The Principles of Automatic Control
Lab #3 （online）

Department of Automation
Dec, 2022

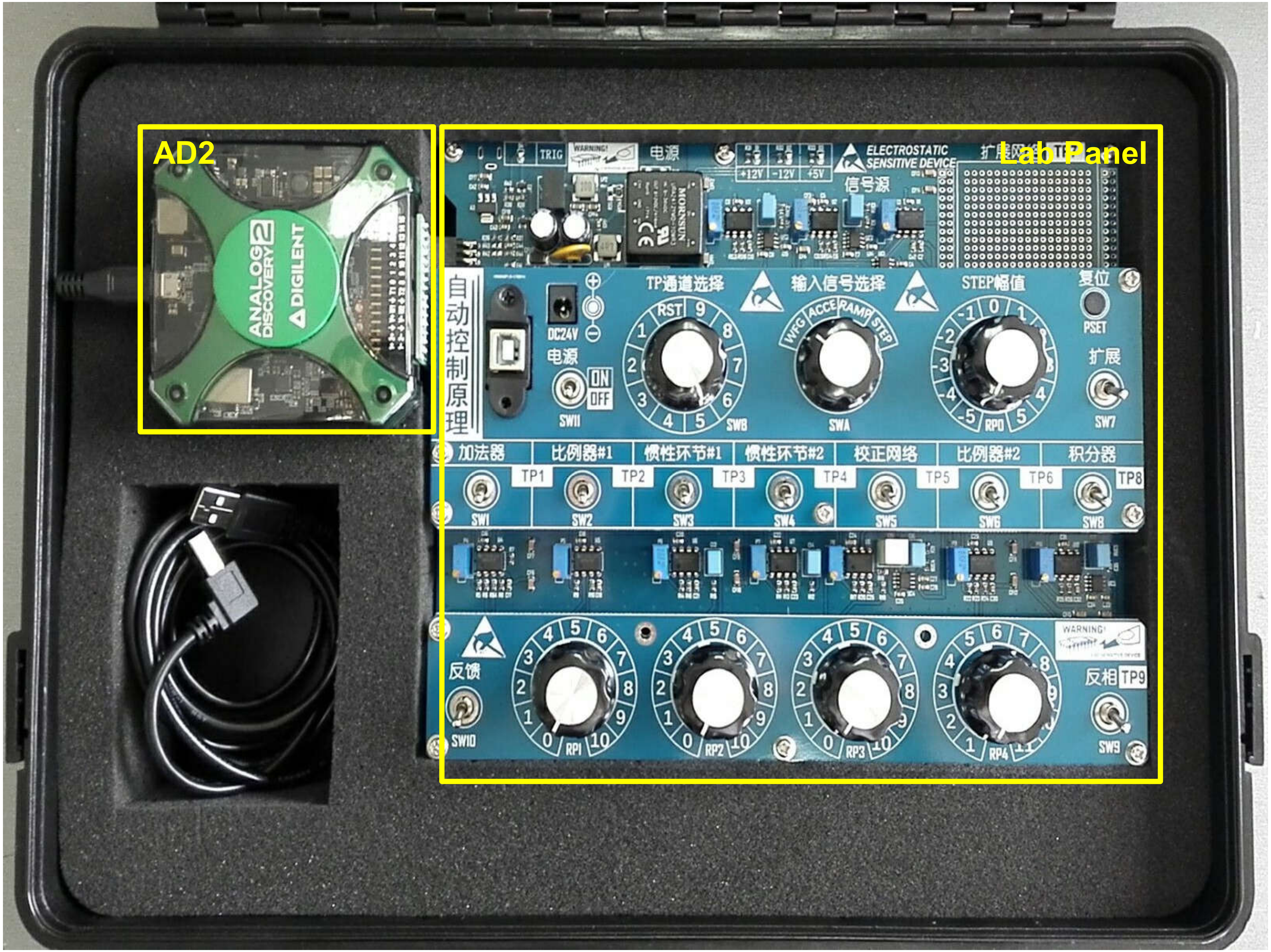
Agenda

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
电源
+12V
-12V
+5V
ELECTROSTATIC SENSITIVE DEVICE
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
RPO
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
WARNING!
反相
TP9
SW9

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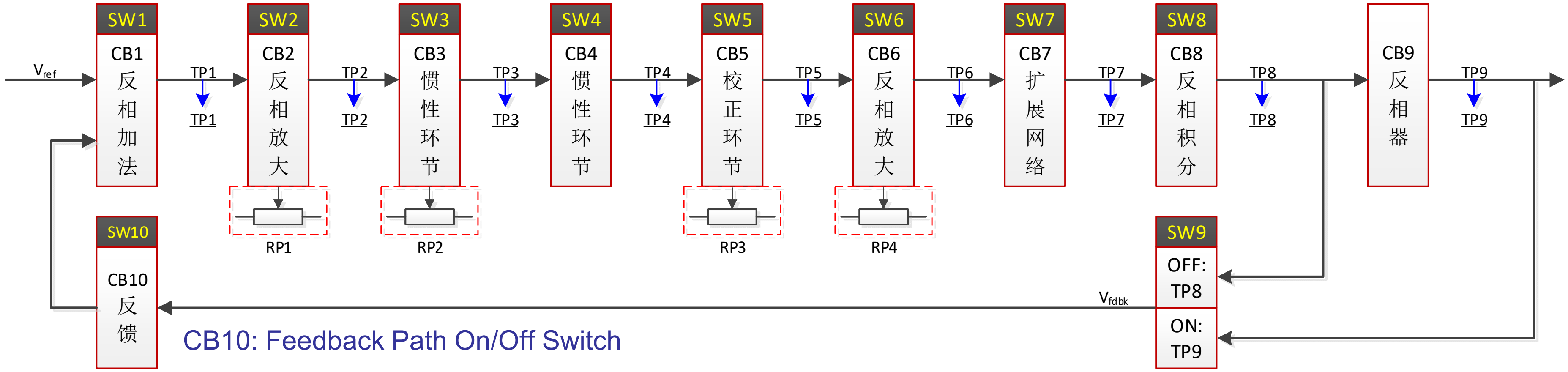
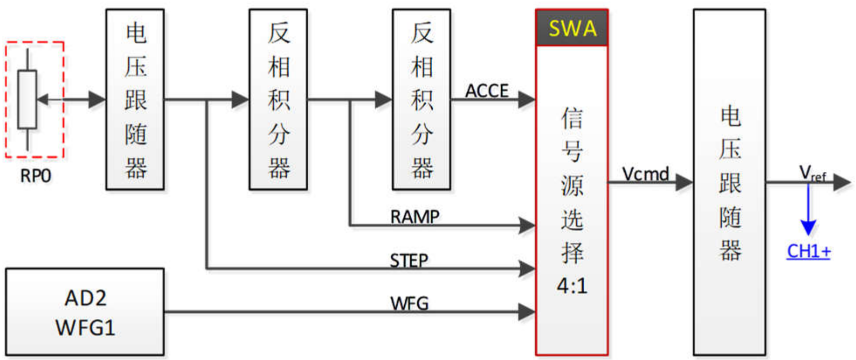
Lab Kit Block Diagram Overview

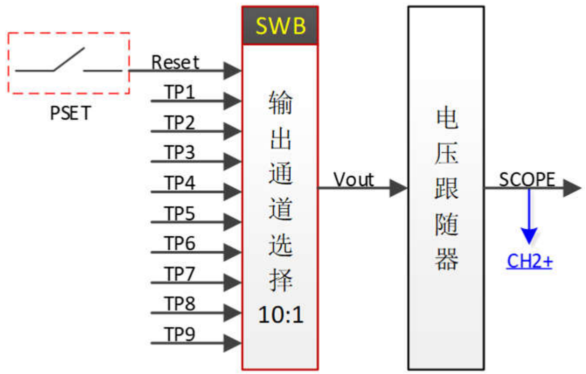


CB1: Inverted Adder
CB2: Inverted Amplifier #1
CB3: Inverted 1st-Order Delay #1
CB4: Inverted 1st-Order Delay #2

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

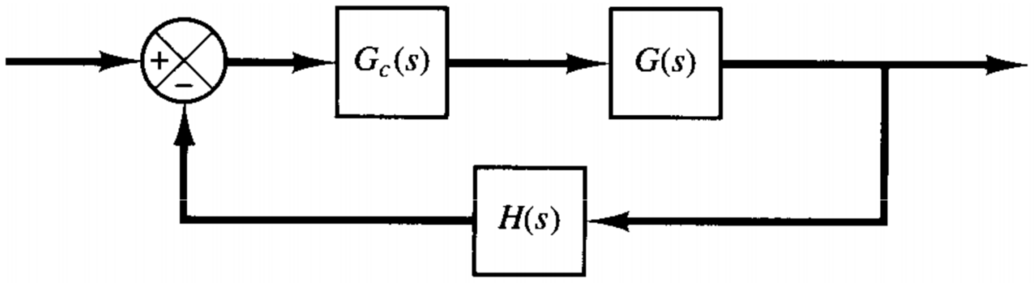




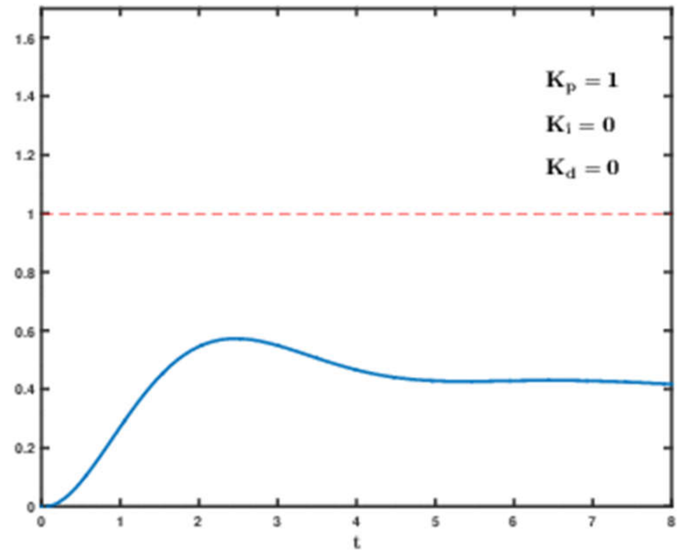
V_{ref} Signal Source Scheme
AD2-SCOPE CH1+ is fixedly connected to V_{ref}

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

Series Compensation Techniques



$$K_p + \frac{K_i}{s} + K_d s = \frac{K_d s^2 + K_p s + K_i}{s}$$

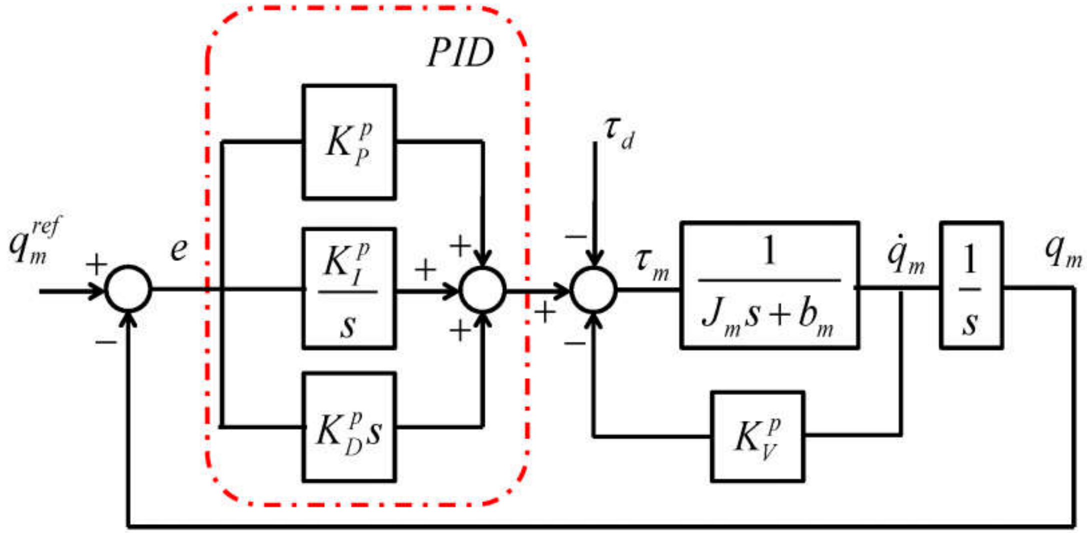


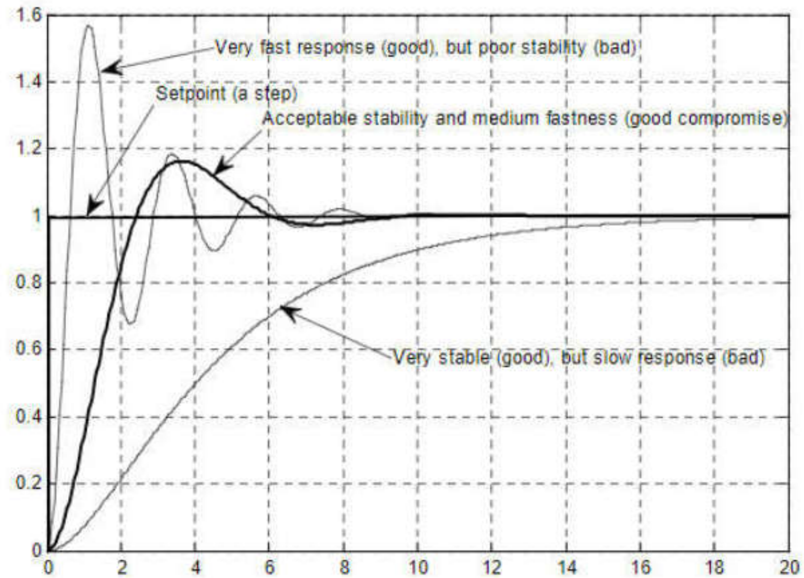
CL RESPONSE	RISE TIME	OVERSHOOT	SETTLING TIME	S-S ERROR
Kp	Decrease	Increase	Small Change	Decrease
Ki	Decrease	Increase	Increase	Decrease
Kd	Small Change	Decrease	Decrease	No Change

PID Parameters Tuning

When you are designing a PID controller for a given system, follow the steps shown below to obtain a desired response.

1. Obtain an open-loop response and determine what needs to be improved
2. Add a proportional control to improve the rise time
3. Add a derivative control to reduce the overshoot
4. Add an integral control to reduce the steady-state error
5. Adjust each of the gains K_p, K_i, and K_d until you obtain a desired overall response.

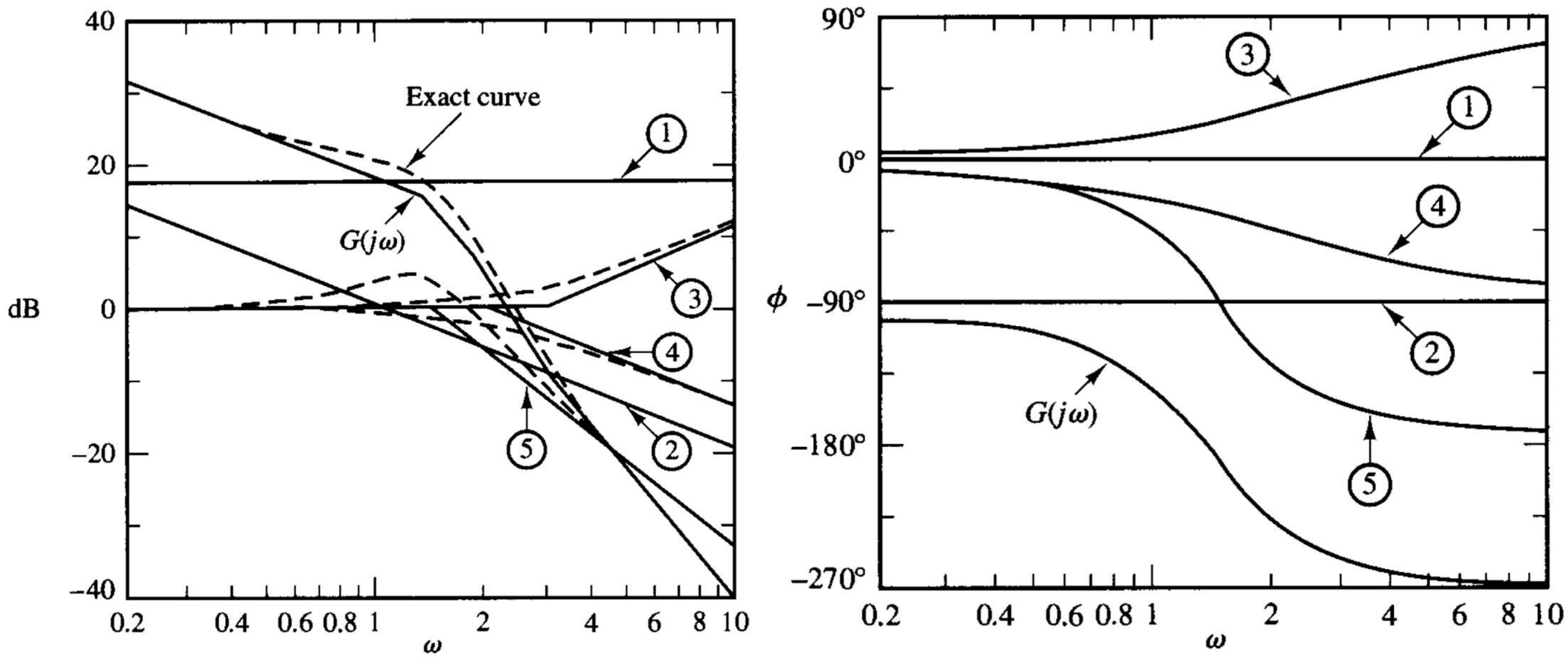




How to Draw the Bode Diagram for a Relatively Complex System

Draw the Bode diagram for the following TF:

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

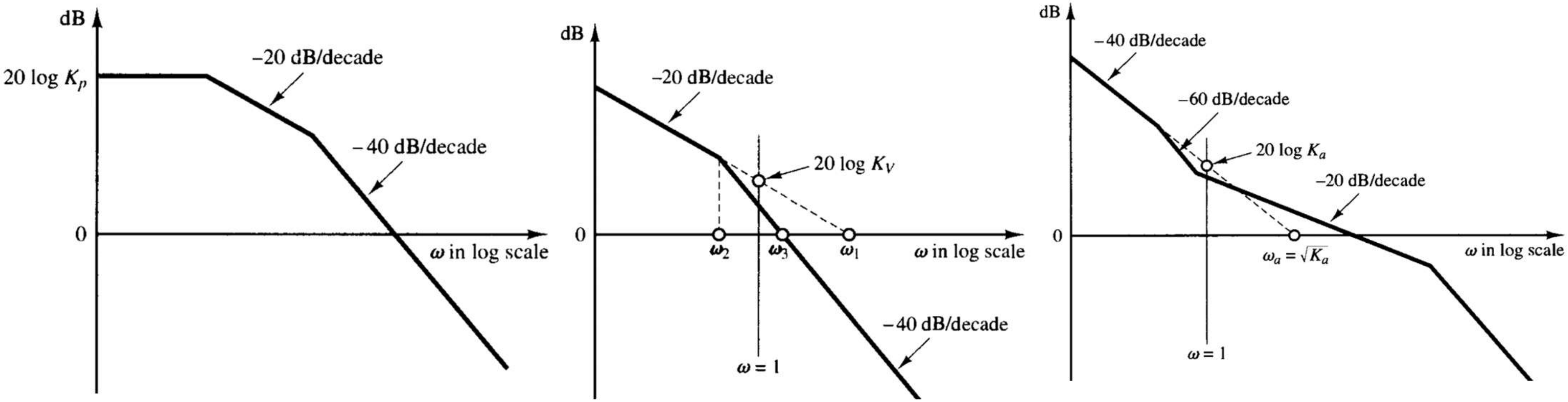


Bode Diagram Features

Relationship between system type and log-magnitude curve

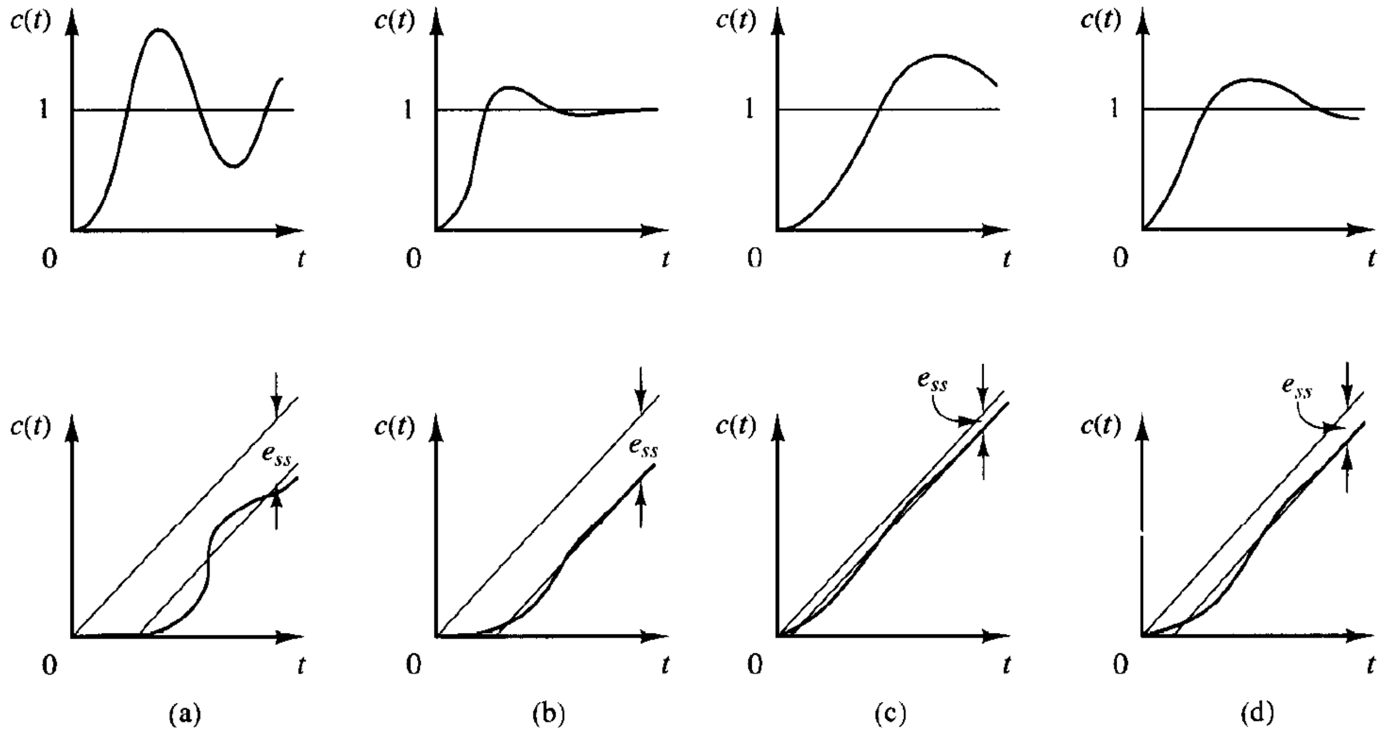
- Type 0, Type 1, Type 2
- Kp, Kv, Ka

Experimental Determination of TF



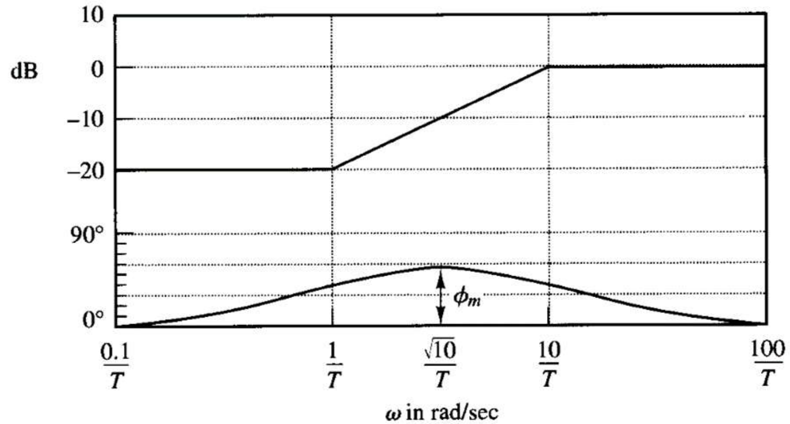
Basic characteristics of different compensation

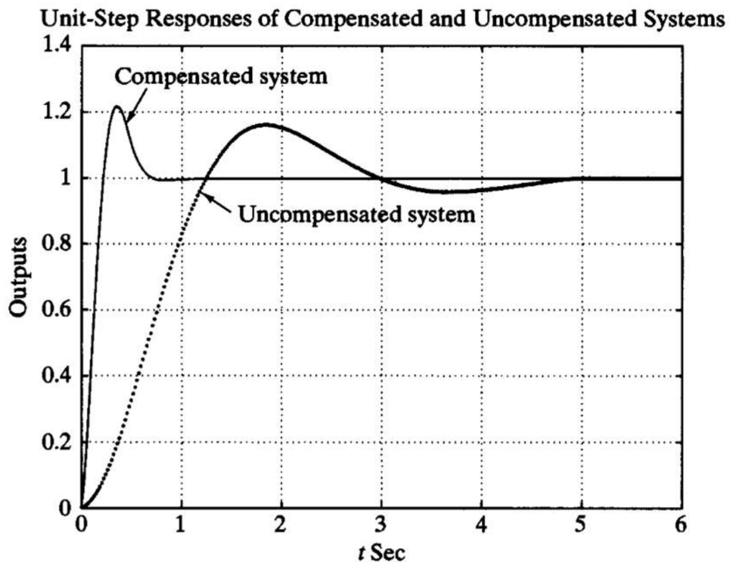
- Lead compensation （b）
- Lag compensation （c）
- Lag-lead compensation （d）

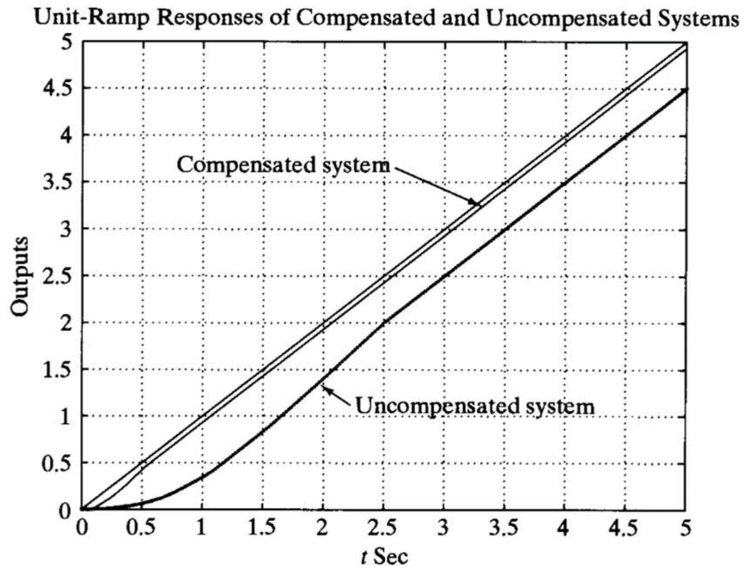


Characteristics of lead compensators

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

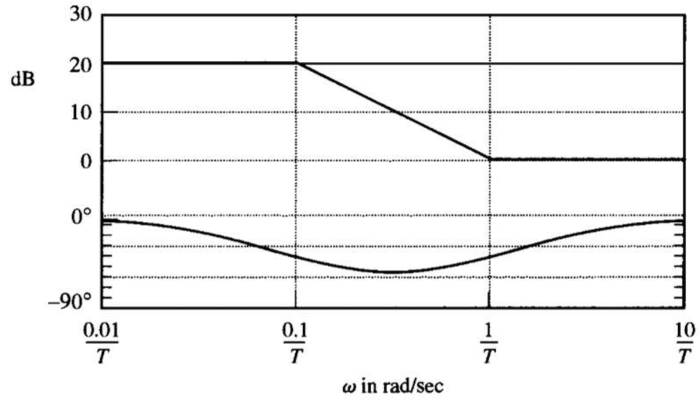


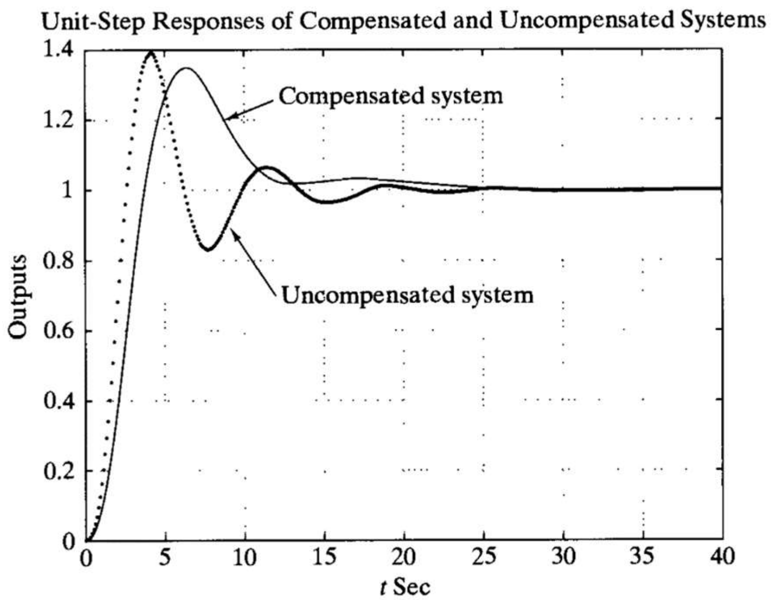


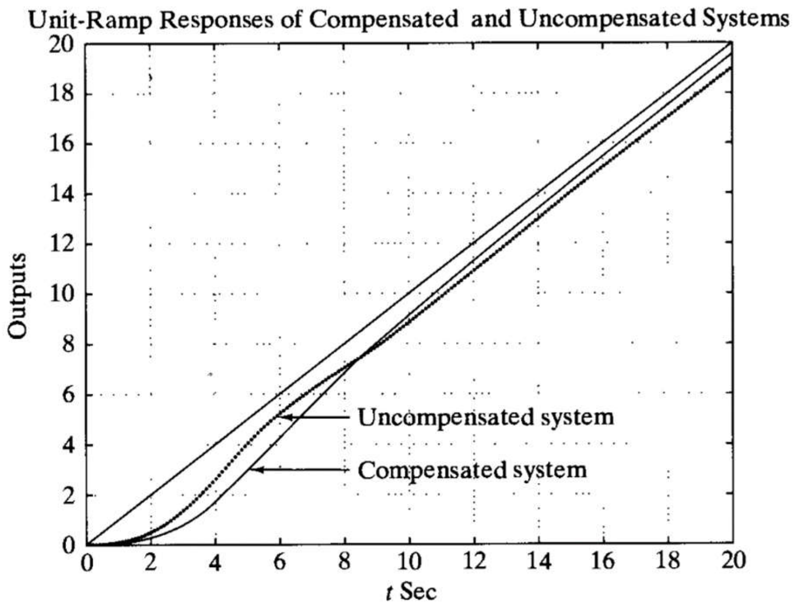


Characteristics of lag compensators

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



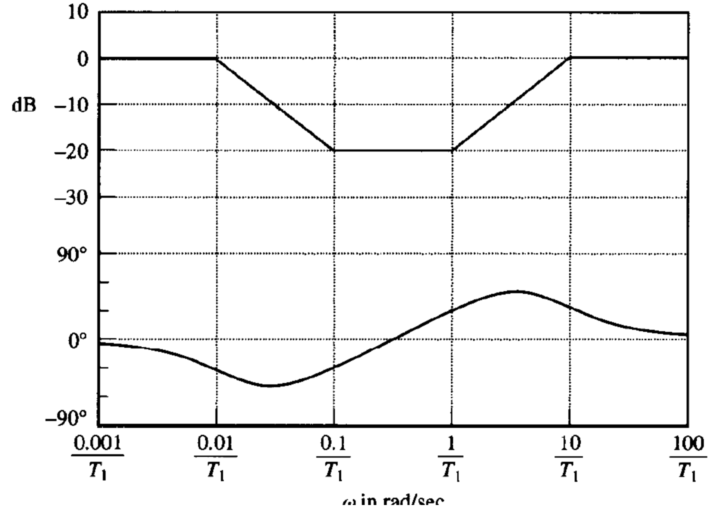


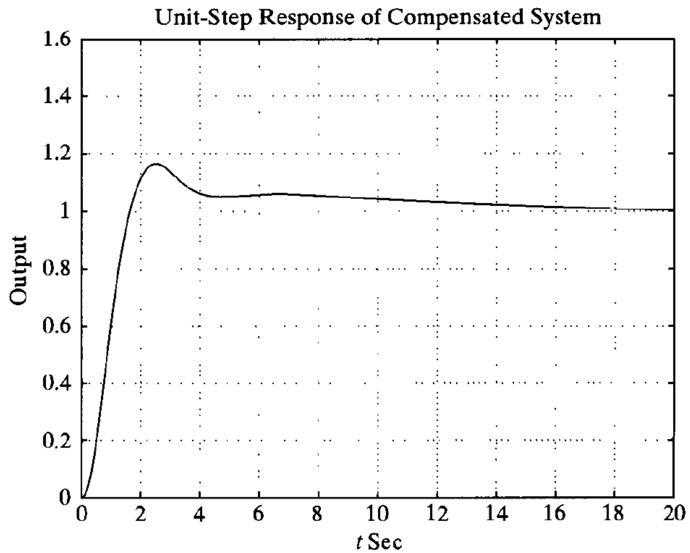


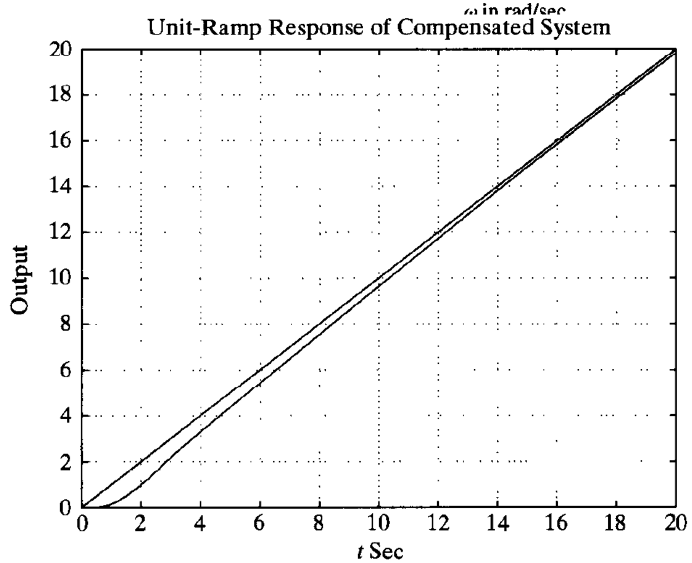
Lead-Lag Compensation

Characteristics of lead-lag compensators

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







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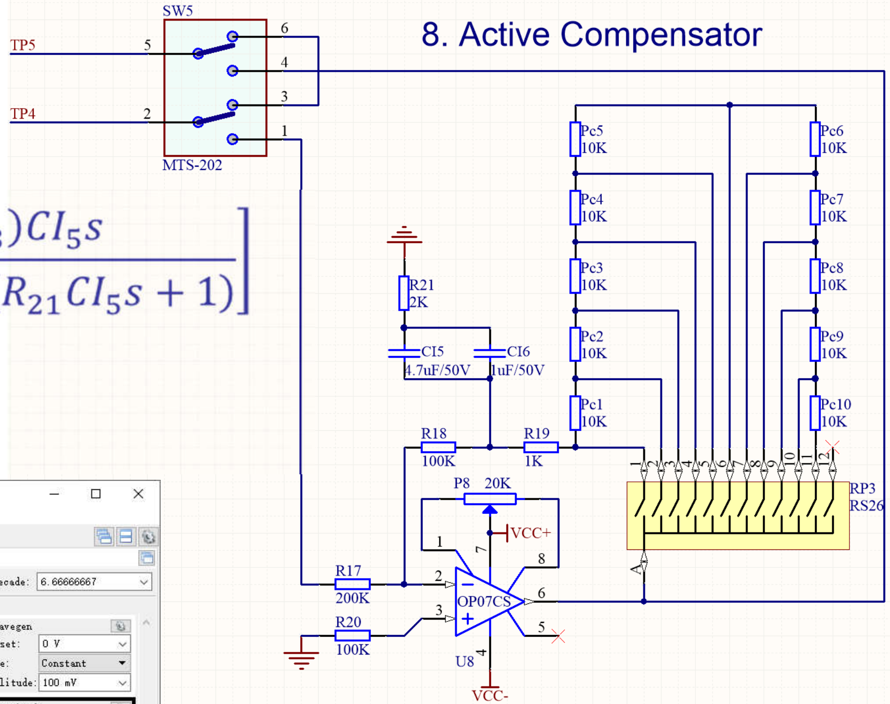
CB5 (SW5): Compensation Network

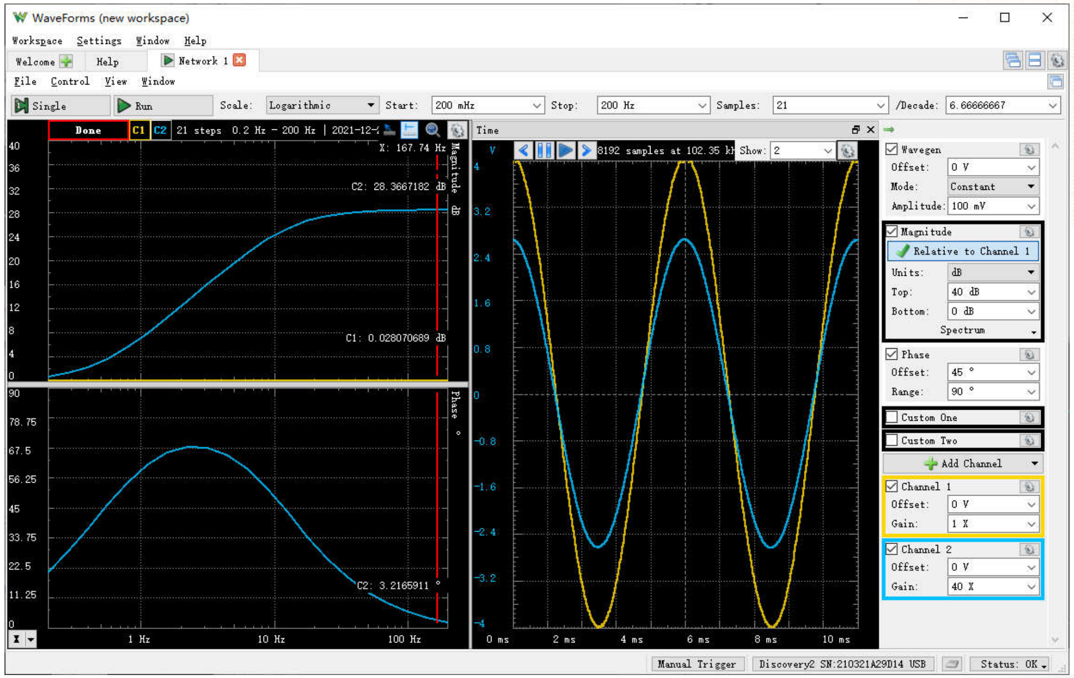
Key Points

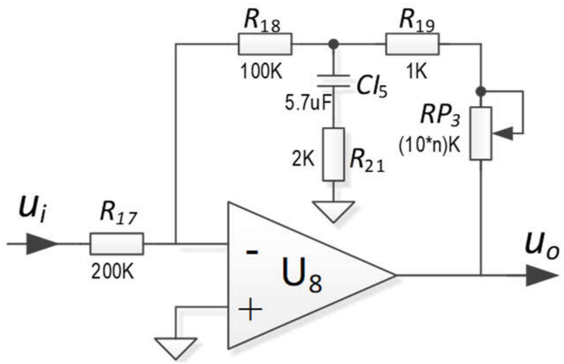
- Transfer function

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

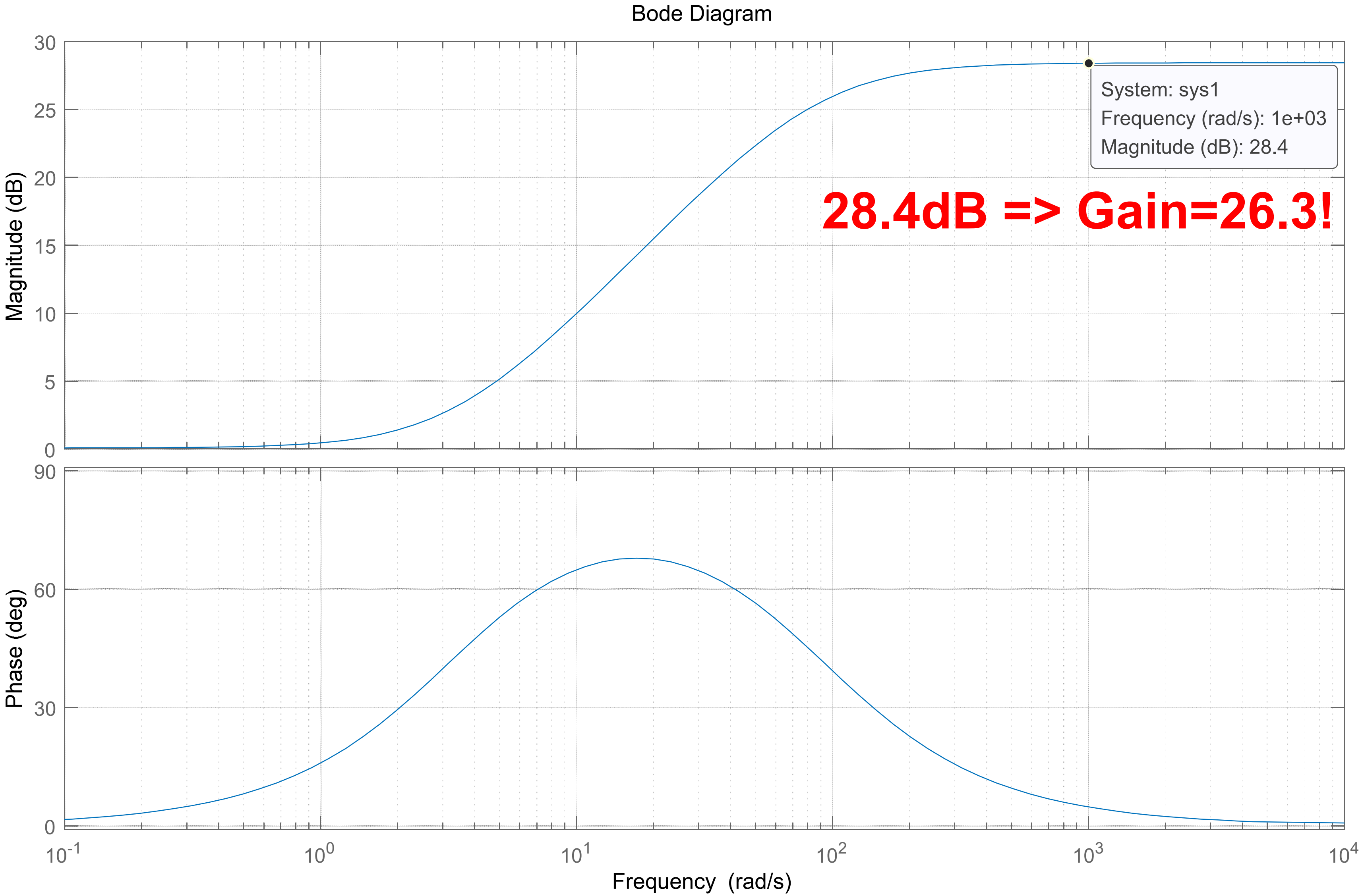
$$K_c\alpha\frac{Ts+1}{\alpha Ts+1}=K_c\frac{s+\frac{1}{T}}{s+\frac{1}{\alpha T}}\qquad(0<\alpha<1)$$







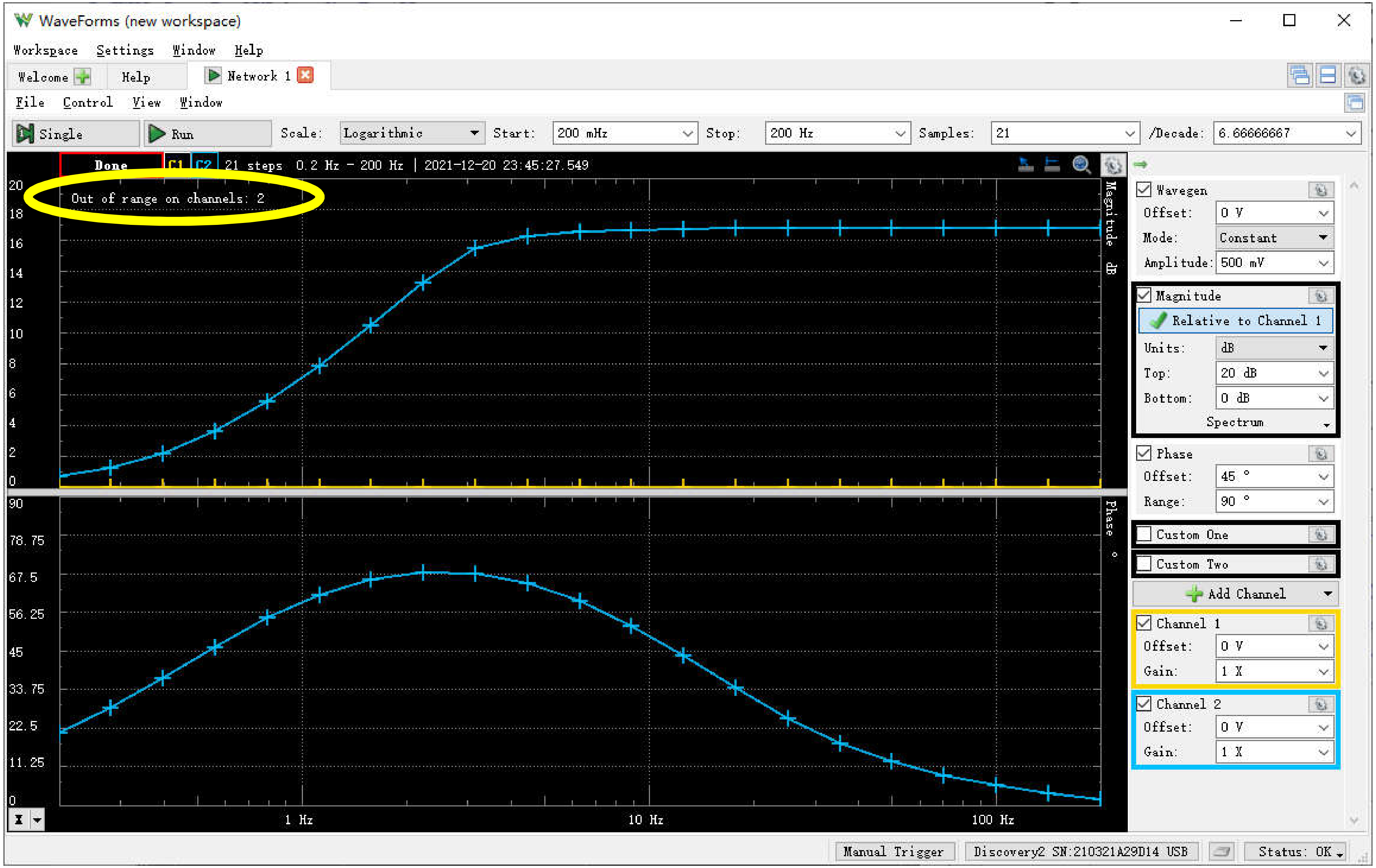
NOTE: the gain at high frequency!



28.4dB => Gain=26.3!

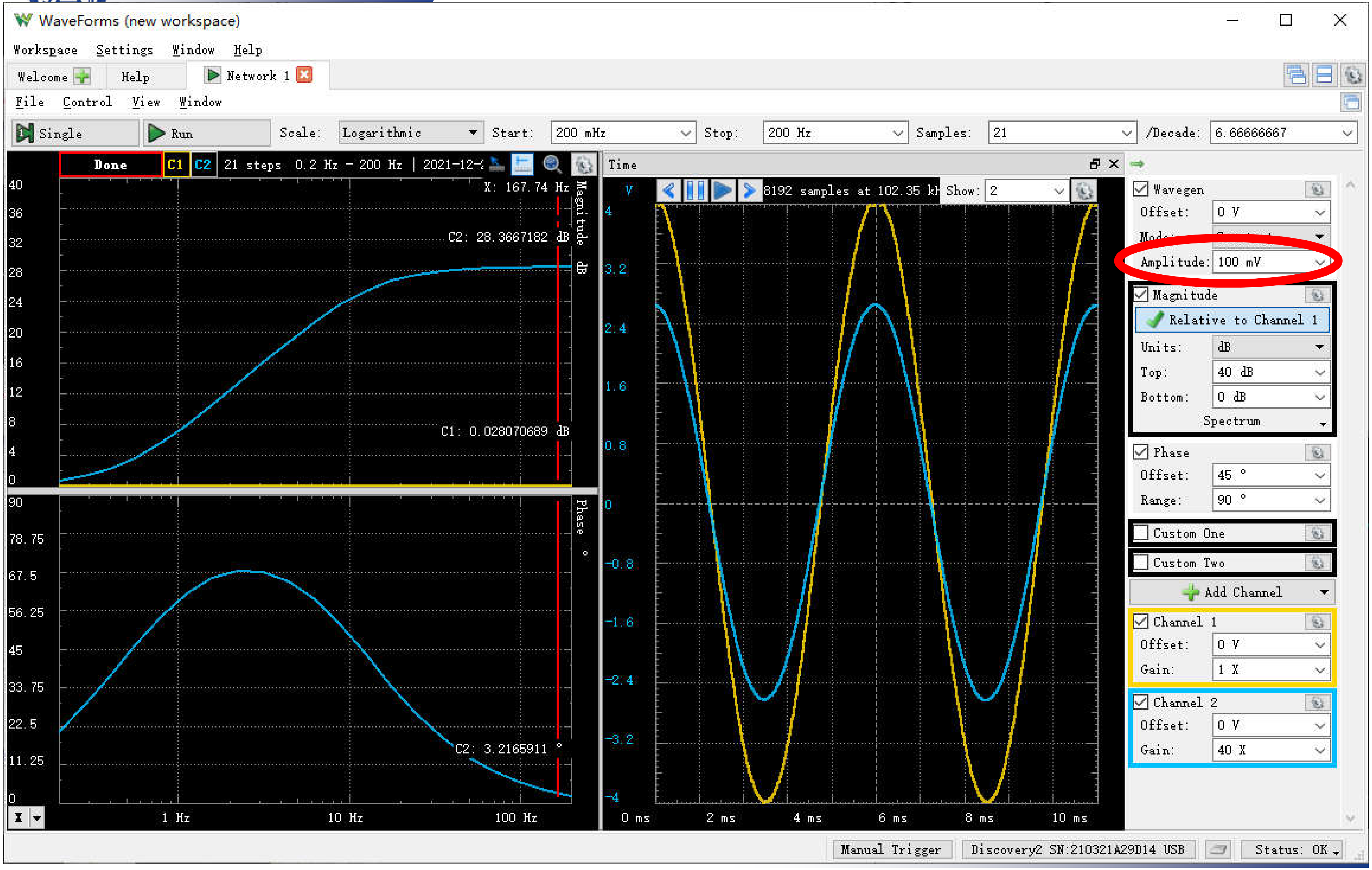
Lead compensator (ACLab3.m, Krp3=10)

Make sure to record correct result!



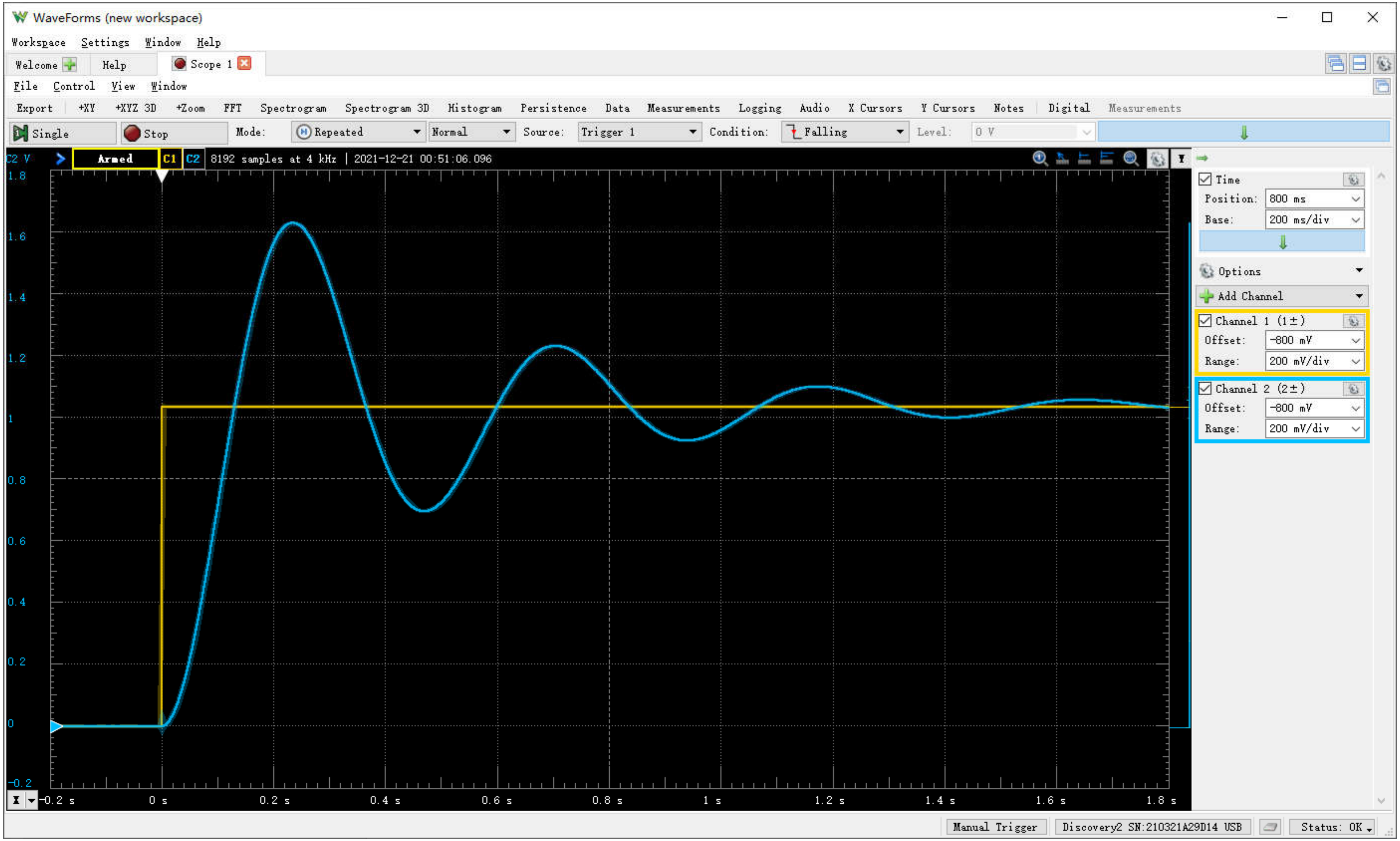
Lead compensator (CB5+CB9, Krp3=10)

DON'T run into saturation!



Lead compensator (CB5+CB9, Krp3=10)

Un-compensated Dynamic Response



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

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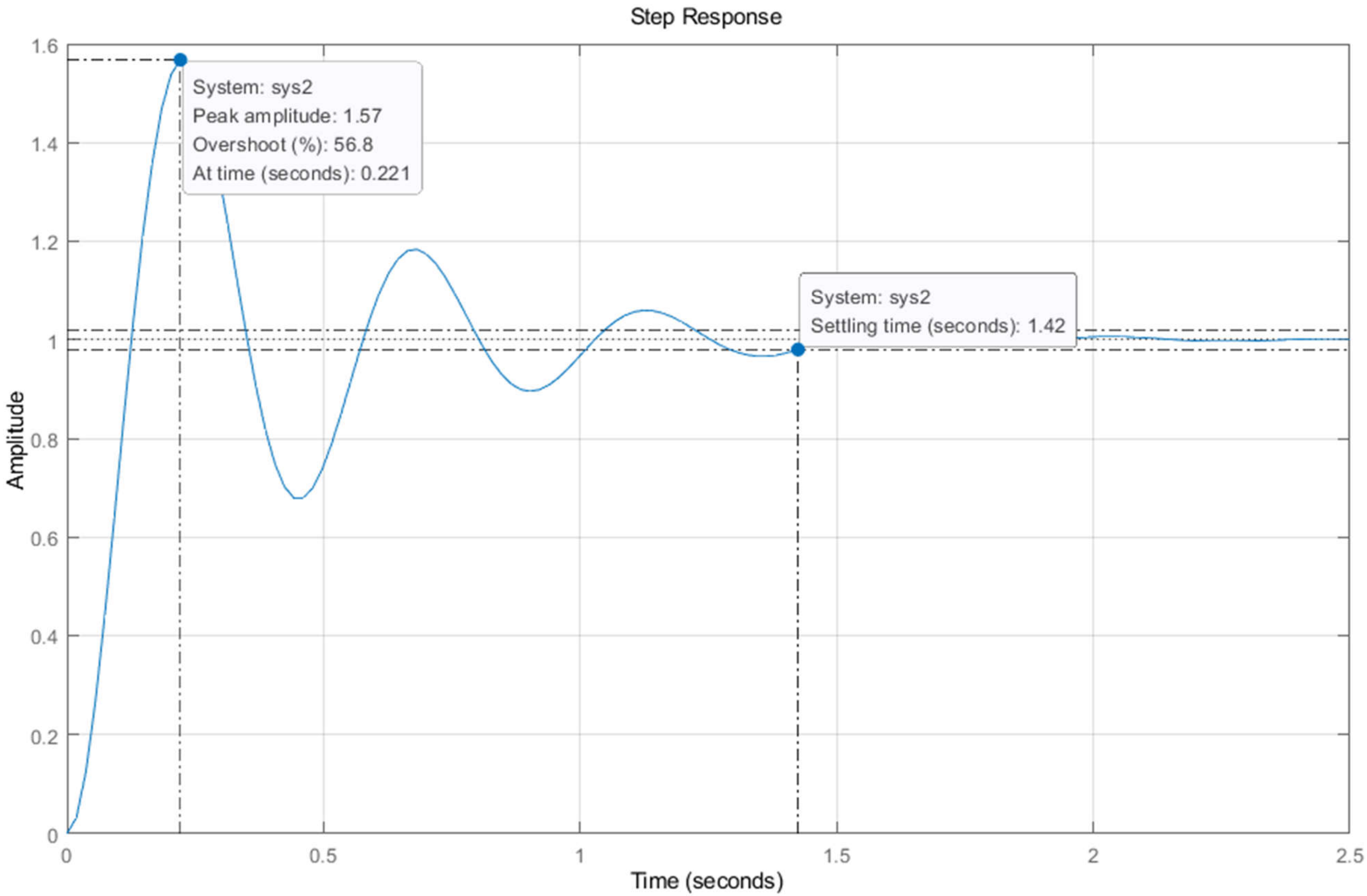
Un-compensated Response by Matlab



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

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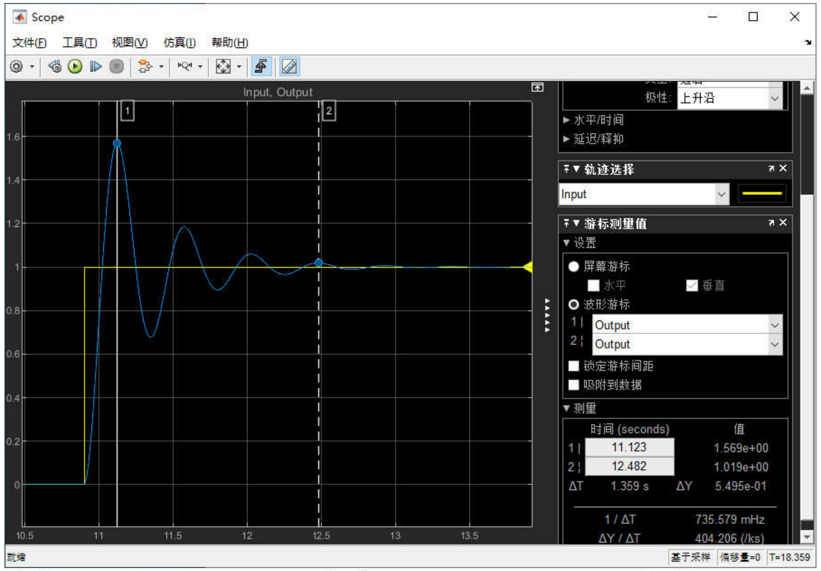
Simulink Model ACLab3_2.slx

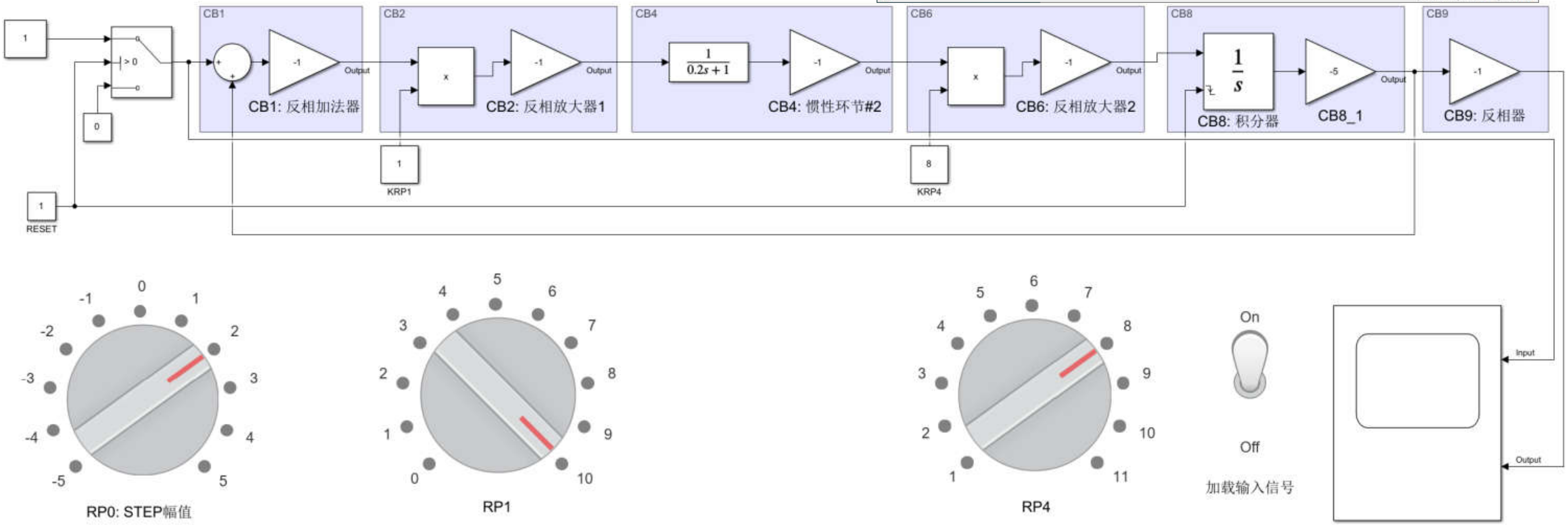
Set parameters

- RP0
- RP1, RP4

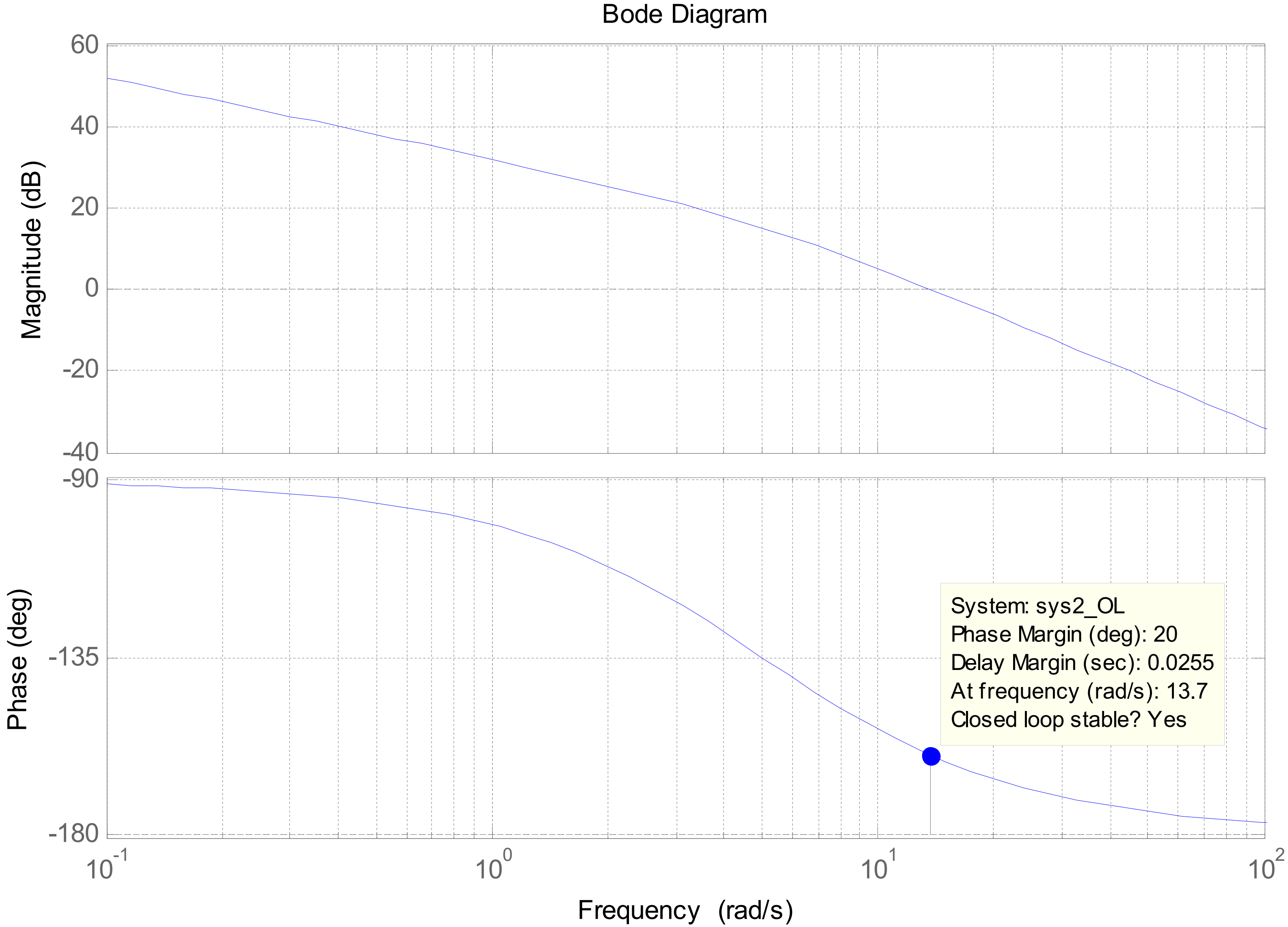
Operation

- Trigger





OL Bode plots by Matlab
Un-compensated



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

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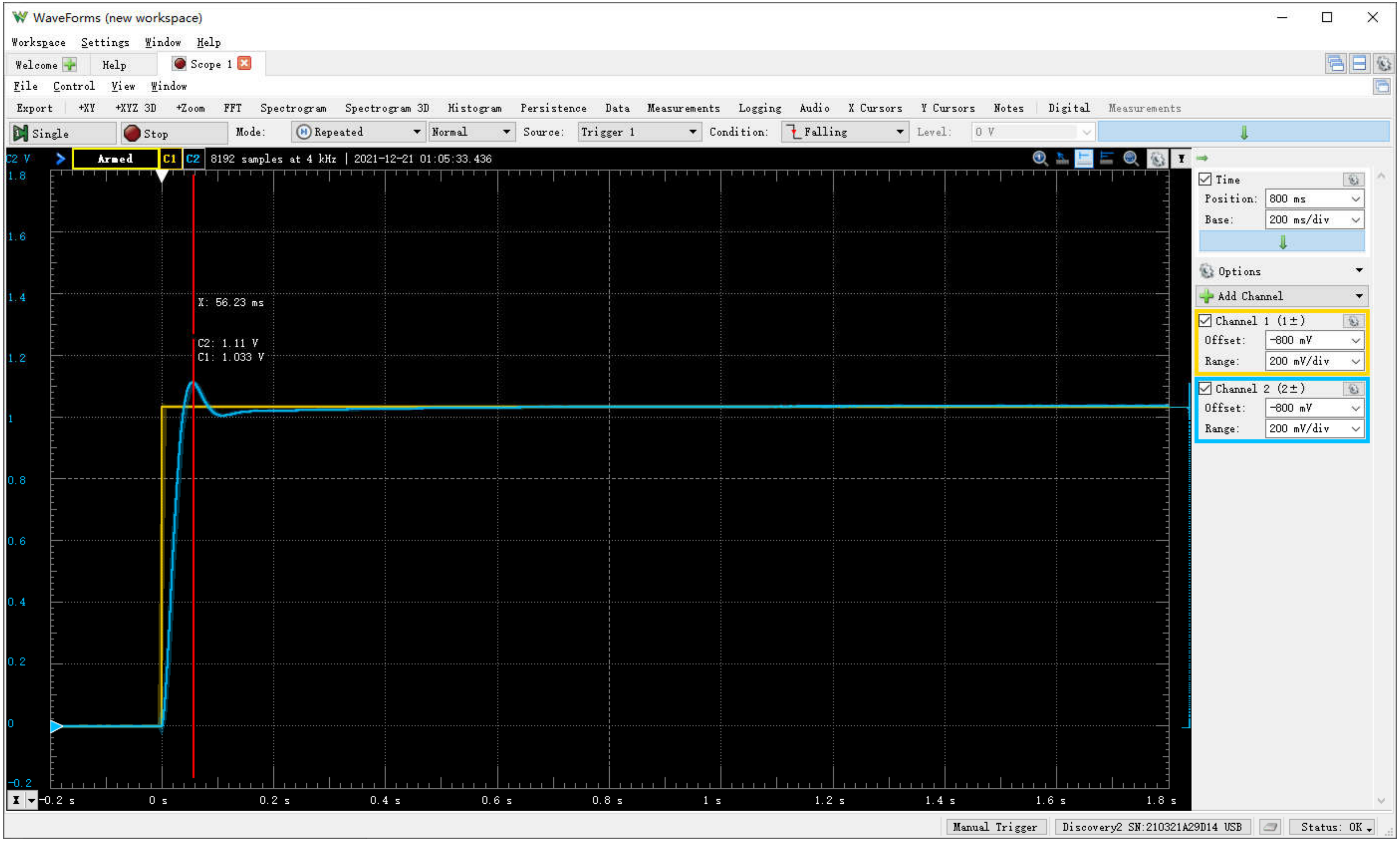
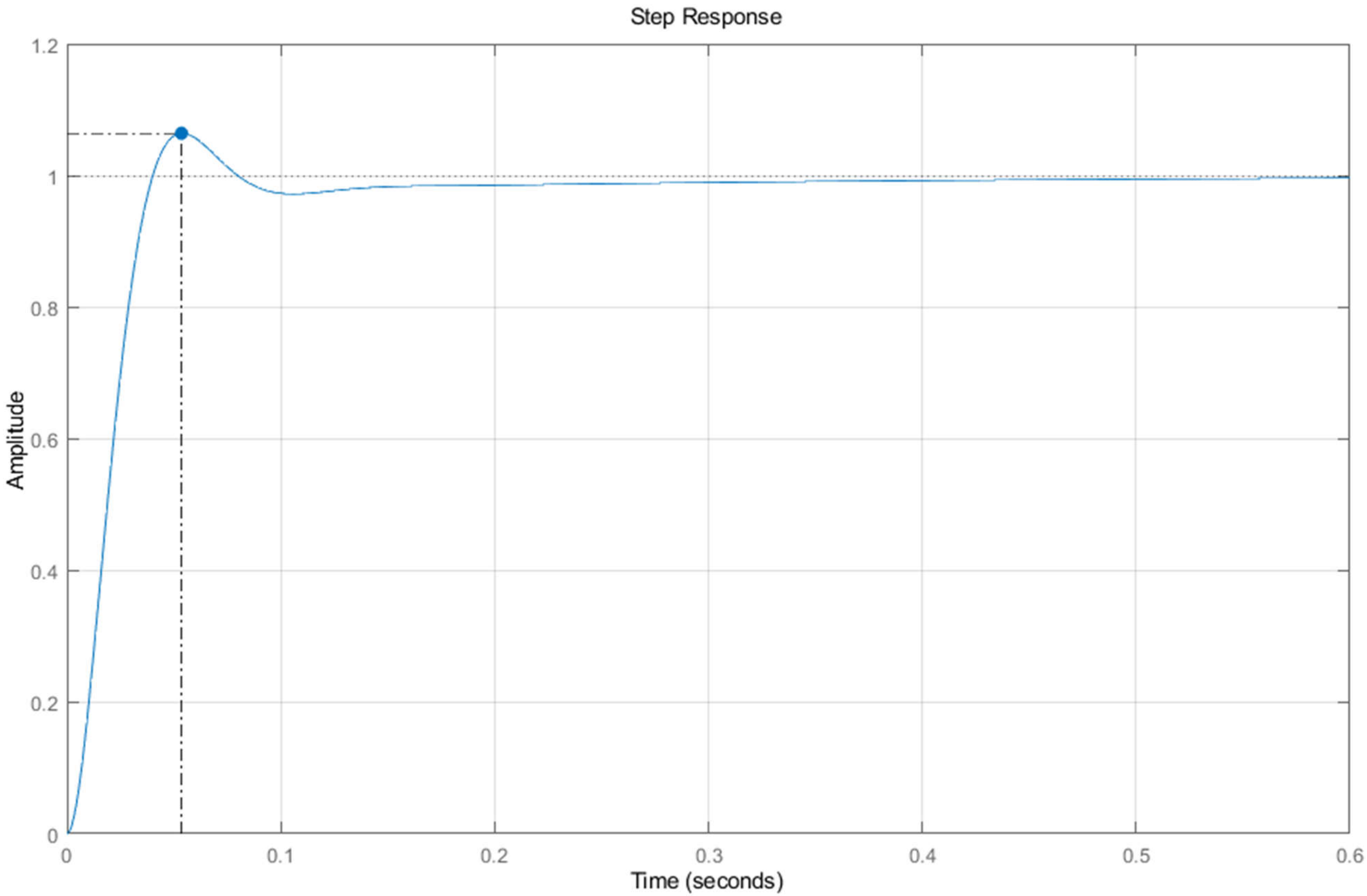
Compensated Dynamic Response



Lead compensated (Krp3=10, Krp4=8)

Compensated Response by Matlab



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

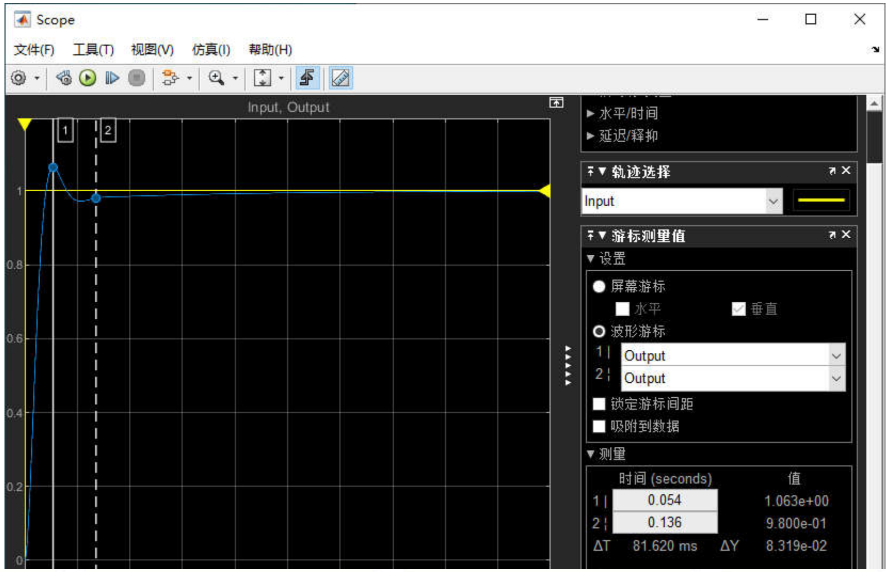
Simulink Model ACLab3_3.slx

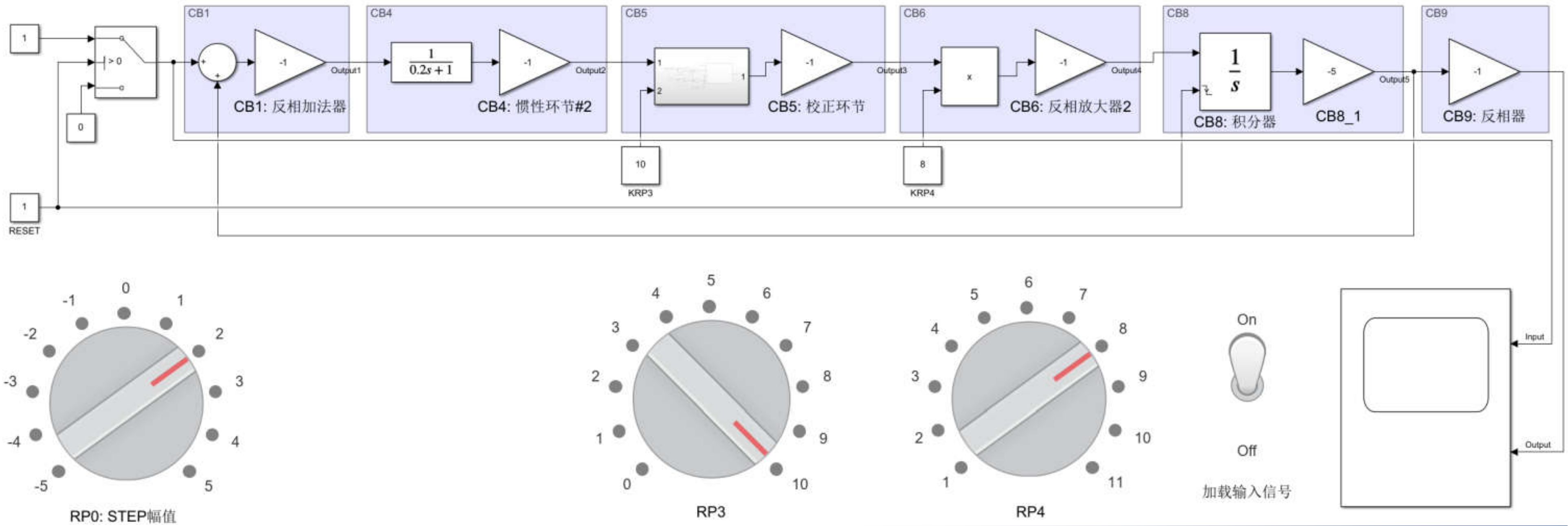
Set parameters

- RP0
- RP3, RP4

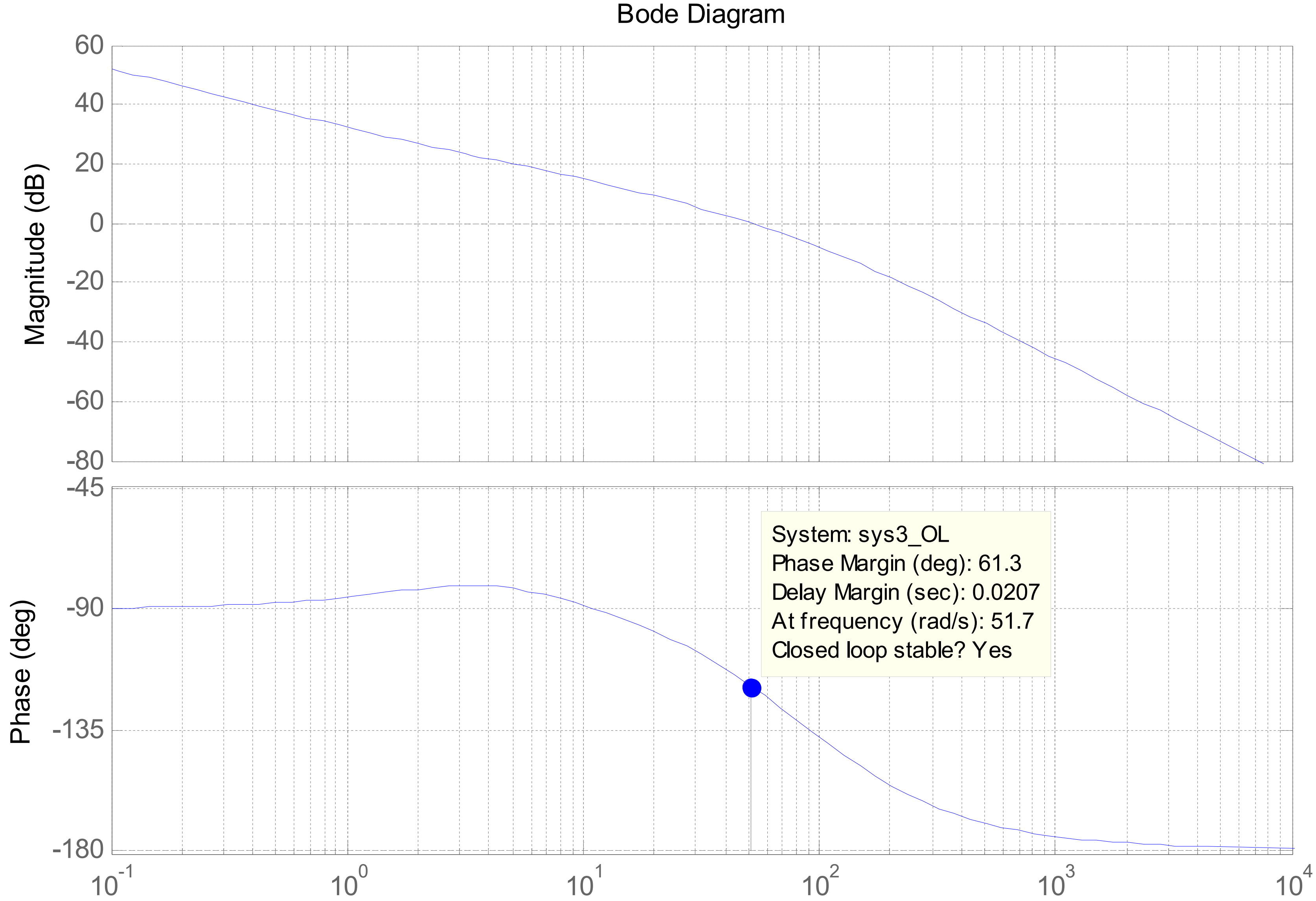
Operation

- Trigger



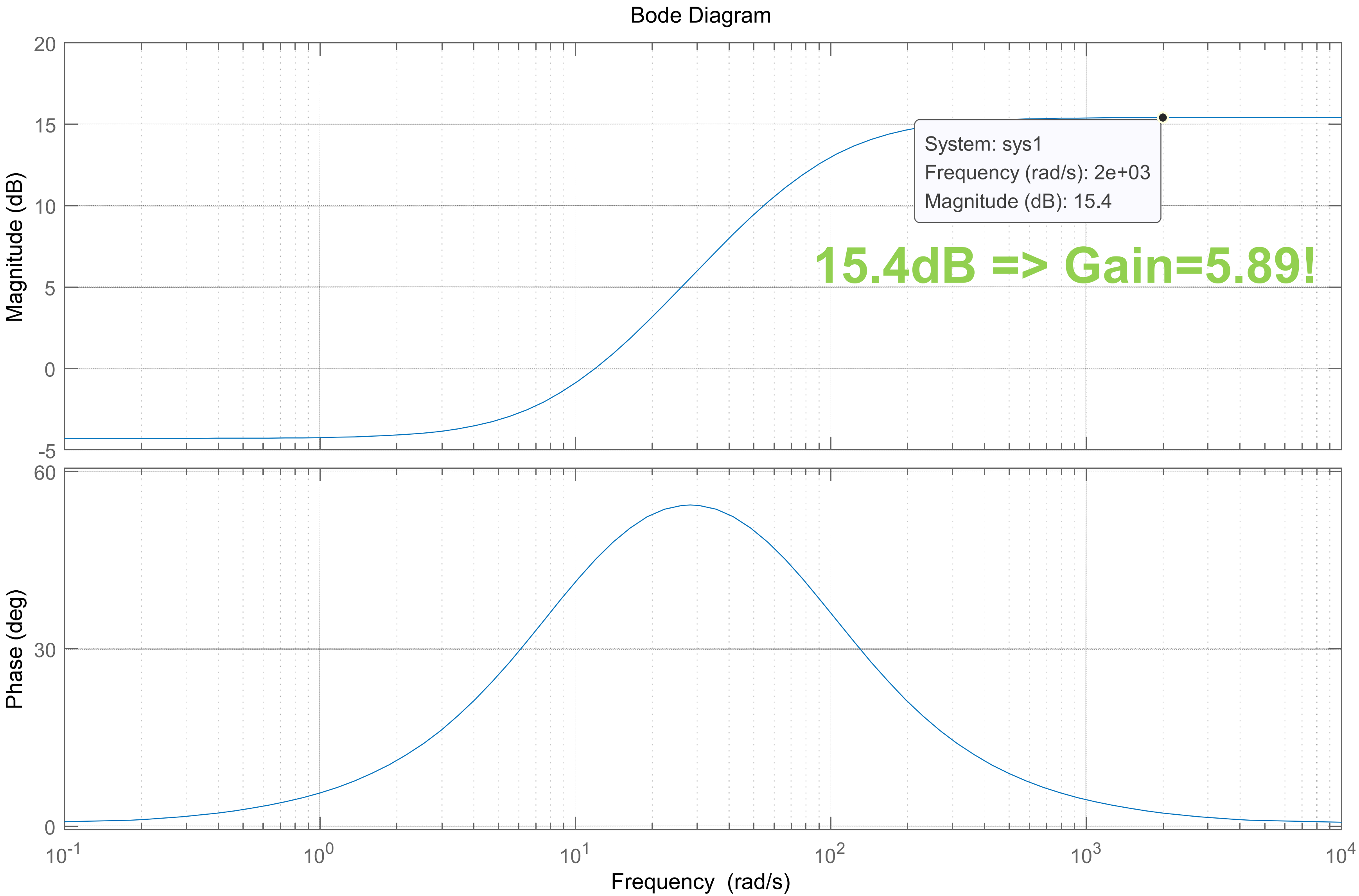


OL Bode plots by Matlab compensated



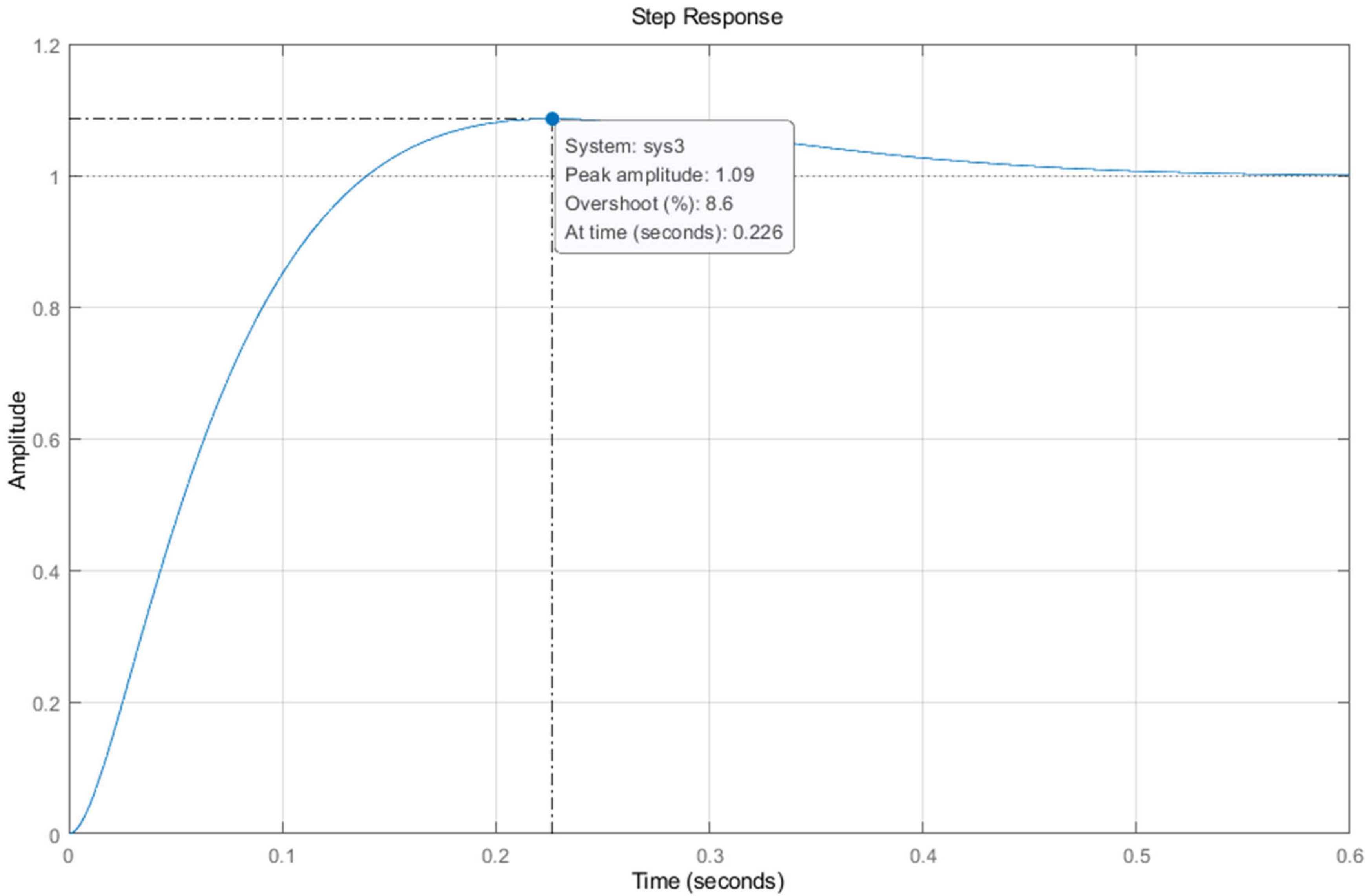
Compensated (ACLab3.m, Krp3=10, Krp4=8)

Alternative Krp3 Values



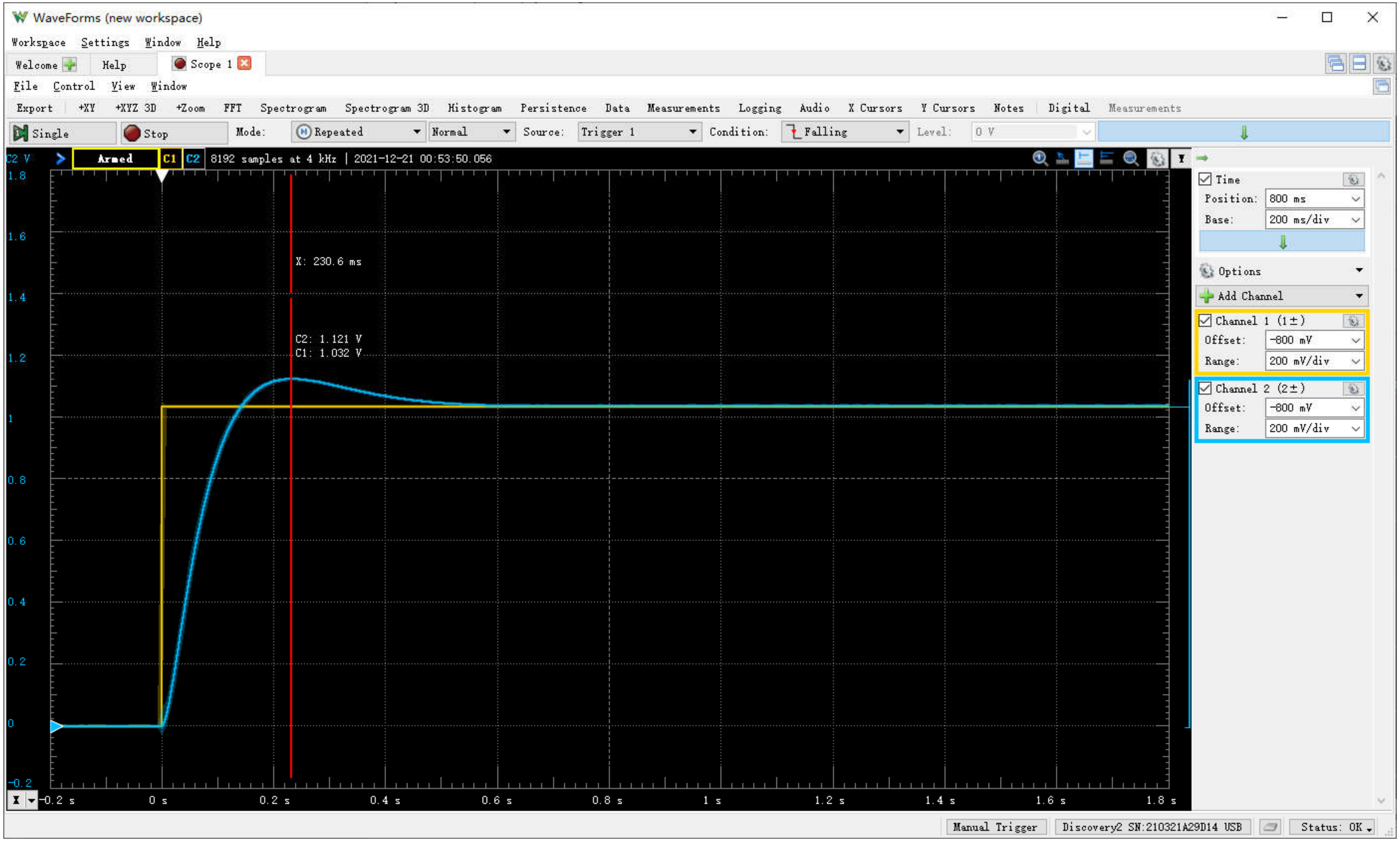
Lead compensator (ACLab3.m, Krp3=2)

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