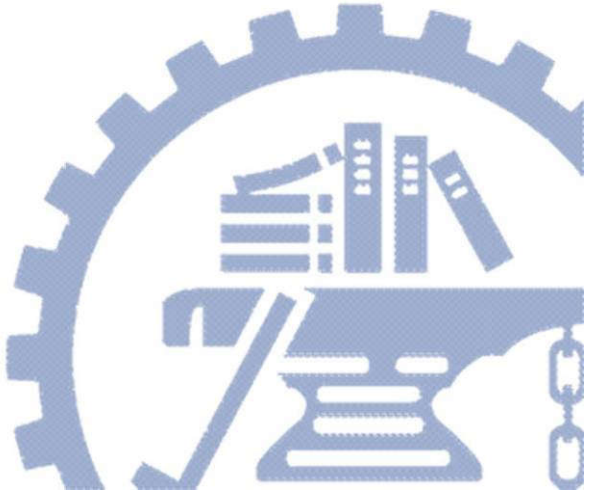
上海交通大學
Shanghai Jiao Tong University

The Principles of Automatic Control
Lab #3

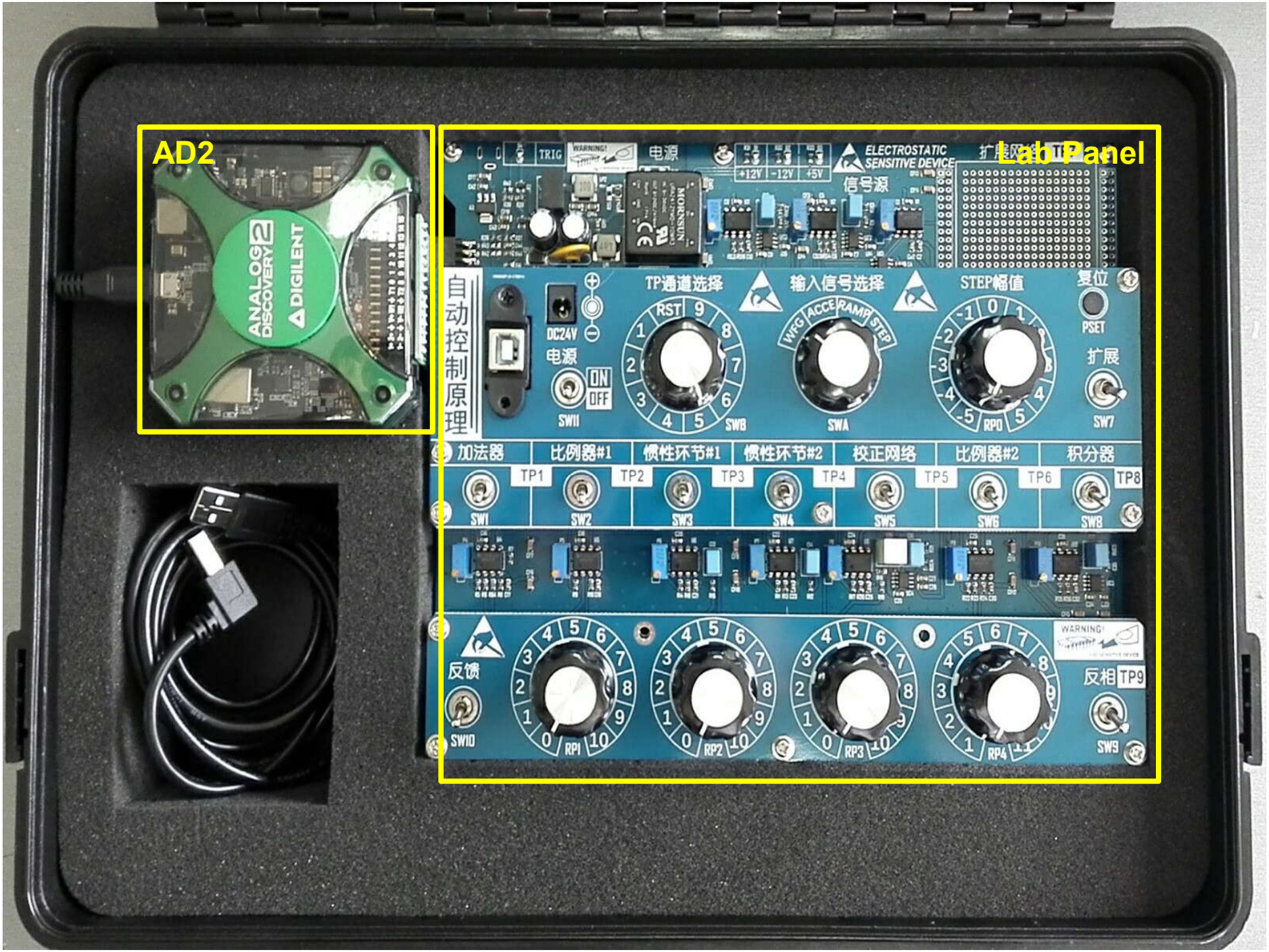
Department of Automation

Dec, 2021

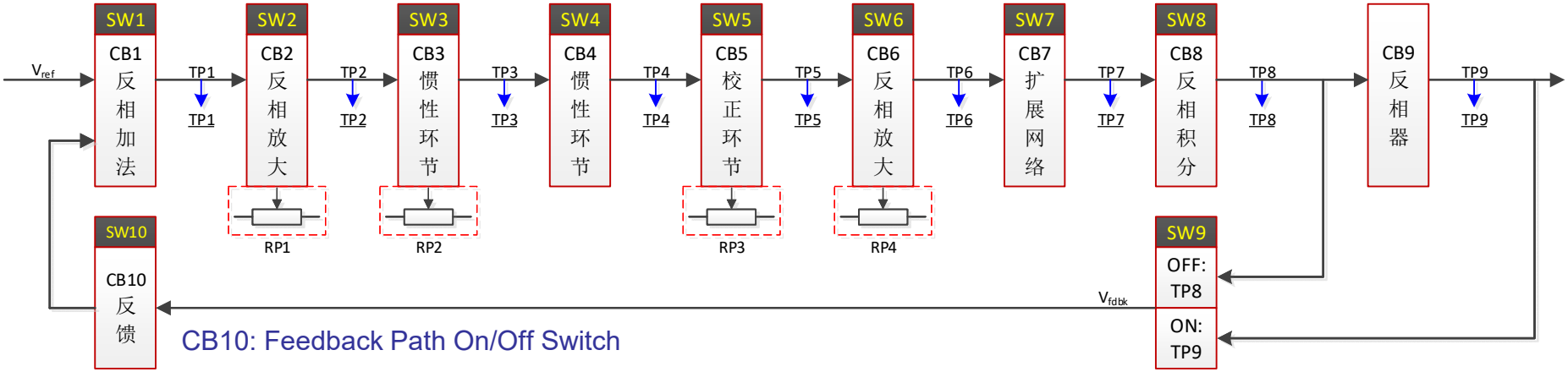


Agenda

- Frequency-Response Analysis Review
  - Definition of System Frequency-Response
  - Bode Diagrams
- Control Systems Design by Frequency Response
  - Lead Compensators
  - Lag Compensators
  - Lead-Lag Compensators

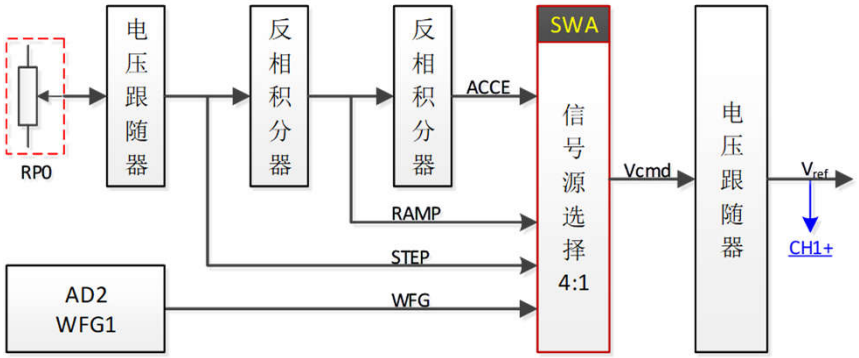

AD2
Lab Panel
ANALOG DISCOVERY 2
DIGILENT
TRIG
WARNING!
电源
ELECTROSTATIC SENSITIVE DEVICE
+12V -12V +5V
信号源
自动控制原理
DC24V
电源
ON OFF
SW11
TP通道选择
RST
SW8
输入信号选择
WFG ACCE RAMP STEP
SWA
STEP幅值
RP0
复位
PSET
扩展
SW7
加法器
比例器#1
惯性环节#1
惯性环节#2
校正网络
比例器#2
积分器
TP1
TP2
TP3
TP4
TP5
TP6
TP8
SW1
SW2
SW3
SW4
SW5
SW6
SW8
反馈
SW10
RP1
RP2
RP3
RP4
反相
TP9
SW9

Lab Kit Block Diagram Overview

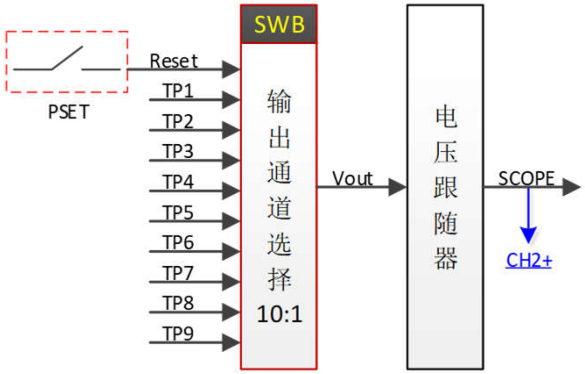


CB10: Feedback Path On/Off Switch

CB1: Inverted Adder
CB2: Inverted Amplifier #1
CB3: Inverted 1st-Order Delay #1
CB4: Inverted 1st-Order Delay #2
CB5: Compensator
CB6: Inverted Amplifier #2
CB7: User-Defined Network
CB8: Inverted Integrator
CB9: Inverter (Always Active)
SW9: OFF: V_{fdbk} = TP8
ON: V_{fdbk} = TP9 = -TP8



V_{ref} Signal Source Scheme
AD2-SCOPE CH1+ is fixedly connected to V_{ref}

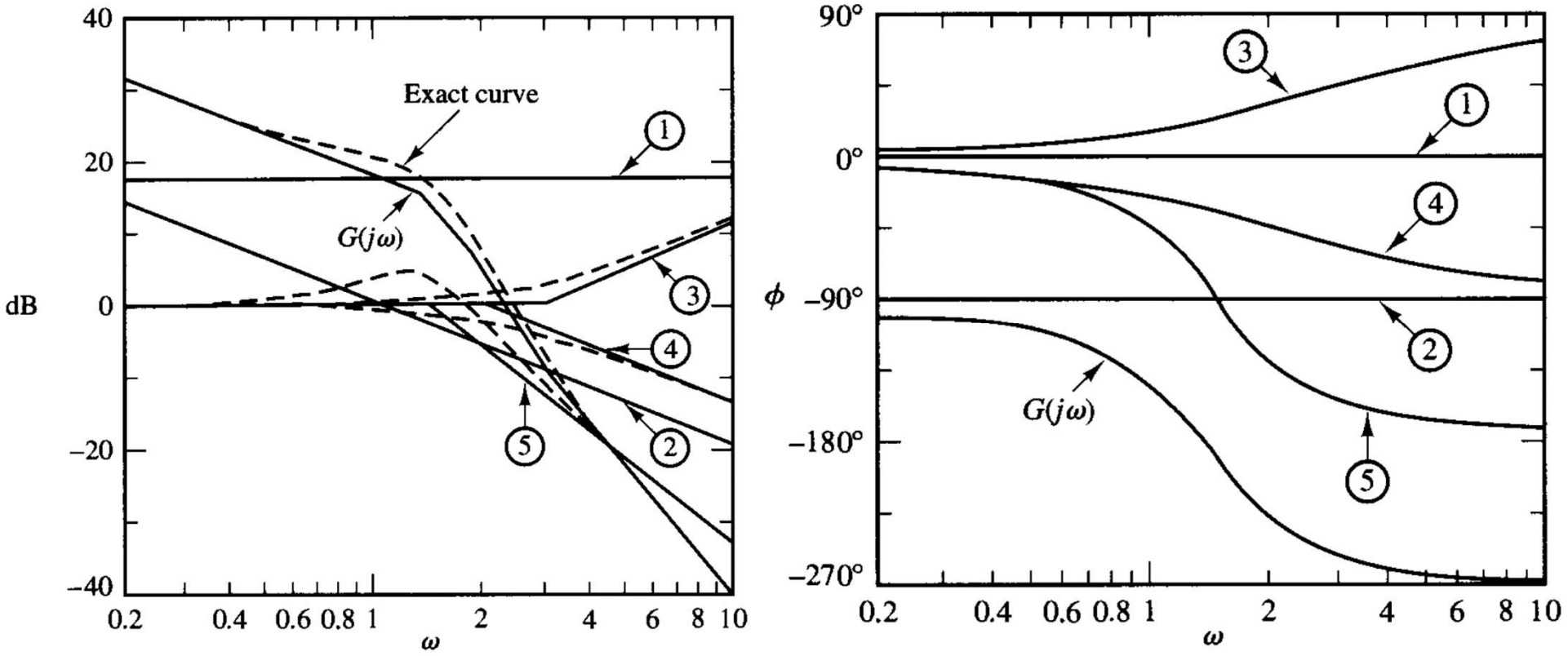


Output Signal Observation Scheme
AD2-SCOPE CH2+ can be selectively switched

How to Draw the Bode Diagram for a Relatively Complex System

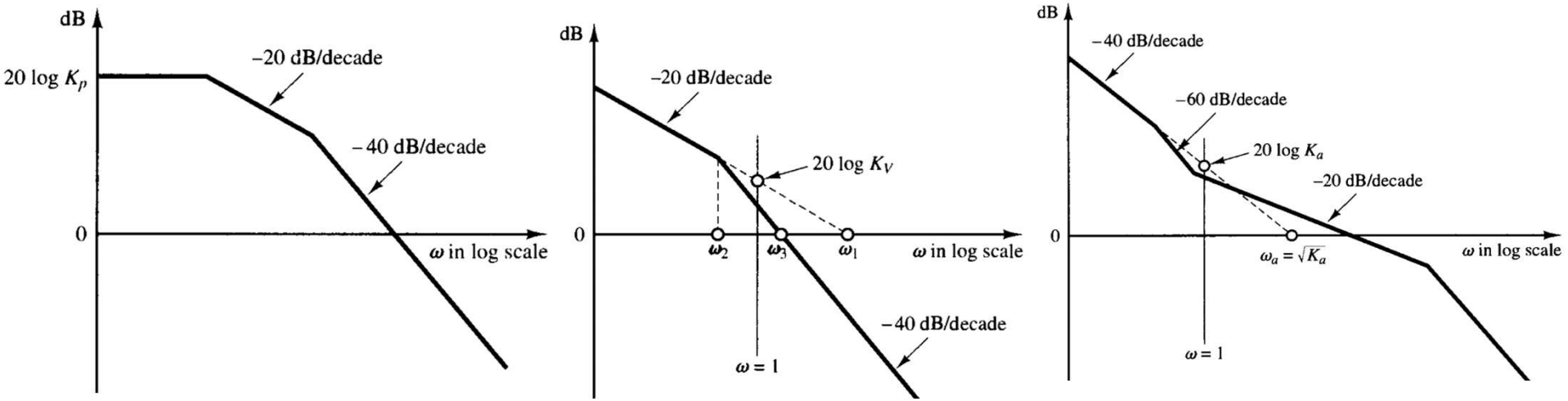
Draw the Bode diagram for the following TF:

$$G(j\omega) = \frac{10(j\omega + 3)}{(j\omega)(j\omega + 2)[(j\omega)^2 + j\omega + 2]}$$



Bode Diagram Features

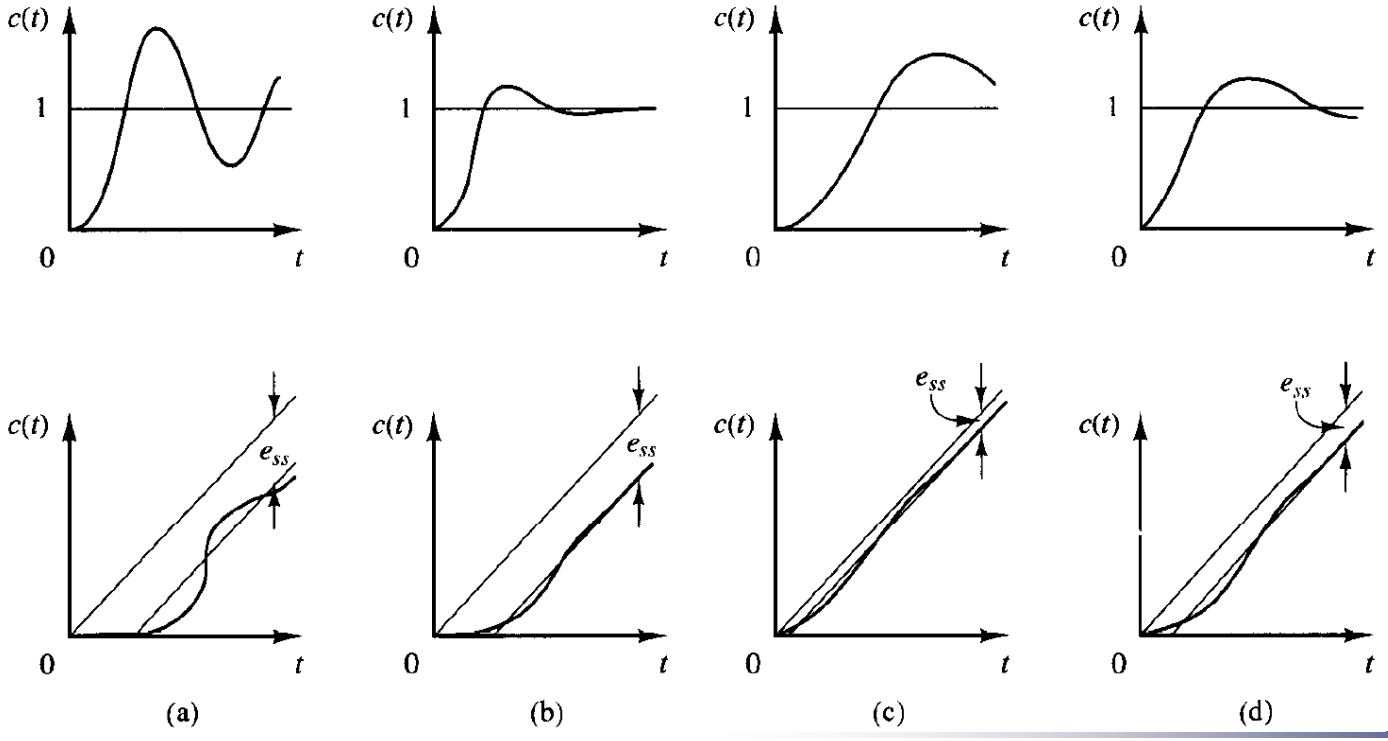
- Relationship between system type and log-magnitude curve
  - Type 0, Type 1, Type 2
  - Kp, Kv, Ka
- Experimental Determination of Transfer Function



Control Systems Design by Frequency Response

Basic characteristics of different compensation

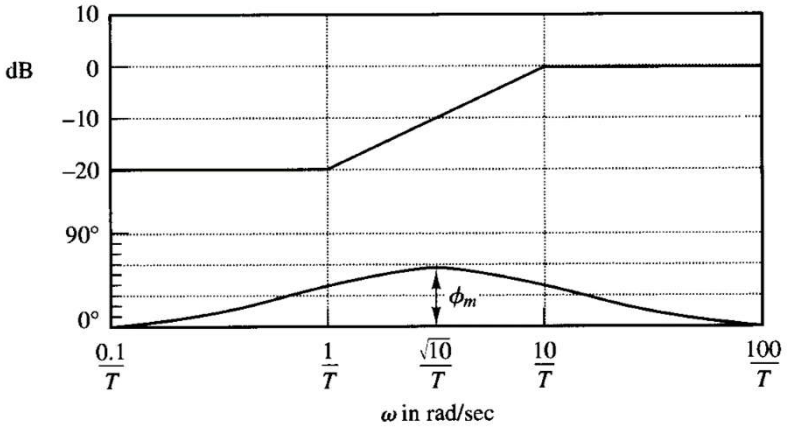
- Lead compensation （b）
- Lag compensation （c）
- Lag-lead compensation （d）

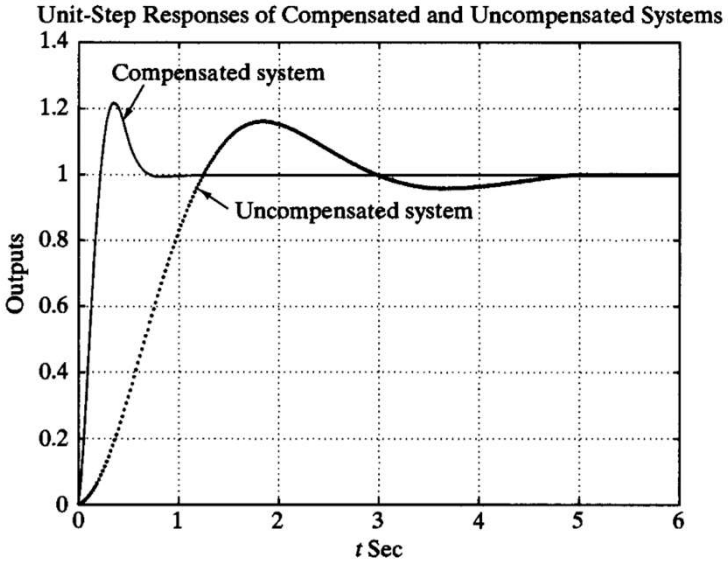


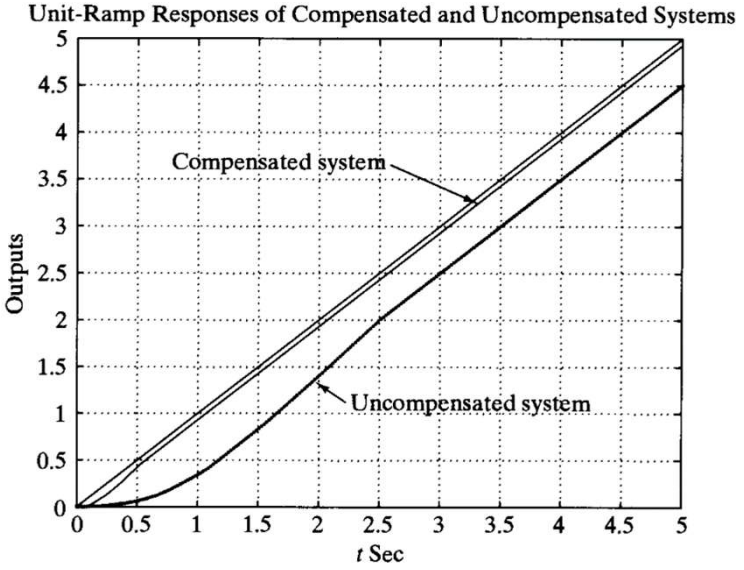
Lead Compensation

Characteristics of lead compensators

$$K_c\alpha\frac{Ts+1}{\alpha Ts+1}=K_c\frac{s+\frac{1}{T}}{s+\frac{1}{\alpha T}}\qquad(0<\alpha<1)$$



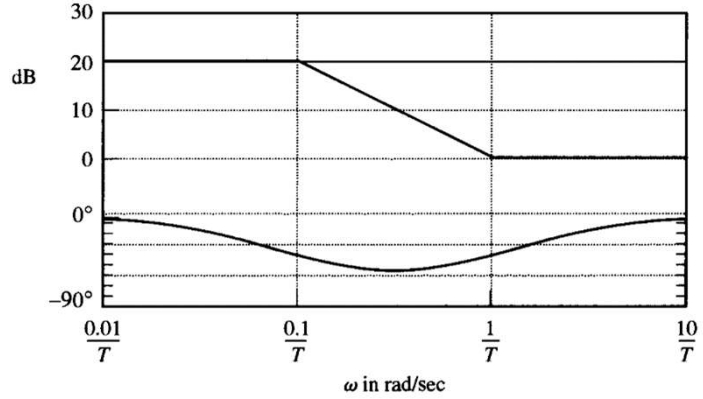


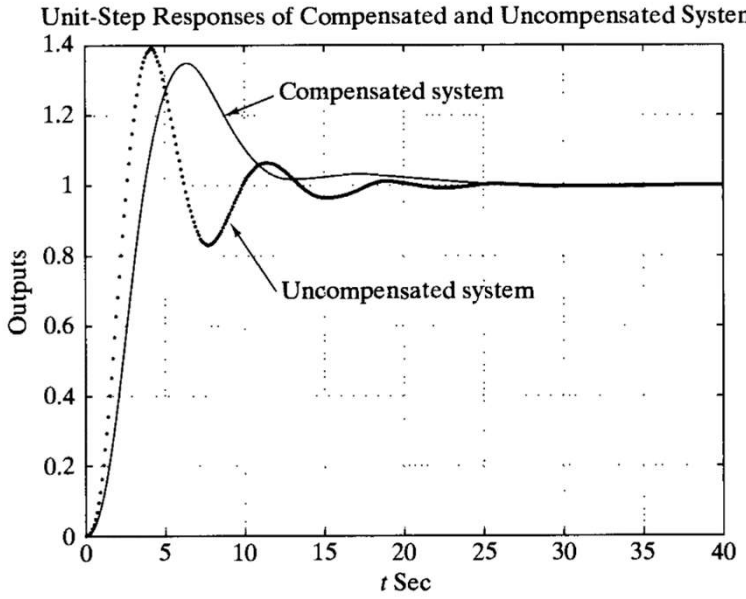


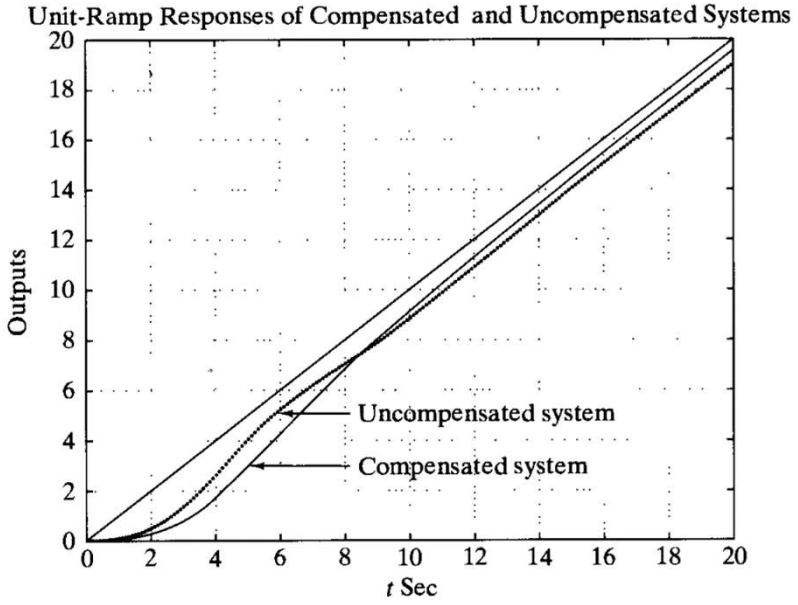
Lag Compensation

Characteristics of lag compensators

$$G_c(s) = K_c\beta\frac{Ts+1}{\beta Ts+1} = K_c\frac{s+\frac{1}{T}}{s+\frac{1}{\beta T}} \qquad (\beta > 1)$$



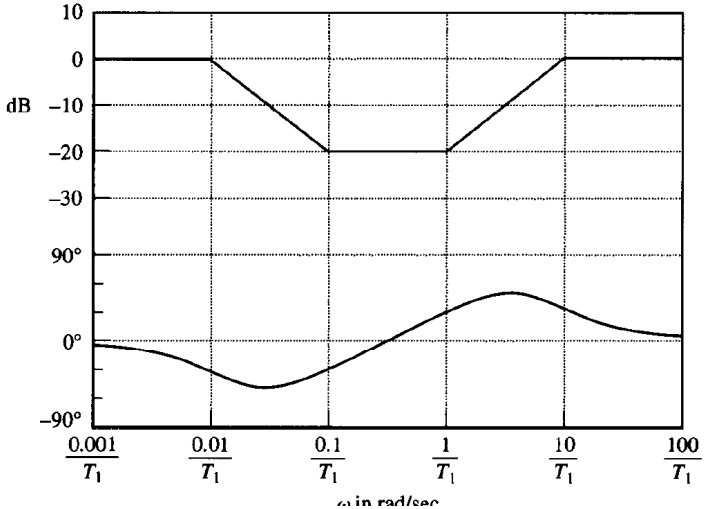


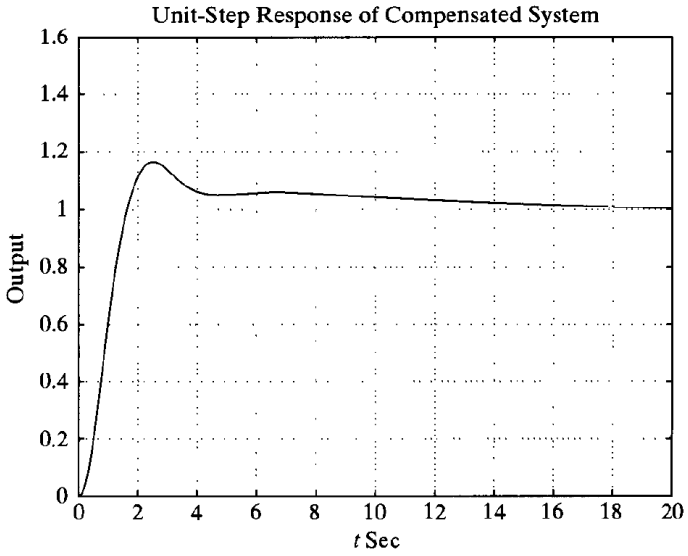


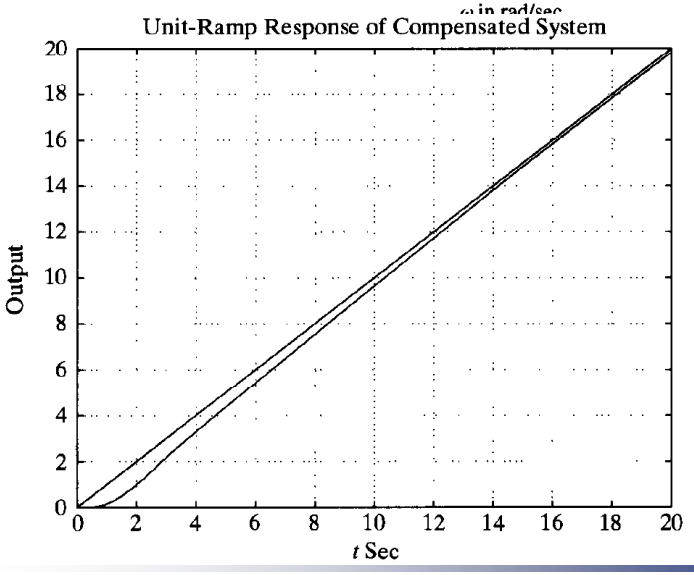
Lead-Lag Compensation

Characteristics of lead-lag compensators

$$G_c(s) = K_c \frac{(T_1 s + 1)(T_2 s + 1)}{\left(\frac{T_1}{\beta} s + 1\right)(\beta T_2 s + 1)} = K_c \frac{\left(s + \frac{1}{T_1}\right)\left(s + \frac{1}{T_2}\right)}{\left(s + \frac{\beta}{T_1}\right)\left(s + \frac{1}{\beta T_2}\right)}$$







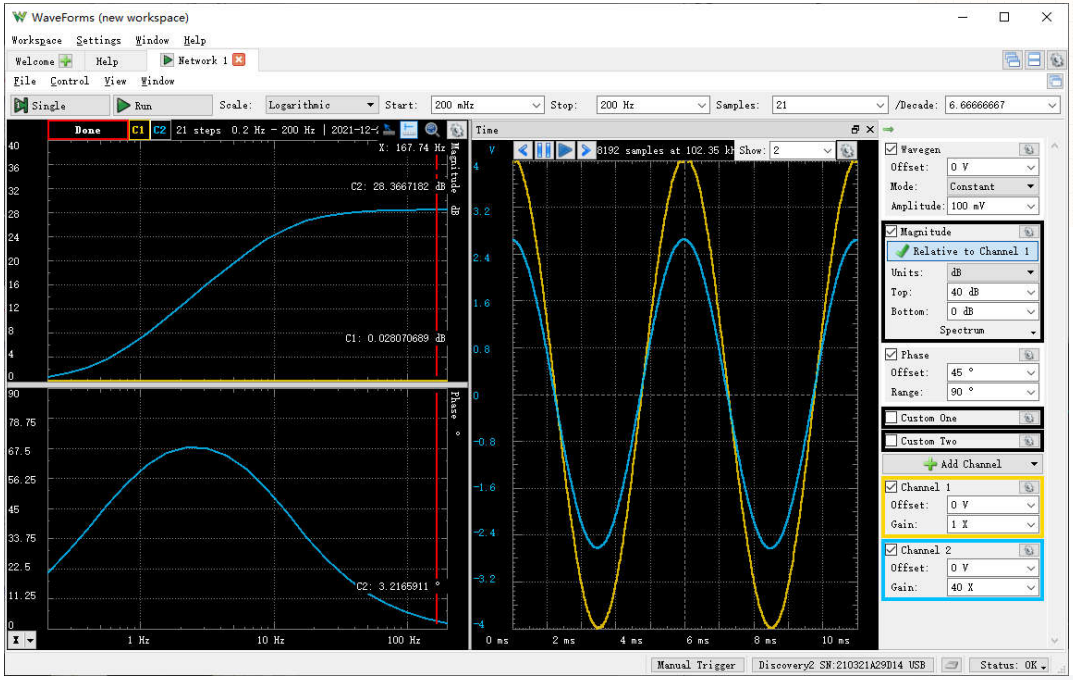
CB5 (SW5): Compensation Network

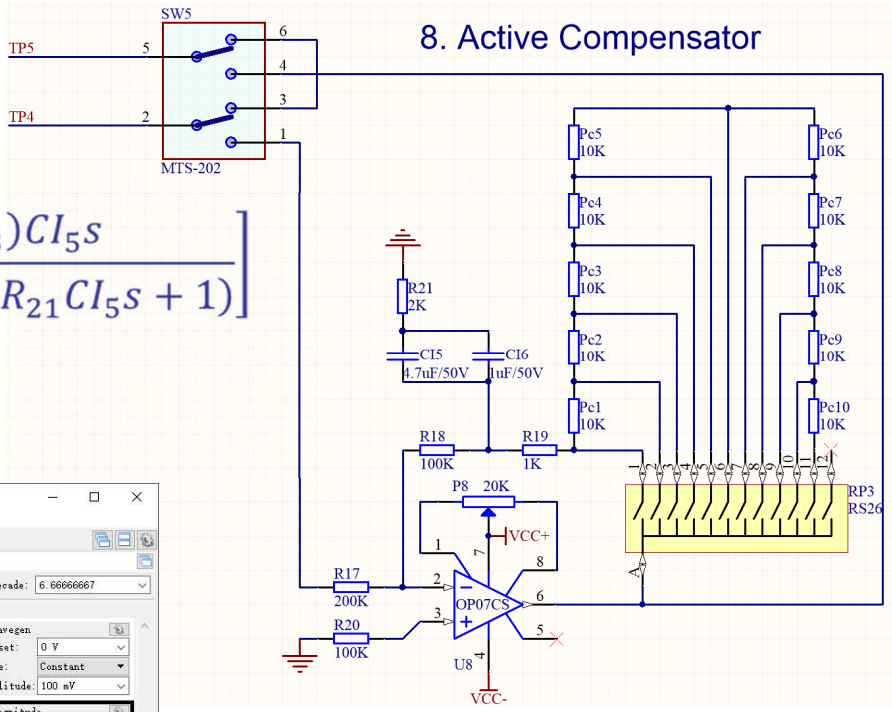
Key Points

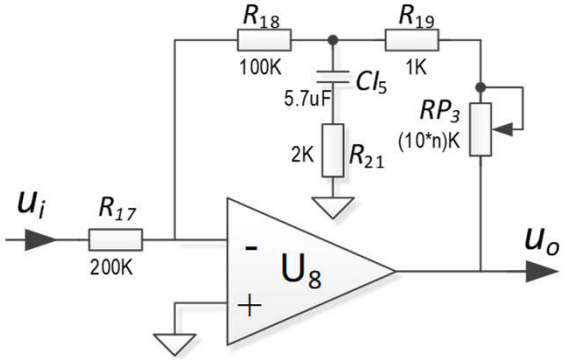
- Transfer function

$$G(s) = \frac{R_{18} + (R_{19} + RP_3)}{R_{17}}\left[1 + \frac{R_{18}(R_{19} + RP_3)CI_5 s}{(R_{18} + (R_{19} + RP_3))(R_{21}CI_5 s + 1)}\right]$$

$$K_c\alpha\frac{Ts+1}{\alpha Ts+1} = K_c\frac{s+\frac{1}{T}}{s+\frac{1}{\alpha T}} \qquad (0<\alpha<1)$$







Matlab Sample Codes: ACLab3.m

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Circuit Blocks

E:\教学\2021-2022-1\自动控制原理\实验资料\2021ACLab3\ACLab3.m

编辑器 发布 视图

```
% ACLab#3 for the Principles of Automatic Control
% Assignment #1: bode plots for the lead compensato
% Assignment #2: step response of the un-compensa
% Assignment #3: step response of the compensated

Krp1 = 10;      %% change value as required
Krp2 = 2;       %% change value as required
Krp3 = 10;      %% change value as required
Krp4 = 8;       %% change value as required

s=tf('s');
Gcb1 = -1;
Gcb2 = -0.1*Krp1;
Gcb3 = -(1+10*Krp2)/49.9/(1+(0.001+0.01*Krp2)*s);
Gcb4 = -1/(0.2*s+1);
Gcb5 = -((102+10*Krp3)/200)*(((1.7214+5.814*Krp3) ...
   *s/(101+10*Krp3)+1)/(0.0114*s+1));
Gcb6 = -Krp4;
Gcb7 = 1;       %% not installed on device
Gcb8 = -5/s;
Gcb9 = -1;
```

UTF-8 脚本 行 1 列 1

Models and Plots

E:\教学\2021-2022-1\自动控制原理\实验资料\2021ACLab3\ACLab3.m

编辑器 发布 视图

```
sys1 = Gcb5 * Gcb9;
sys2 = feedback(Gcb2*Gcb4*Gcb6*Gcb8, 1);
sys2_OL = Gcb2*Gcb4*Gcb6*Gcb8;
sys3 = feedback(Gcb4*Gcb5*Gcb6*Gcb8, 1);
sys3_OL = Gcb4*Gcb5*Gcb6*Gcb8;

%bode(sys1)
%bode(sys2)
%bode(sys2_OL)
%step(sys2)
%step(sys3)
%step(sys3_OL)
```

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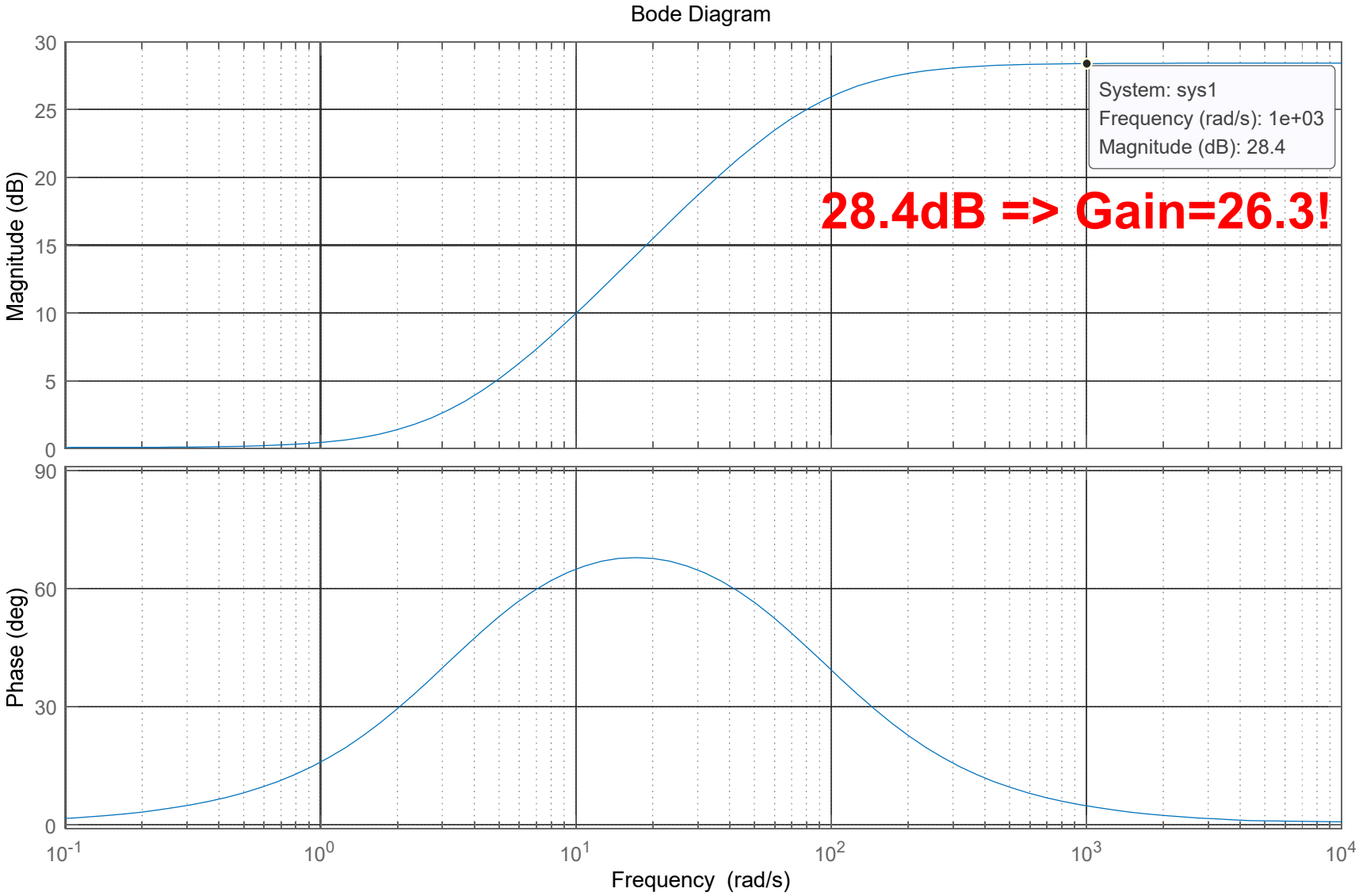
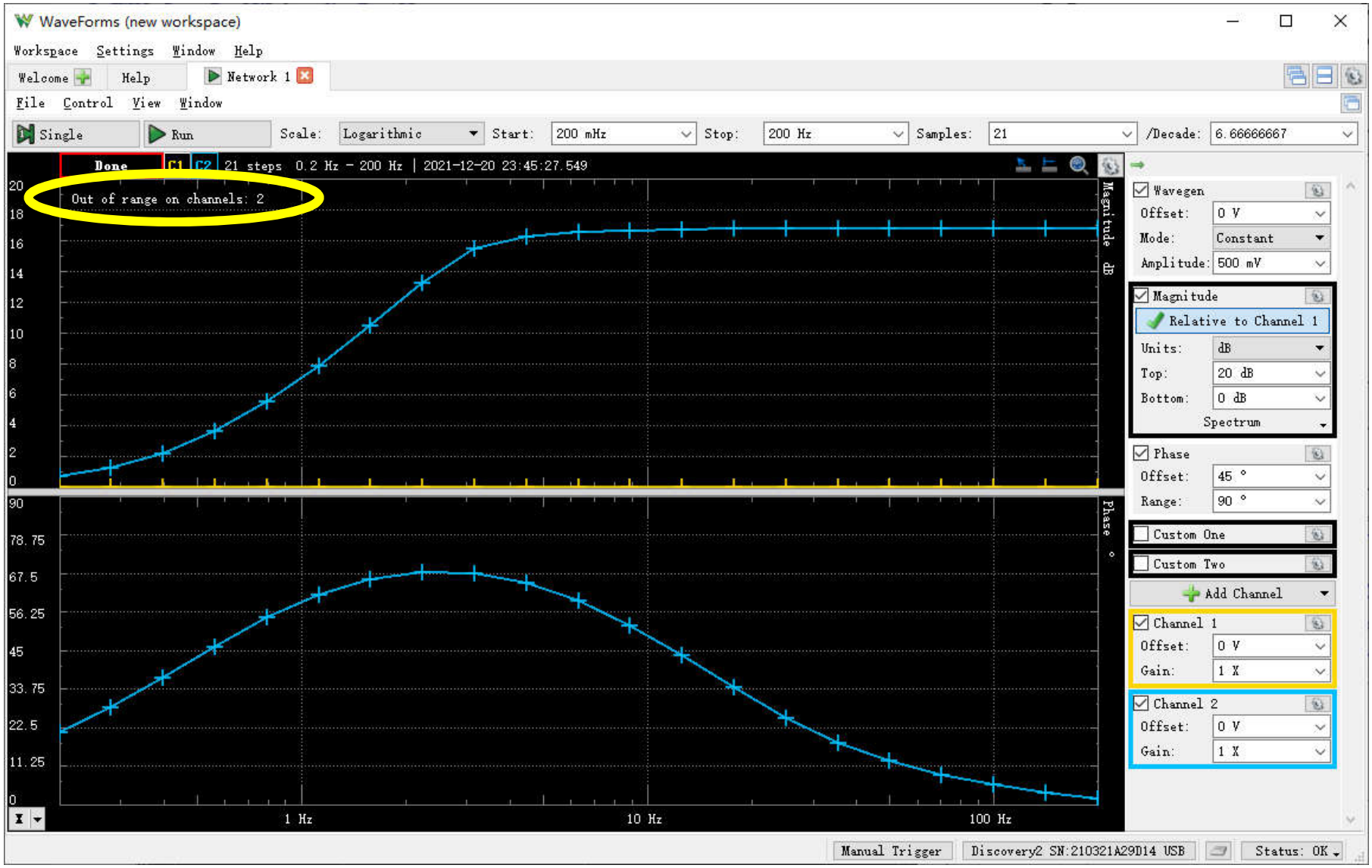
Refer to the circuit schematics and transfer functions for each CB

NOTE: the gain at high frequency!



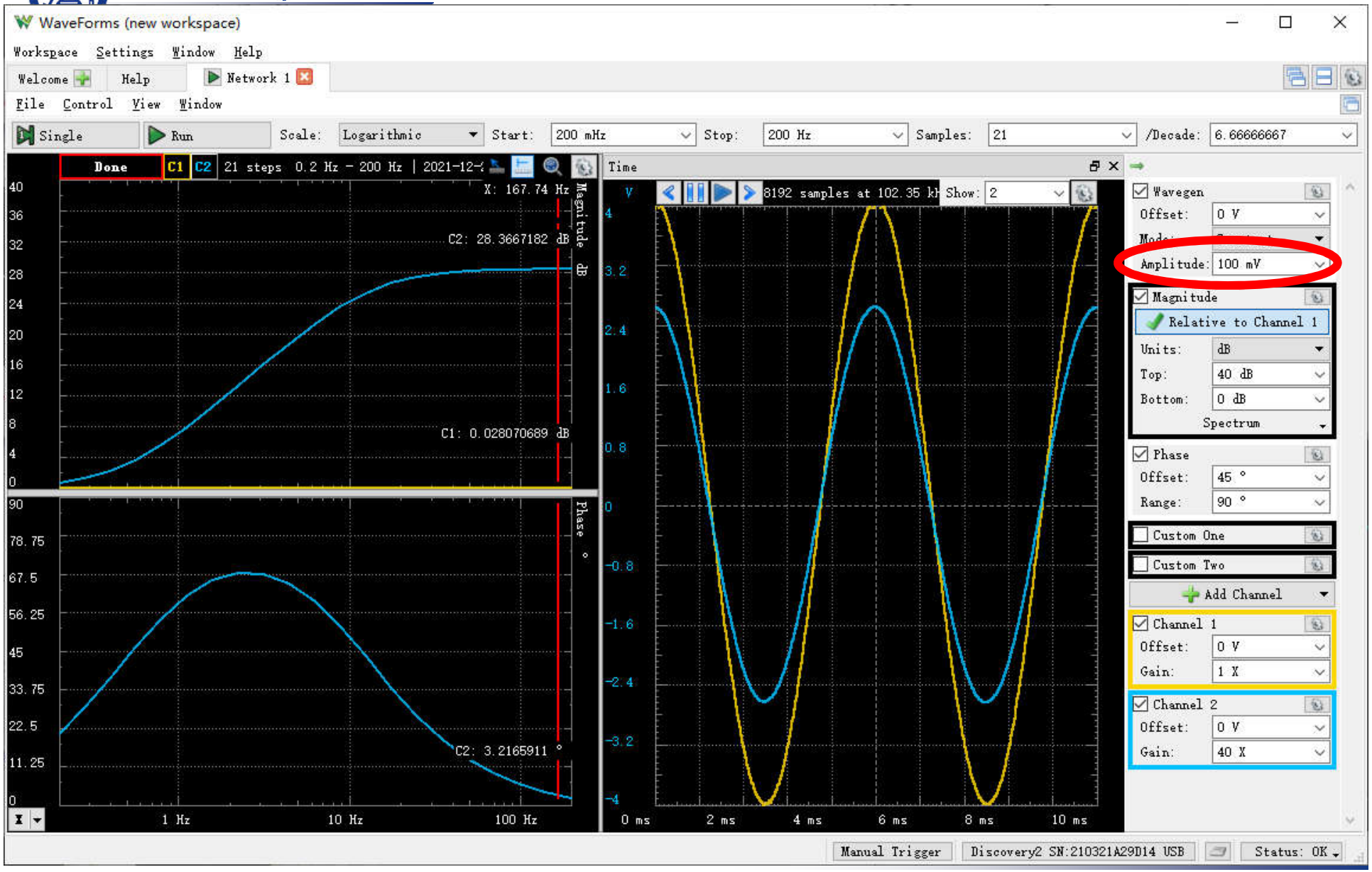
Lead compensator (ACLab3.m, Krp3=10)

Make sure to record correct result!



Lead compensator (CB5+CB9, Krp3=10)

DON'T run into saturation!



Lead compensator (CB5+CB9, Krp3=10)

Un-compensated Dynamic Response

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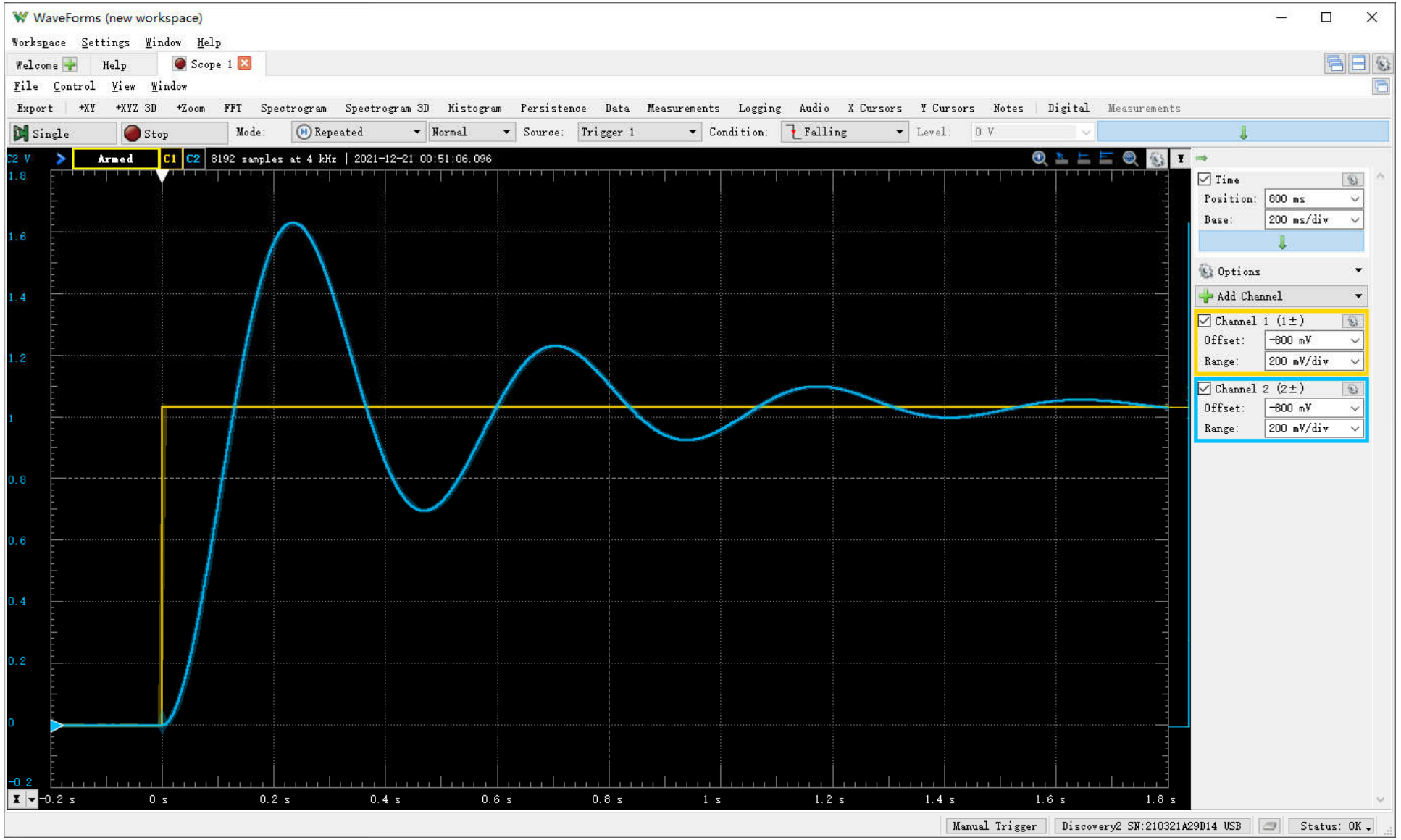
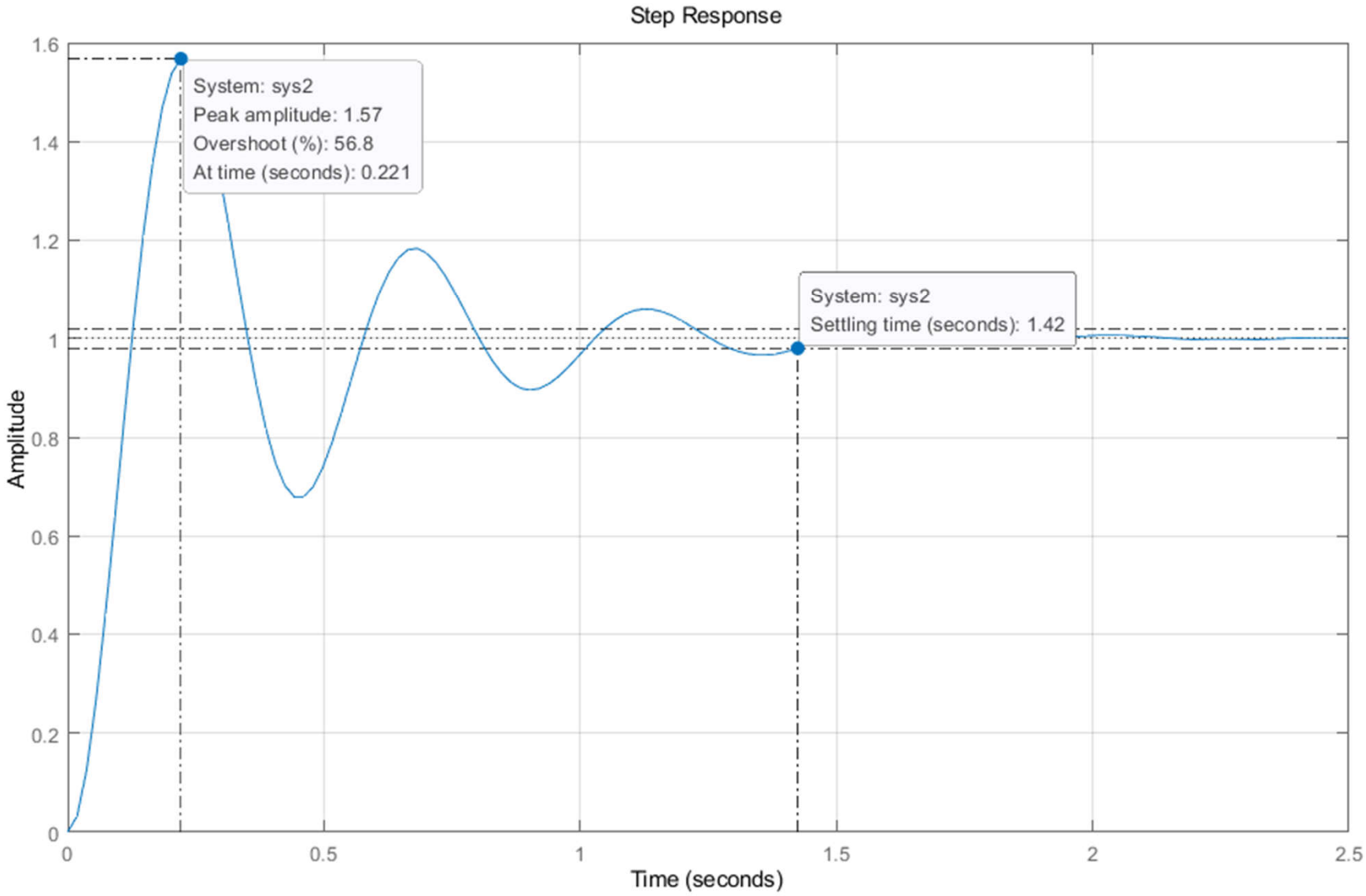


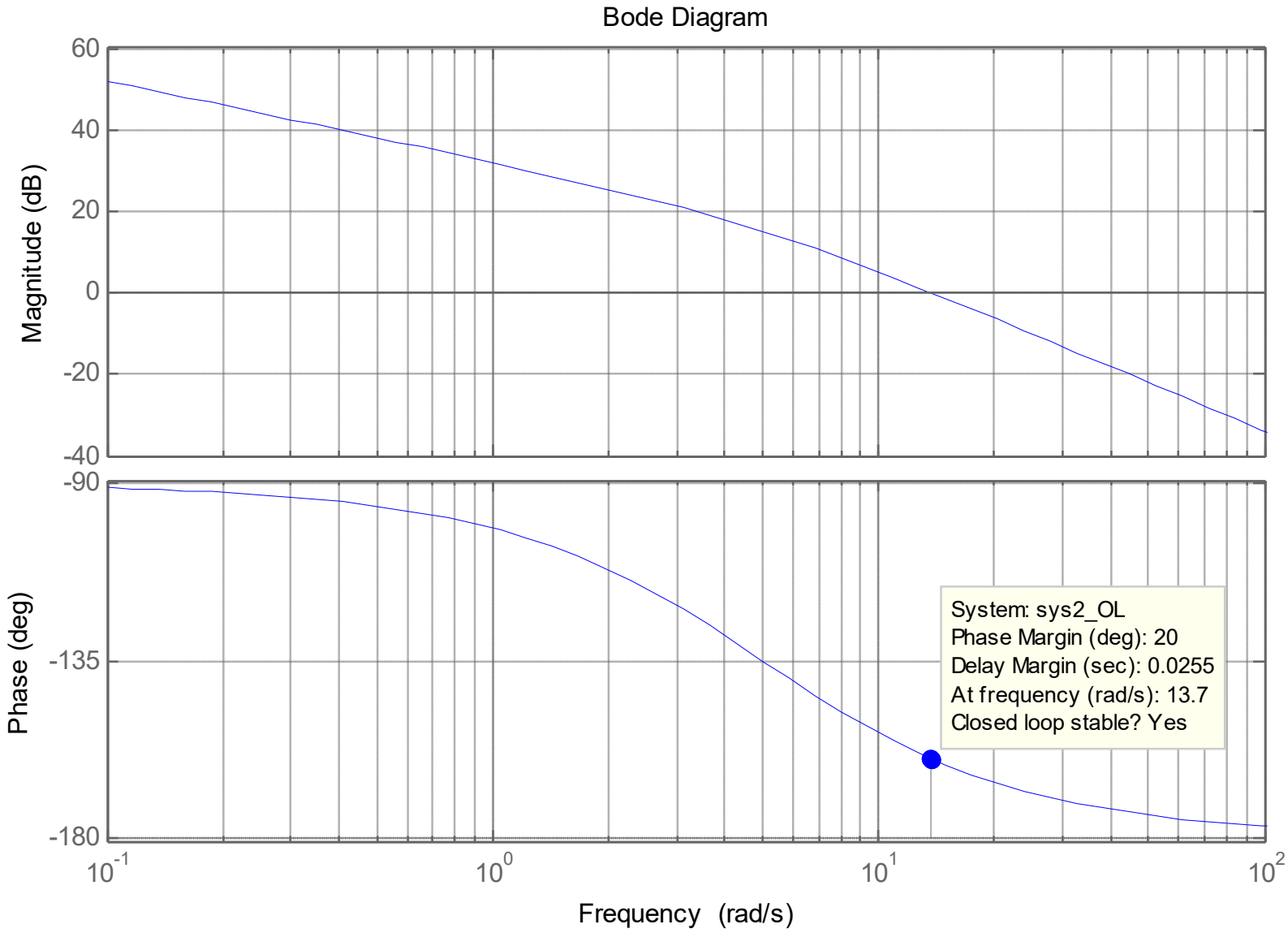
Un-compensated (Krp1=10, Krp4=8)

Un-compensated Response by Matlab



Un-compensated (ACLab3.m, Krp1=10, Krp4=8)

Open-Loop Bode plots by Matlab
Un-compensated



Un-compensated (ACLab3.m, Krp1=10, Krp4=8)

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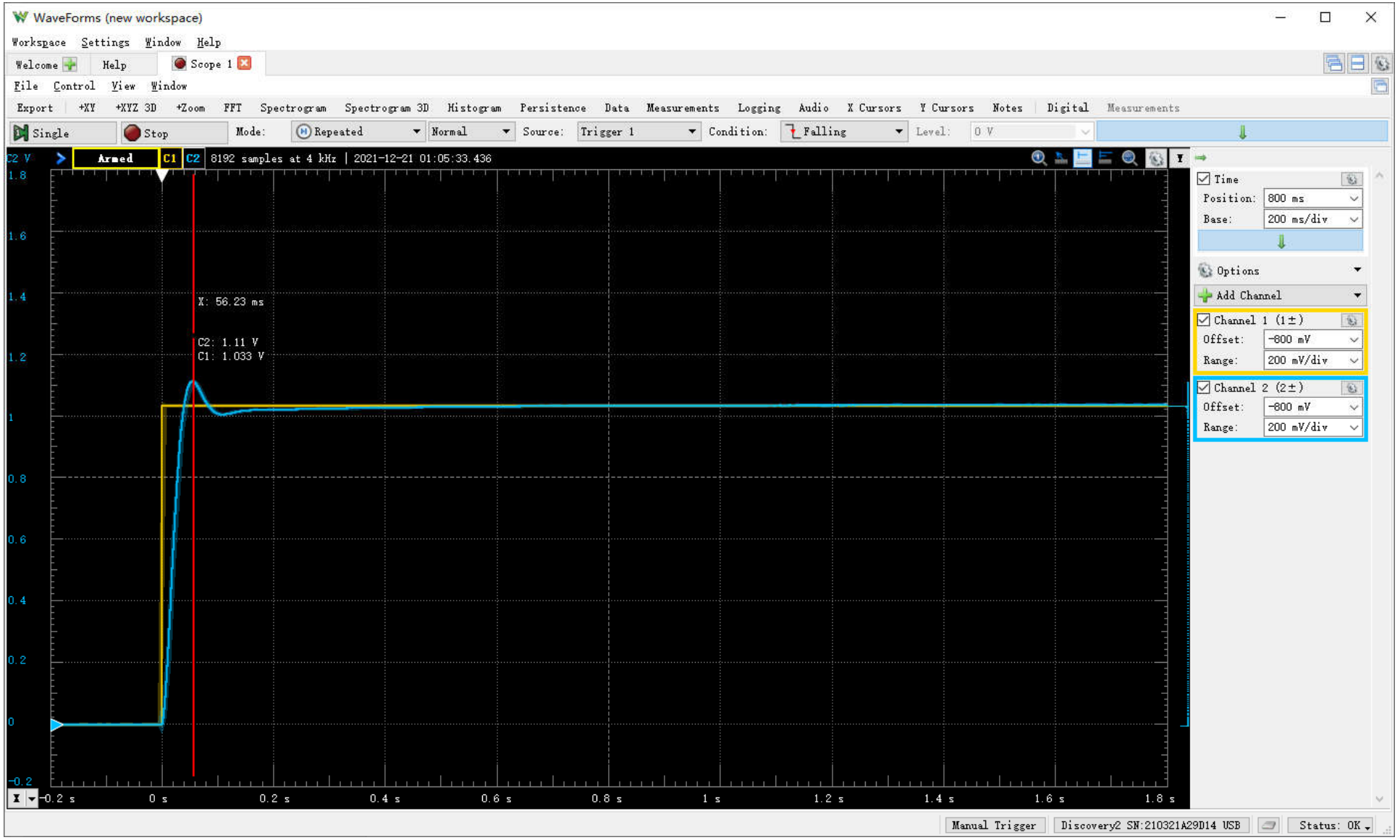
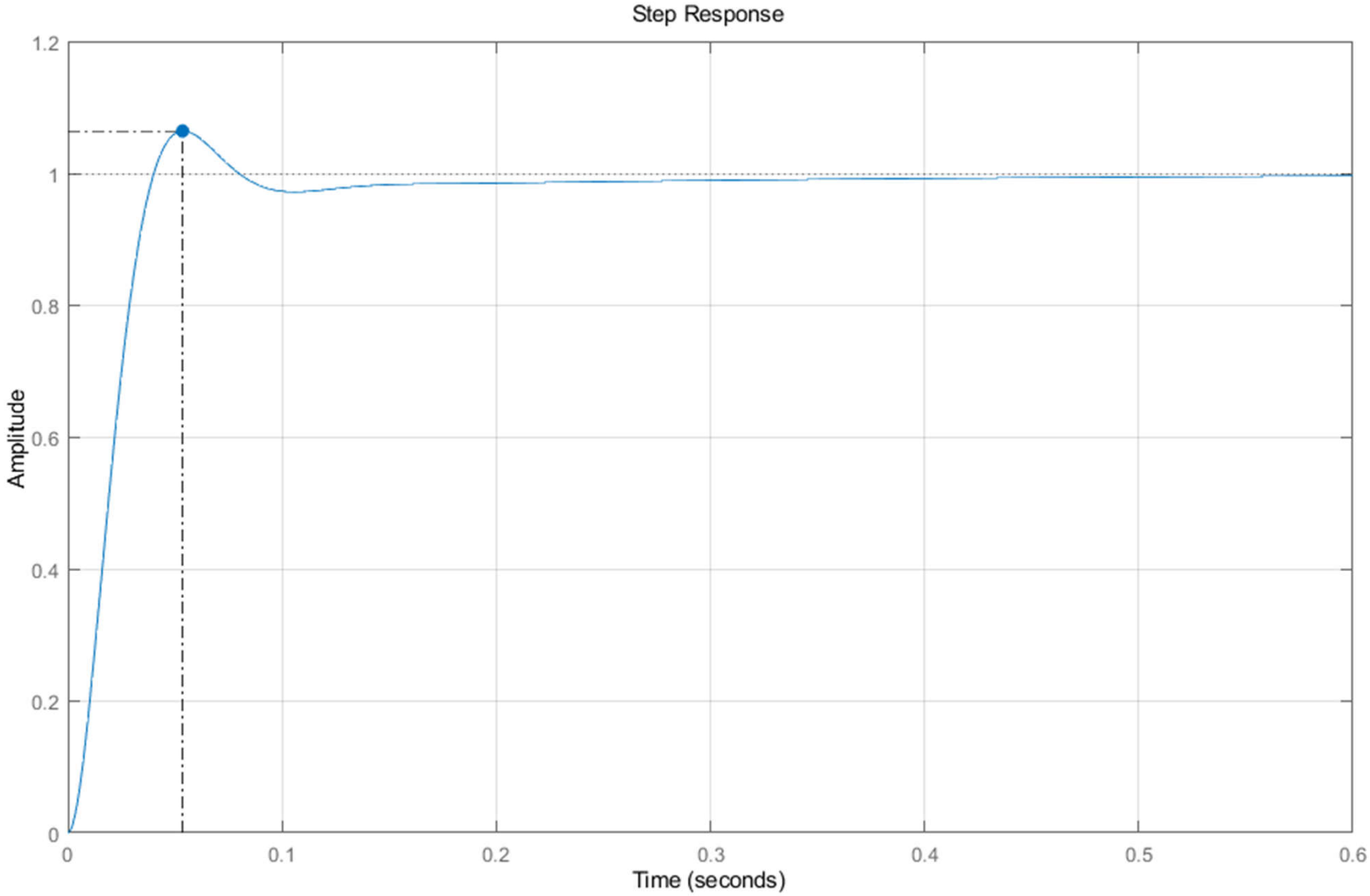
Compensated Dynamic Response



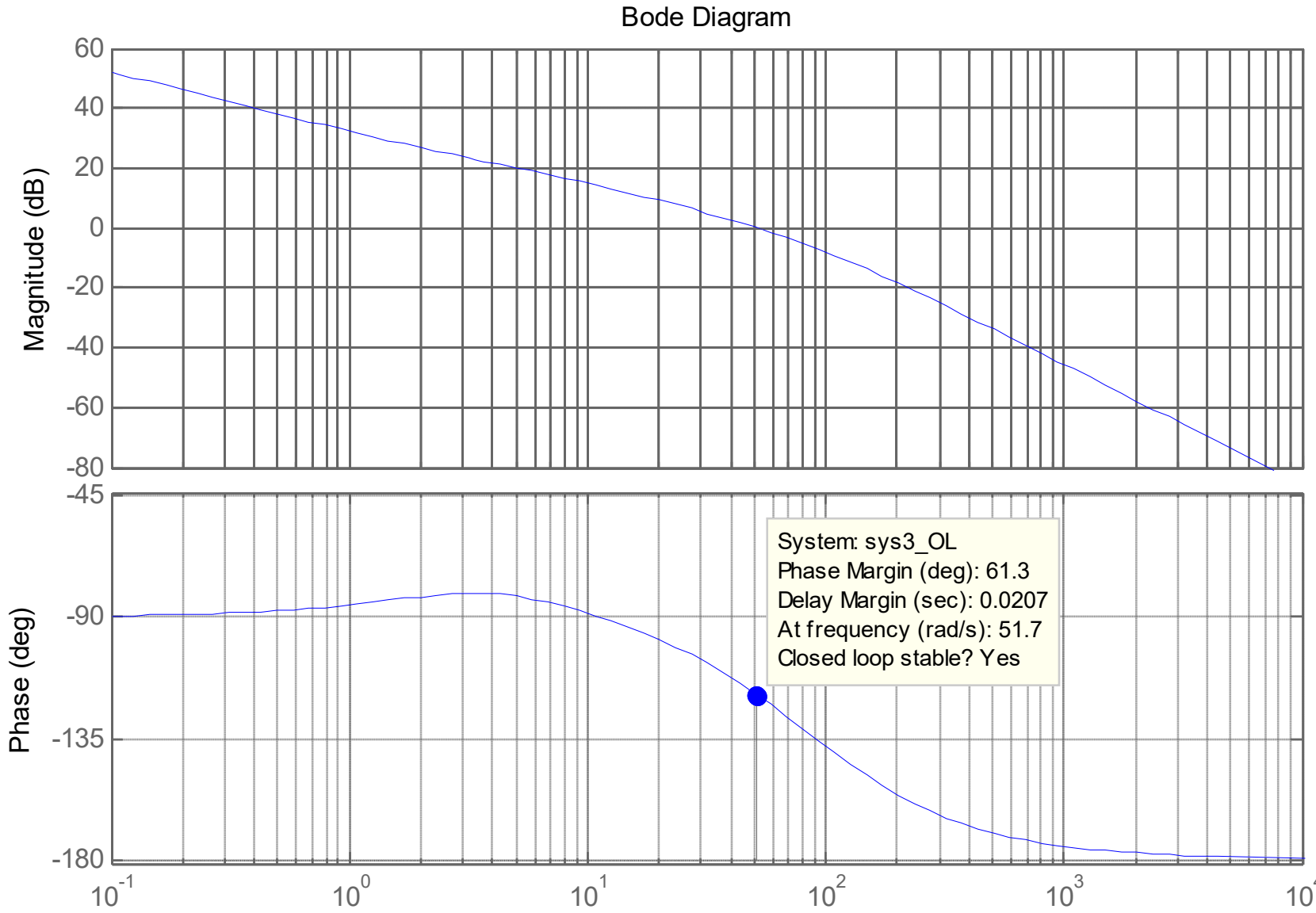
Lead compensated (Krp3=10, Krp4=8)

Compensated Response by Matlab



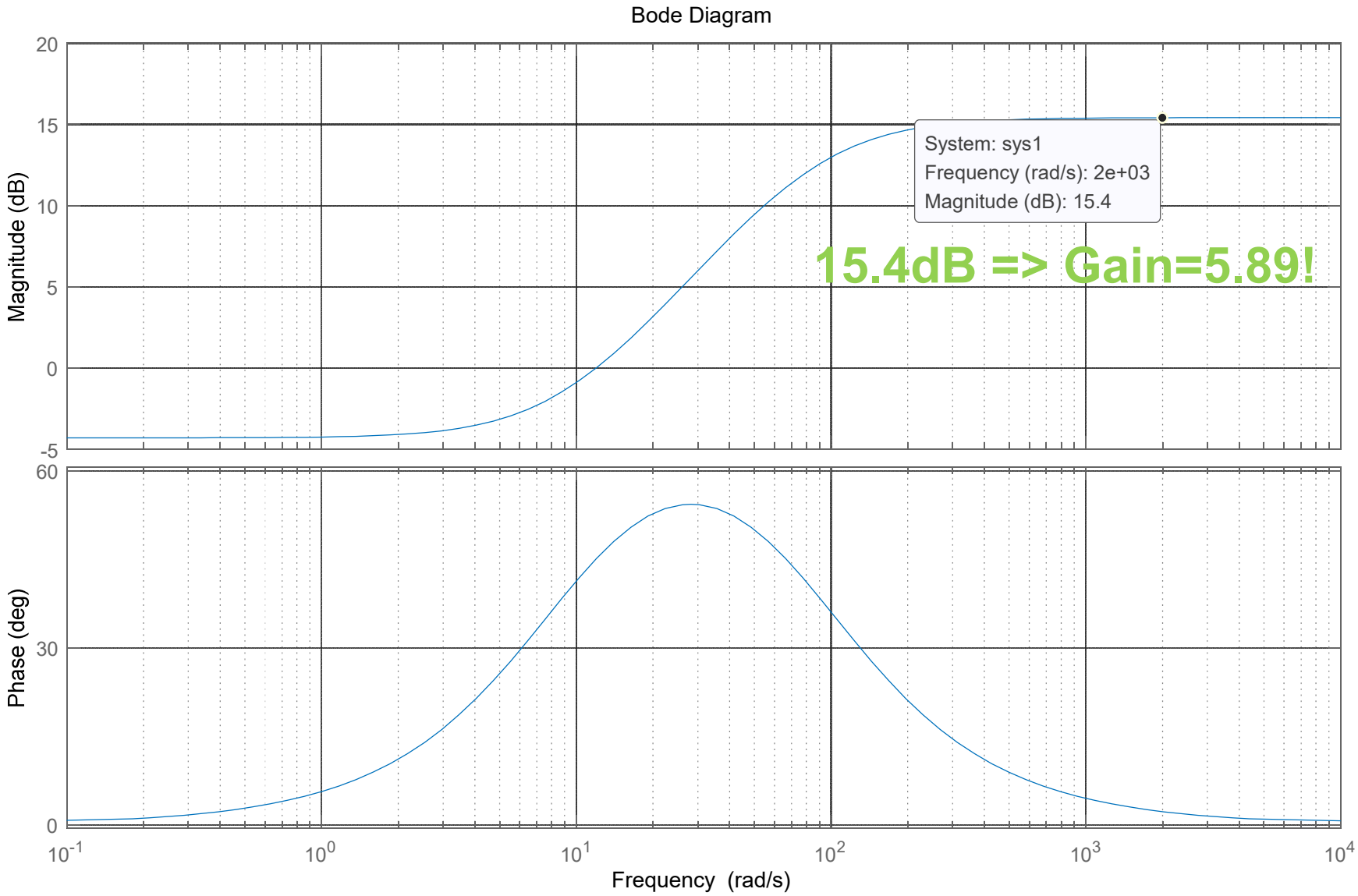
Lead compensated (ACLab3.m, Krp3=10, Krp4=8)

Open-Loop Bode plots by Matlab compensated



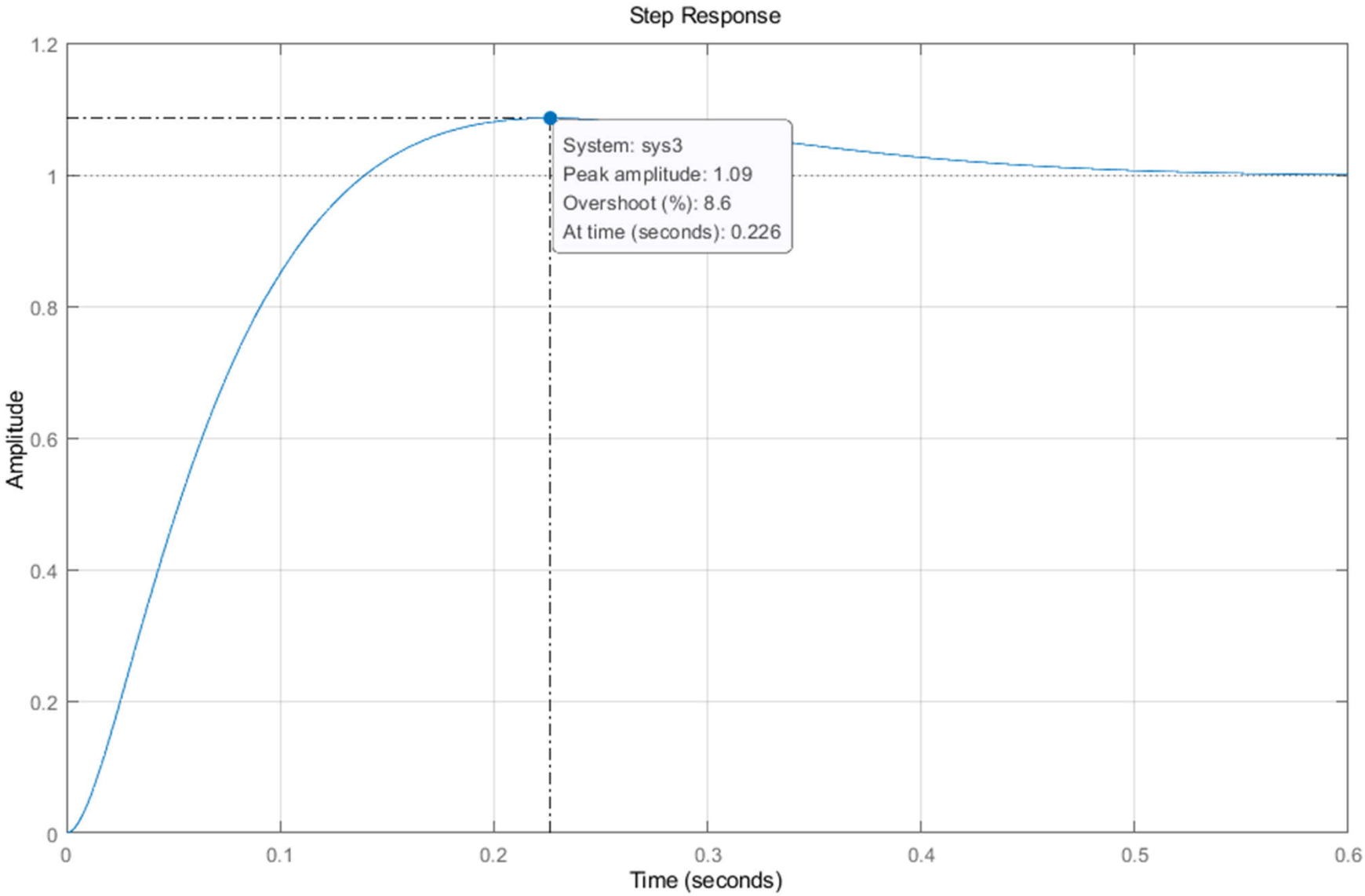
Compensated (ACLab3.m, Krp3=10, Krp4=8)

Alternative Krp3 Values



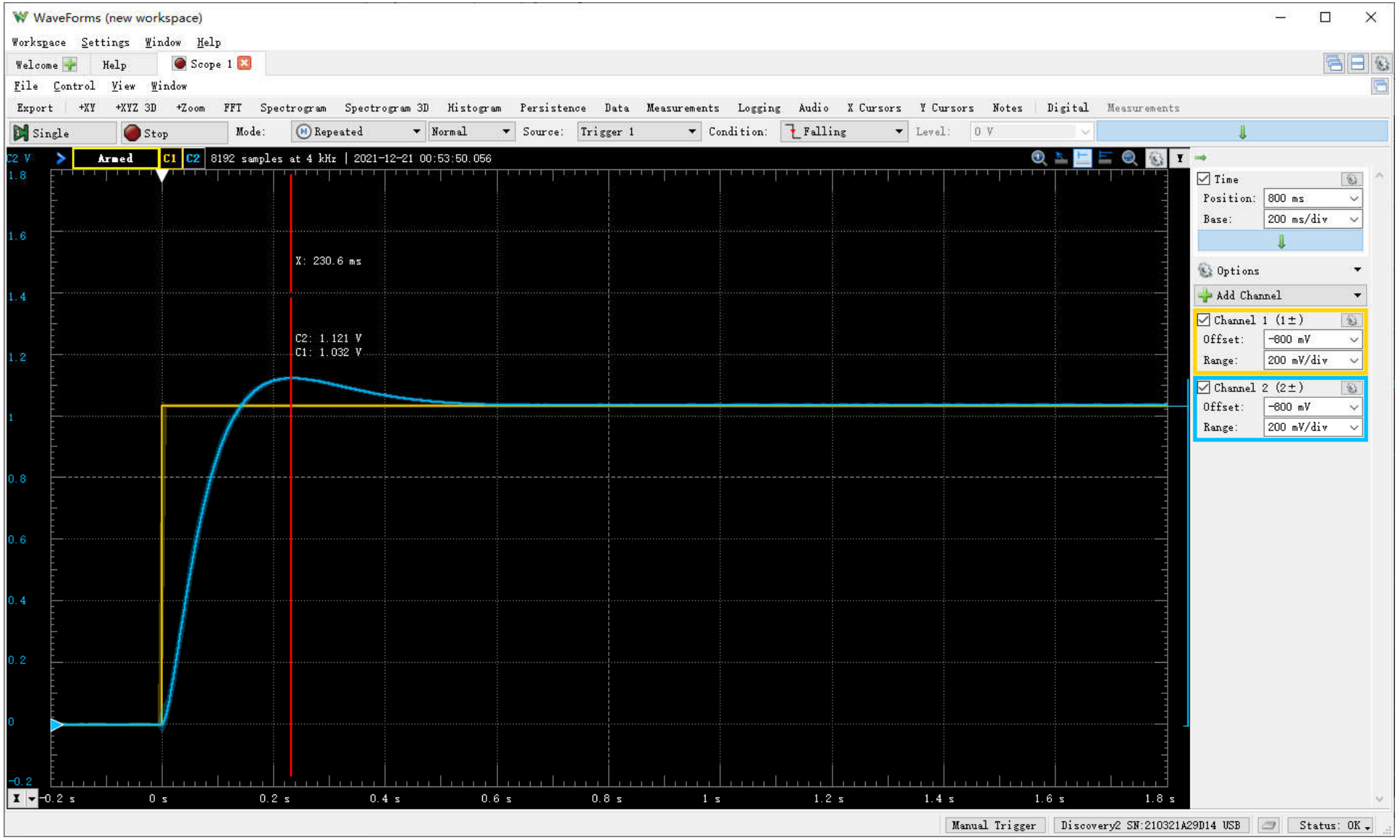
Lead compensator (ACLab3.m, Krp3=2)

Compensated Response by Matlab with Krp3=2



Lead Compensated (ACLab3.m, Krp3=2, Krp4=8)

Compensated Response with Krp3=2



Lead Compensated (Krp3=2, Krp4=8)

Q&A