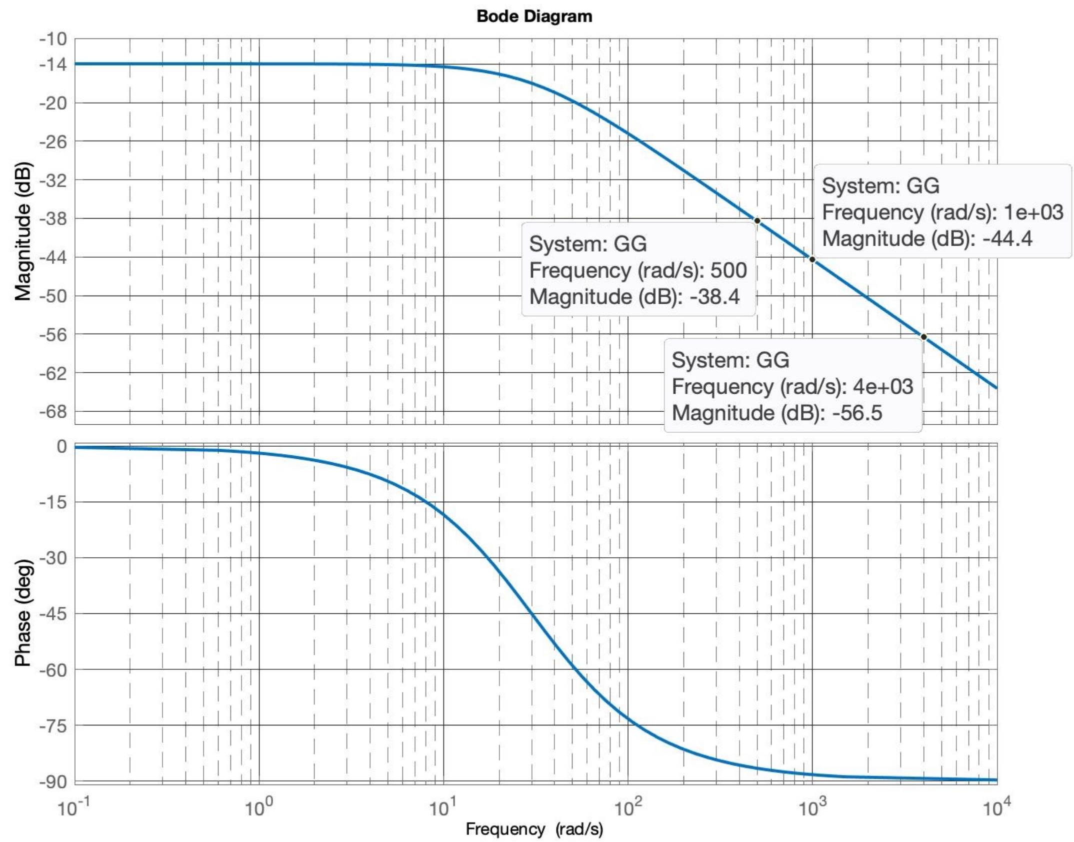
Problem 1. Considering the Bode plots given below,

a) Determine the gain in linear unit at low frequencies.

b) Determine the break frequency using the Bode magn. and phase plots.

c) Fill in the table at the bottom by writing the gain values in dB at the corresponding frequencies from the plots.

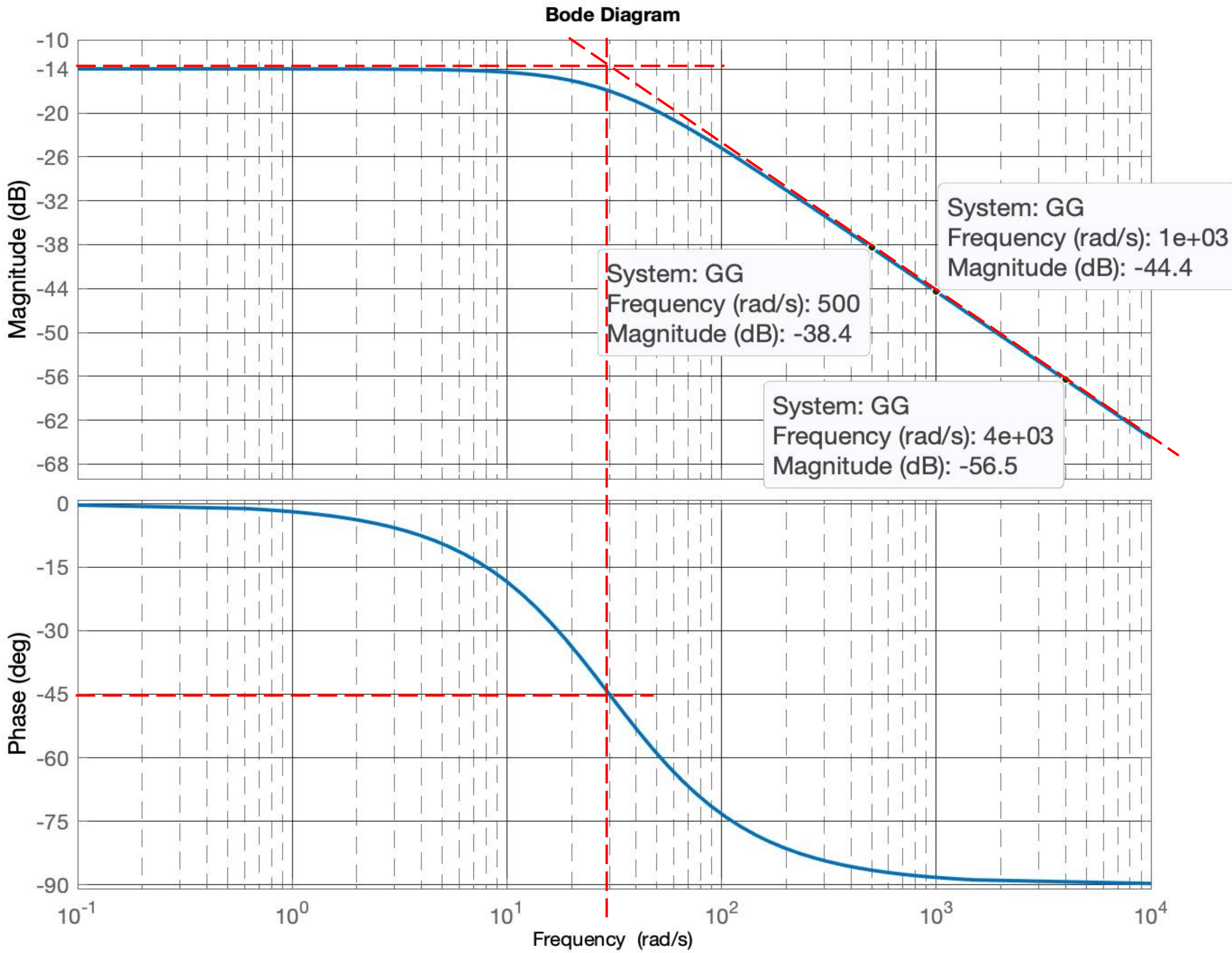
d) What are the slopes at low and high frequencies in dB/octave and dB/decade?



e) Propose a transfer function that would give this Bode plot.

Freq. (r/s)	0.1	1	30	500	1000	4000
Gain (dB)						

Example Problems from the past! – *Solution*:



Freq. (r/s)	0.1	1	30	500	1000	4000
Gain (dB)	-14	-14	-17	-38.4	-44.4	-56.5

Example Problems from the past! – *Solution, cont.'s*:

Solution 1. Considering the Bode plots given below,

a) $20 \log K_{\text{lin}} = -14 \text{ dB} \rightarrow K_{\text{lin}} = 10^{-14/20} = 0.2$

b) We can draw asymptotes on the Bode magnitude plot and find the break frequency at their crossing point as $\omega_c = 30 \text{ rad/s}$. The same result for the break frequency can be found using the Bode phase plot, where the phase angle is $-45°$ at $\omega_c = 30 \text{ rad/s}$.

c) Table was filled in the previous slide.

d) The slope at LF: 0, at HF: -6dB/octave or equivalently -20dB/decade.

- Because the magnitude at 1000 rad/s is -44.4dB, and doubling the frequency twice magnitude drops to -56.5dB.
- The difference at magnitude is 12 dB, hence the slope is -6dB/octave or equivalently -20dB/decade.

Example Problems from the past! – *Solution, cont.'s*:

Solution 1. Considering the Bode plots given below,

e) Propose a transfer function that would give this Bode plot.

We found that the linear gain at LF (dc gain) is $K_{\text{lin}} = 0.2$ and break frequency is $\omega_c = 30$ rad/s, which is the pole. Therefore, the transfer function that produces the above Bode plots should be,

- $G(s) = \frac{K}{s+a} = \frac{\frac{K}{30}}{\frac{s}{30}+1} \rightarrow \frac{K}{30} = 0.2 \rightarrow K = 6 \rightarrow G(s) = \frac{6}{s+30}$

Or,

- $G(s) = \frac{K}{s+a}$, at the dc gain where $s = 0$, $\frac{K}{a} = 0.2 \rightarrow$

$\frac{K}{30} = 0.2 \rightarrow K = 6 \rightarrow G(s) = \frac{6}{s+30}$

Example Problems from the past ! - 2 of 2

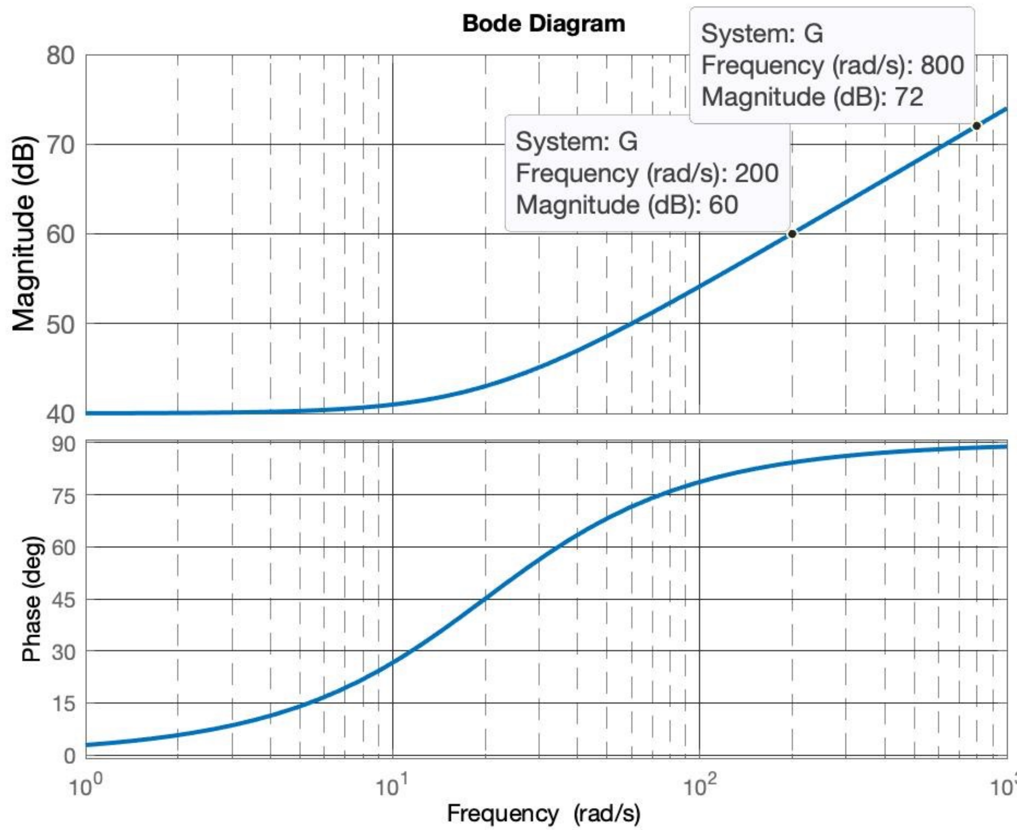
Problem 2. Considering the Bode plots given below,

a) Determine the gain in linear unit at low frequencies.

b) Determine the break frequency using the Bode magn. and phase plots.

c) Fill in the table at the bottom by writing the gain values in dB at the corresponding frequencies from the plots.

d) What are the slopes at low and high frequencies in dB/octave and dB/decade?



e) Propose a transfer function that would give this Bode plot.

Freq. (r/s)	1	4	20	200	400	1000
Gain (dB)						

Solution 2.

(a) $20 \log K_{\text{lin}} = 40$ dB

$K_{\text{lin}} = 10^{40/20} = 100$

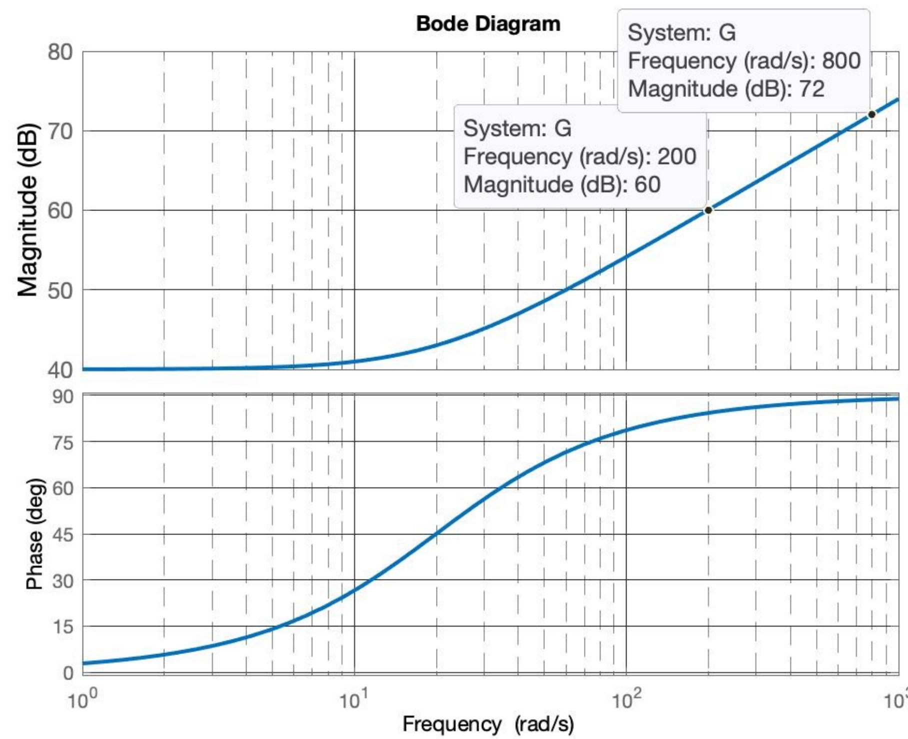
(b) We can draw asymptotes on the Bode magnitude plot and find the break frequency at their crossing point as $\omega_c = 20$ rad/s. The same result for the break frequency can be found using the Bode phase plot, where the phase angle is 45° at $\omega_c = 20$ rad/s.

(c) Table is filled as follows.

Frequency (rad/s)	1	4	20	200	400	1000
Gain (dB)	40	40	43	60	66	74

(d) The slope at LF: 0, at HF: 6dB/octave or equivalently 20dB/decade.

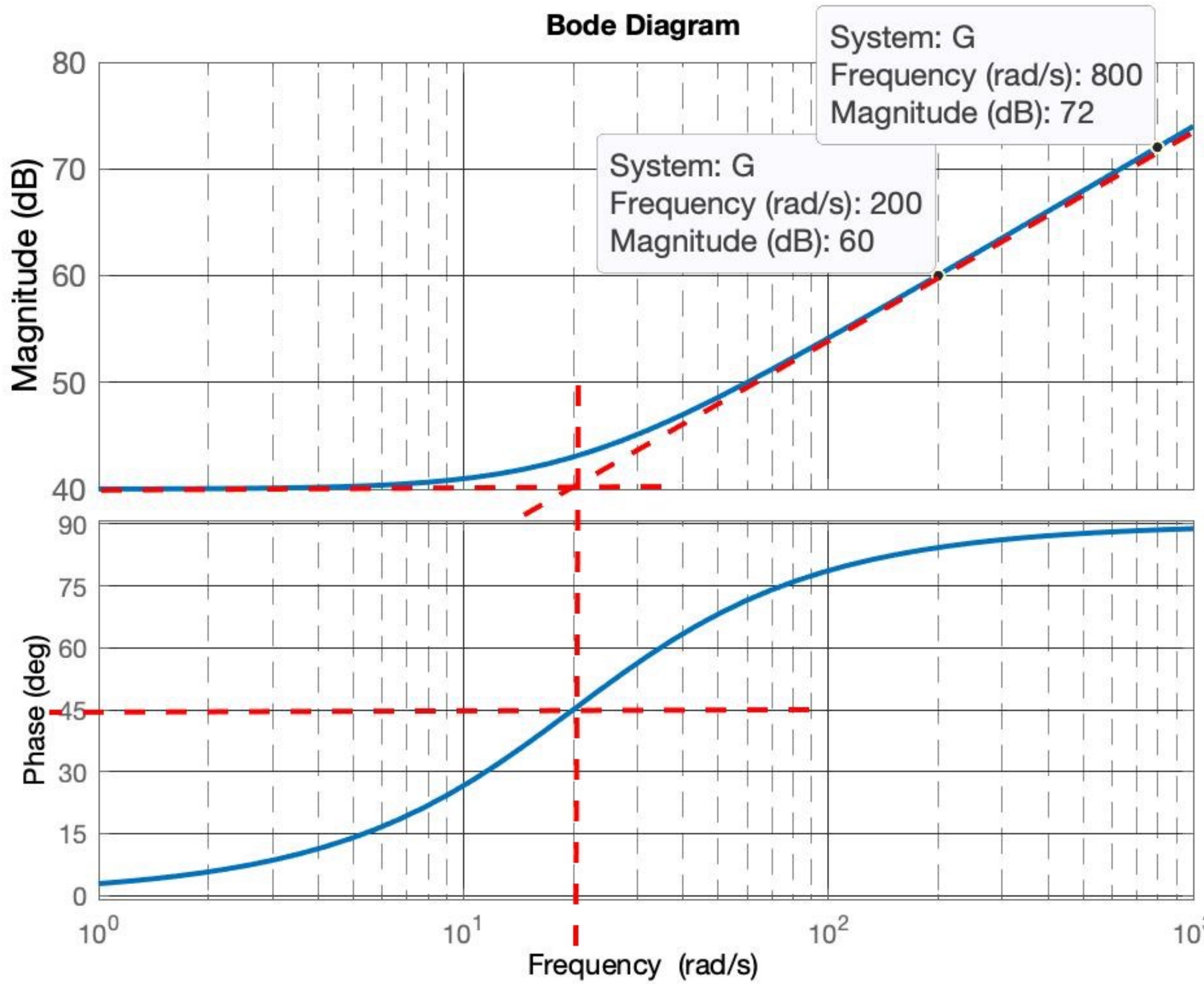
Because the magnitude at 200 rad/s is 60dB, and doubling the frequency twice magnitude rises to 72dB. The difference at magnitude is 12 dB, hence the slope is 6dB/octave or equivalently 20dB/decade.



(e) We found that the linear gain at LF (dc gain) is $K_{\text{lin}} = 40$ and break frequency is $\omega_c = 20$ rad/s, which is the zero. Therefore, the transfer function that produces the above Bode plots should be,

$$G(s) = K(s+a) = Ka(s/a+1) = 20K(s/20+1) \Rightarrow 20K = 100 \Rightarrow K = 5 \Rightarrow G(s) = 5(s+20)$$

Alternatively, $G(s) = K(s+a)$, at the dc gain where $s = 0$, $Ka = 100 \Rightarrow 20K = 100 \Rightarrow K = 4 \Rightarrow G(s) = 5(s+20)$



Bode Plots for Ratio of First-Order Factors – A Simple Example

- Obtain Bode plots of $G(s)=K/[(s+2)(s+4)]$
  - by hand (asymptotical plot) and
  - in MATLAB (actual plot):

- **Solution for $K=1$**
  - $G(s) = \frac{1}{(s+2)(s+4)} = \frac{1}{8}\frac{1}{(s/2+1)(s/4+1)}$
  - We can now think of $G(s)$ consisting of three components: a gain of $\frac{1}{8}$, $\frac{1}{(s+2)}$ and $\frac{1}{(s+4)}$
  - The first component is the gain and contributes to the magnitude plot as a constant level of

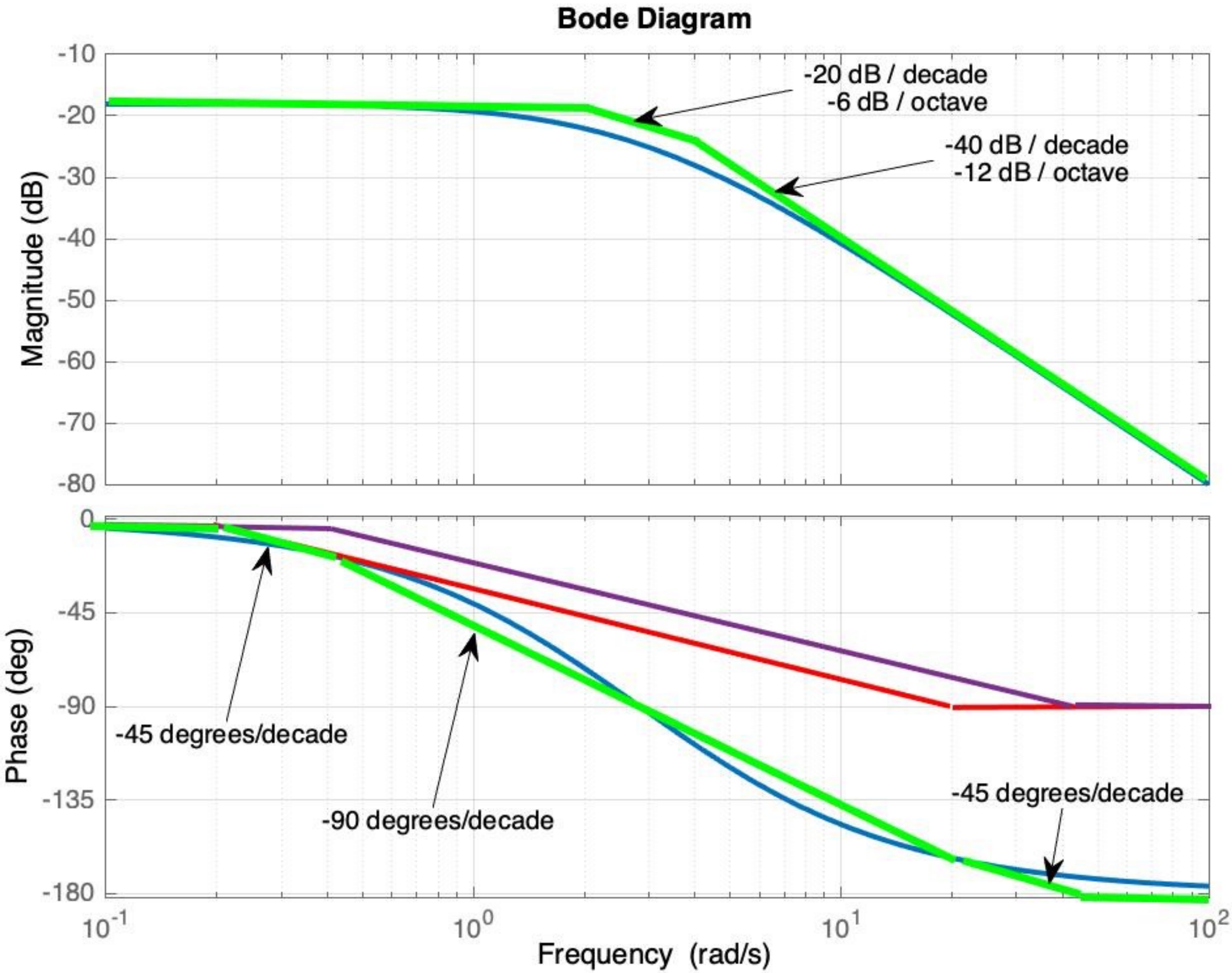
$$20\log\frac{1}{8} = -18.062\text{ dB}$$

  - The next two components contribute a -20 db/dec at 2 rad/s and another -20 db/dec at 4 rad/s

Bode Plots for Ratio of First-Order Factors – A Simple Example, *solution cont.'s*...

- Now, the phase plot of $G(s) = \frac{1}{(s+2)(s+4)} = \frac{1}{8}\frac{1}{(s/2+1)(s/4+1)}$
- The gain component does not contribute to the phase since it is just a real number, $\frac{1}{8}\angle 0°$.
- The phase plots of the terms of $\frac{1}{(s+2)}$ and $\frac{1}{(s+4)}$ are the same:
  - Starts from $0°$ and remains the same up to $\omega = 0.2\ \mathrm{rad/s}$,
  - Drops to $-45°$ at $\omega = 2\ \mathrm{rad/s}$
  - Then, to $-90°$ at $\omega = 20\ \mathrm{rad/s}$ and remains there at $-90°$.
- The last term will be the same for $\omega = 0.4, 4$ and $40\ \mathrm{rad/s}$.
- Therefore, the **total** or **final plot** will change from $\phi = 0°$ at low frequencies and reaches at $-180°$ at high frequencies.

Bode plots of $G(s)=1/[(s+2)(s+4)]$ by hand (asymptotical) and MATLAB (actual)



End of Week-1 for KOM3712 Control Systems Design Spring 2023

Week-2 starts with

- Bode plots for ratio of first-order factors
- Bode plots for systems with two complex poles and/or zeros: $G(s) = (s^2 + 2\,\zeta\omega_n s + \omega_n{}^2)^{\mp 1}$
- Bode plots for nonminimum-phase systems
- Steady-state errors from Bode magnitude plot

Please refer to
Chapter 10.1 Frequency Response Techniques
(from slide 51 of Chap-10-1-Freq_Resp_Avesis.pdf)

See you next week!