



# The Principles of Automatic Control Lab #2 (online)

# Department of Automation 2022-12









- Lab kit operation
- Frequency-Response Analysis
  - Definition of System Frequency-Response
  - Bode Diagrams
  - 8 typical factors and their Bode Diagrams
- Bode Diagrams by MATLAB
  - How to build TF; nyquist(), bode(), margin()

## System simulation by MATLAB/Simulink

- Validity of the measurement result
- Signal saturation, low SNR (Signal-to-Noise Ratio)



## VI Software: Waveforms App

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- Scope
- Wavegen

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- Network
- Script

| 🌋 WaveForms (new work               | kspace)                      | >   | < |  |  |  |  |  |  |
|-------------------------------------|------------------------------|---|---|--|--|--|--|--|--|
| Workspace <u>S</u> ettings <u>W</u> | índow <u>H</u> elp           |   |   |  |  |  |  |  |  |
| Welcome 🛖 Help                      |                              |   |   |  |  |  |  |  |  |
| - Scope                             | 💙 Open Workspace             | To create custom application see the <u>SDK</u> .<br>For more information visit <u>digilentinc.com/waveforms</u> .<br>Observations are welcome on <u>this forum page</u> or <u>via</u> email. |   |  |  |  |  |  |  |
| Wavegen                             | Recent:                      |   |   |  |  |  |  |  |  |
| ⊣⊨ Supplies                         |                              |   |   |  |  |  |  |  |  |
|                                     |                              |   |   |  |  |  |  |  |  |
| Logger                              |                              |   |   |  |  |  |  |  |  |
| Logic                               |                              |   |   |  |  |  |  |  |  |
| Fatterns                            |                              |   |   |  |  |  |  |  |  |
| StaticIO                            |                              |   |   |  |  |  |  |  |  |
| addaha Spectrum                     |                              |   |   |  |  |  |  |  |  |
| Network                             |                              |   |   |  |  |  |  |  |  |
| Impedance                           |                              |   |   |  |  |  |  |  |  |
| Protocol                            | New Save MS                  | Analog ICs provided by  | ¥ |  |  |  |  |  |  |
| (15) Script                         | Open last workspace on start | A National Instruments Company  |   |  |  |  |  |  |  |
| Manual Trigger                      |                              | Discovery2 SN:210321A18D39 Status: OK 🚳   |   |  |  |  |  |  |  |



## ACLab Kit Block Diagram



CB1: Inverted Adder

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CB2: Inverted Amplifier #1

CB3: Inverted 1<sup>st</sup>-Order Delay #1

CB4: Inverted 1<sup>st</sup>-Order Delay #2

CB5: Compensator CB6: Inverted Amplifier #2 CB7: User-Defined Network CB8: Inverted Integrator



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



SW9:

CB9: Inverter (Always Active)

 $V_{fdbk} = TP8$ 

 $V_{fdbk} = TP9 = -TP8$ 

OFF:

ON:

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

### 

Typical 2<sup>nd</sup>-Order System in General Form



Building a 2<sup>nd</sup>-Order System with Lab Kit



System Transfer Function Analysis

### **Frequency-Response Analysis**

Linear Time-Invariant (LTI) System G(s)

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## **Bode Diagrams**

### Bode Diagrams / Logarithmic Plots

- Magnitude in DB versus frequency
- Phase angle in degrees versus frequency



## **Bode Diagrams for Basic Factors**

Basic Factors

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- Gain K
- Integral / Derivative factors  $(j\omega)^{\pm 1}$
- 1<sup>st</sup>-order factors  $(1+j\omega)^{\pm 1}$
- Quadratic factors  $[1+2\zeta(j\omega/\omega_n)+(j\omega/\omega_n)^2]^{\pm 1}$



## Frequency-Response by Matlab ACLab2.m

Refer to the attached .pdf file and .m scripts

- Build Transfer Function sys = tf(num,den)
- bode(sys)

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- nyquist(sys)
- [gm,pm,wcg,wcp] = margin(sys)

Digital simulation of the mathematical model

- Close enough to the theoretical analysis result
- No problem with signal saturation or SNR

### Matlab Sample Codes: ACLab2.m o Tona University

### Circuit Blocks

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## Models and Plots

| ✓ E:\数学\20   | 21-2022-1\自动控制原理\实验资料\ACLab_Matla   | ab\ACLab2.m -   | - 🗆 X   | ✓ E:\數学\20   | 021-2022-1\自动控制  | 則原理\实验资料\ACLa   | ab_Matlab\ACLab2.m   |
|--|---|---|---|--|--|---|--|
| 编辑器<br>1<br>2<br>3<br>4<br>5<br>6  | 发布 视图<br>% ACLab#2 for the Princ<br>% Assignment #1: bode p<br>% Assignment #2: bode p<br>% Assignment #3: bode p<br>% Assignment #4: bode p  | iples of Automatic<br>olots for 1st-order i<br>plots for integrator<br>plots for 2 1st-order<br>plots for an under- | Contro A<br>nertial f.<br>factor<br>r inertia<br>dampec | <del>集編器</del><br>23 —<br>24 —<br>25 —<br>26 —<br>27 | 发布<br>sys1 = Gct<br>sys2 = Gc<br>sys3 = Gc<br>sys4 = fee | 视图<br>b4 * Gcb9;<br>b8 * Gcb9;<br>b3 * Gcb4;<br>edback(Gcb                    | 2*Gcb3*Gcl   |
| 7<br>8 -<br>9 -<br>10 -<br>11  | Krp1 = 10; %% change<br>Krp2 = 10; %% change<br>Krp4 = 5; %% change   | e value as required<br>value as required<br>value as required   |   | 28<br>29<br>30<br>31                                 | subplot(2<br>subplot(2<br>subplot(2<br>subplot(2         | 2,2,1), bode(<br>2,2,2), bode<br>2,2,3), bode<br>2,2,3), bode<br>2,2,4), bode | (sys1), grid (<br>(sys2), grid<br>(sys3), grid<br>(sys4), grid |
| 12 - 13 - 14 - 15 - 16 - 17 - 18 - 19 - 20 - 100 - 1 | s=tf('s');<br>Gcb1 = -1;<br>Gcb2 = -0.1*Krp1;<br>Gcb3 = -(1+10*Krp2)/49.9<br>Gcb4 = -1/(0.2*s+1);<br>Gcb5 = -1; %% to be up<br>Gcb6 = -Krp4;<br>Gcb7 = 1; %% not inst<br>Gcb8 = -5/s; | 9/(1+(0.001+0.01*K)<br>pdated<br>talled on device   | rp2)*s);  |  | UTF-8  | 脚本  |  |
| 21 —<br>[<   | GCD9 = -1;<br>UTF-8 脚本  | 行 31  | ◆<br>列 37   |  |  |   |  |

2 2 9 0 视图 -90 \* Gcbo; \* Gcb9; \* Gcb4; back(Gcb2\*Gcb3\*Gcb6\*Gcb8, 1); ,1), bode(sys1), grid on; ,2), bode(sys2), grid on; ,3), bode(sys3), grid on; ,4), bode(sys4), grid on; 脚本 行 27 列 1

×

Change Krp1/Krp2/Krp4 values as required \*\*



## Frequency-Response by AD2

|  | Automatical Sciences |   | 26   | -                               | · · ·              |
|--|----------------------|---|--|---------------------------------|--------------------|
| ₩ WaveForms (new work  | space)               |   | 34 <u>—</u>  |                                 | X                  |
| Workspace <u>S</u> ettings <u>W</u> in                                       | dow <u>H</u> elp     |   |  |                                 | 1 100              |
| Welcome 🔐 Help   | 👚 Open Workspace     | To create custom application see the <u>Wav</u><br>For more information visit <u>Digilent Inst</u><br>Observations are welcome on <u>Scopes &amp; Ins</u> | eForm <u>s SDK</u> .<br>rumentation R<br>truments Foru | <u>eference</u> .<br><u>n</u> . |                    |
| Wavegen     Image: Supplies     Voltmeter     Image: Logger     Image: Logic | Recent:              |   |  |                                 | <ul><li></li></ul> |
| Patterns   Patterns   StaticIO   Image: Spectrum   Network                   | Network Analyzer     |   |  |                                 |                    |
| Impedance  |                      |   |  |                                 | ~                  |
| {JS} Script  | New Save Save As     |   |  | Provided by<br>NALOG<br>VICES   |                    |
|  |                      | Manual Trigger Discovery2 SN:210321A3688B U   | SB 🗐 St  | atus: OK                        |                    |

Instrument: Network Analyzer; may conflict with other instruments



## Frequency-Response by AD2

| ₩ WaveForms (new  | v workspace) |           |          |          |               |                 |            |           |                  |                         |  |                 | 1 <u>238</u> 8 |          | ×     |
|-------------------|--------------|-----------|----------|----------|---------------|-----------------|------------|-----------|------------------|-------------------------|--|-----------------|----------------|----------|-------|
| Workspace Control | Settings Wi  | ndow Help |          |          |               |                 |            |           |                  |                         |  |                 |                |          |       |
| Welcome 🐺 Help    | 🕨 Netv       | vork 1 🔀  |          |          |               |                 |            |           |                  |                         |  |                 |                | BE       | 1 12  |
| File Control Vie  | w Window     |           |          |          |               |                 |            |           |                  |                         |  |                 |                |          | 6     |
| 🕅 Single 🗹        | Time         | Ý         | Steps:   | 151      | V Source:     | Wavegen Ci      | ~          | Amplitude | : 1 V            | 🗸 Scale: Logarit        | hmic $\sim \frac{1+}{N}$                 |                 |                |          |       |
| Nun -             | FFT          | ~         | /Decade: | 50       | √ Mode:       | Constant        | ~          | Offset:   | 0 γ              | ✓ S Options             | •  | [DUT2]>         |                |          |       |
| Read              | Nyquist      |           |          |          | R.            | ⊨ @ @           | Time       |           |                  |                         | đΧ                                       |                 |                |          |       |
| 10                | Nichols      | · _ ·     |          |          |               | Mag             | y          |           | >                | Show: 2                 | ~ 🚯                                      | 🗹 Magni tud     | le             | 8        |       |
| 0                 | Notes        |           |          |          |               | zi.             | 1          |           | and handless the |                         |  | 🚽 Rel           | ative to       | Ref      |       |
| -10               | Notes        |           |          |          |               | ide             |            |           |                  |                         |  | Units:          | dB             | ~        |       |
| -20               |              |           |          |          |               |                 | 0,8        |           |                  |                         |  | Top:            | 10 dB          | ~        | 4     |
| -30               |              |           |          |          |               |                 |            |           |                  |                         | n an | Bottom:         | -90 dB         | ~        |       |
| -40               |              |           |          |          |               |                 | 0.6        |           |                  |                         |  |                 | pectrum        | 100      |       |
| -50               |              |           |          |          |               | ana 1           |            |           |                  |                         |  | ✓ fnase<br>Ref: | Channel        | 1 ~      |       |
| -60               |              |           |          |          |               |                 | 0.4        |           |                  |                         |  | Offset:         | 0 °            | ~        | 7     |
| -70               |              |           |          |          |               |                 |            |           |                  |                         |  | Range:          | 360 °          | ~        |       |
| -80               |              |           |          |          |               |                 | 0.2        |           |                  |                         |  | Custom C        | Ine            | 0        |       |
| -90               |              |           |          |          |               |                 |            |           |                  |                         |  | Custom T        | 'wo            | 63       |       |
| 180               |              |           | _        |          |               | اج المحد        | 0          |           |                  |                         |  | 🔶 j             | dd Channe      | 1 •      | 7     |
| 135               |              |           |          |          |               | 125 P           |            |           |                  |                         | o inte                                   | 🗹 Channel       | 1              | 1        |       |
| 133               |              |           |          |          |               | 2 <b>9</b> - 53 | -0.2       |           |                  |                         |  | Offset:         | 0 γ            | ~        |       |
| 90                |              |           |          |          |               |                 |            |           |                  |                         | line.                                    | Gain:           | 1 X            | V        |       |
| 45                |              |           |          |          |               |                 | -0.4       |           |                  |                         |  | 🗹 Channel       | 2              | 3        |       |
| <u> </u>          |              |           |          |          |               |                 |            |           |                  |                         |  | Offset:         | 0 V            | ~        |       |
|                   |              |           |          |          |               |                 | -0.6       |           |                  |                         |  | Gain:           | 1 X            | ~        |       |
| -45               |              |           |          |          |               |                 | 0.0        |           |                  |                         |  |                 |                |          |       |
| -90               |              |           |          |          |               |                 |            |           |                  |                         |  |                 |                |          |       |
| -135              |              |           |          |          |               | 17              | -0.8       |           |                  |                         |  |                 |                |          |       |
|                   |              |           |          |          |               |                 |            |           |                  |                         |  |                 |                |          |       |
| -180              |              | 10 kHz    |          | 100 kHz  | <u> a a s</u> | <br>1 MHz       | -1<br>0 ms | i         |                  | 1.2 ms 1.6 ms           |  |                 |                |          |       |
|                   |              |           |          | 100 1011 |               | 1. 11011        | E Contract | Mony      | al Trigger       | 1 5 50 10 210 21 A      | 18139 158                                | WWW 18 1        | St.            | tue: Ok  |       |
|                   |              |           | _        |          |               |                 | _          | manu      | ar 1118861   1   | riscoveryz c Sm.210321P | 10039 03B                                | nrJ. 10. 1      | 518            | itus. Of | in li |

Single; Settings; View Options: Time; Nyquist; Nichols



two 1<sup>st</sup>-order factors in series(CB3+CB4, RP2=2)



1<sup>st</sup>-order factor(CB3+CB9, RP2=6)



1<sup>st</sup>-order factor(CB3+CB9, RP2=6)



Integrator (CB8+CB9)

## "Problems" with Lab for Frequency Response



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Signal saturation? Too low SNR? Too long time to get fine plots?

#### A 2<sup>nd</sup>-Order System Bode Plots 上海交通大學 ai Jiao Tong University ③ CB1 + CB2(RP1=10) + CB4 + CB6(RP4=8) + CB8 • SW10 ON; $M_r$ =9.02dB= $\rightarrow M_r$ =2.87 ∨ Samples: 51 ∨ /Decade: 16.6666667 Single D Run Scale: Logarithmic ▼ Start: 100 mHz ✓ Stop: 100 Hz Done C1 C2 51 steps 0.1 Hz - 100 Hz | 2020-11-24 10:41:09.626 📐 🔚 🎯 C2: 9.01881127 dB 🗹 Wavegen 3 Out of range on channels: 2 Warning: C1: 0.02229207 dB 0 1 Offset: v Mode: Constant Out of range. 2 Amplitude: 1 V $\sim$ -13 🗸 Magni tude 1.2 -24 🥒 Relative to Channel 1 -35 Mnits' dB X: 2.09 Hz -46 Top: 20 dB Bottom: -90 dB -57 Spectrum -68 Phase 1 0 ° Offset: V 360 ° Range: $\sim$ Custom One 135 Custom Two 🔶 Add Channel Channel 1 金 0 1 Offset: V Gain: 1 X $\sim$ Channel 2 3 -45 C2: -83.052447094 ° Offset: 0 1 -90 Gain: 1 X 135

Warning: it takes more than 20mins to get the above figure.

10 Hz

100 Hz Manual Trigger Discovery2 SN:210321A29C3D USB 🍠 Status: OK 🗸

1 Hz

-180 **I v** 100 mHz



Warning: it takes about **13mins** to get the above figure.



## Lab2-4 Step Response $M_{\rm P}$ vs $\zeta$

Rede Depented w Series Trigger 1 w Condition Falling w Lord U.V.

@ 1 = 0 m





• Step response in Lab#1



![](_page_23_Picture_0.jpeg)

Textbook formula (5-103)

![](_page_23_Figure_2.jpeg)

# Lab2-4 Closed-system Model Analysis Shanghai Jiao Tong University

CB2: Inverted Proportional Amplifier ( $K_{RP1}$ =4)

CB6: Inverted Proportional Amplifier ( $K_{RP4}$ =6)

![](_page_24_Figure_3.jpeg)

![](_page_25_Picture_0.jpeg)

( CB3: Inverted Inertial Factor ( $K_{RP2}$ =8)

CB8: Inverted Integrator

![](_page_25_Figure_3.jpeg)

![](_page_25_Figure_4.jpeg)

# System Simulation by MATLAB

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![](_page_26_Figure_2.jpeg)

E:\教学\2022-2023-1\实验资料\2022ACLab2Online\ACLab2.m 8 ? 8 0 编辑器 视图 % 🙀 🖓 三 分节符 ÷ fx H □比较▼ ~ 探查器 重构 图 图 图 🔄 运行并前进 Q 查找 ▼ 新建 打开 保存 🚔 打印 🖌 转至 运行 运行 步进 停止 分析 ■ 书签 ▼ • 14 • 🔄 运行到结束 ----导航 代码 文件 sys1 = Gcb3 \* Gcb9; 20 lode sys2 = Gcb8 \* Gcb9: D 21 sys3 = Gcb3 \* Gcb4 \* Gcb2 \* Gcb9; 22 sys4 = feedback(Gcb2\*Gcb3\*Gcb6\*Gcb8, 1); 23 24 25 bode(sys1); % bode(sys2); 26 Run % step(sys3); 27 % bode(sys3); 28 simulation % step(sys4); 29 % bode(sys4); 30 31 grid on 行 31 列 8 Zoom: 200% UTF-8 CRLF 脚本

![](_page_26_Figure_4.jpeg)

#### 手済気道大学 Shanghai Jiao Tong University Frequency Response by MATLAB ACLab2.m

![](_page_27_Figure_1.jpeg)

### 上海交通大学 Shanghai Jiao Tong University

# System Simulation by Simulink ACLab2\_1.slx

## Model Construction

- How to build a simulation model based on TF
- How to manipulate variable parameters

## Model Operation

![](_page_28_Figure_6.jpeg)

![](_page_29_Figure_0.jpeg)

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![](_page_29_Figure_2.jpeg)

### 上海交通大学 Shanghai Jiao Tong University

# System Simulation by Simulink ACLab2\_2.slx

## Model Construction

- How to build a simulation model based on TF
- How to manipulate initial value (affect output offset)

## Model Operation

• How does the Trigger work?

![](_page_30_Figure_7.jpeg)

![](_page_30_Figure_8.jpeg)

### 上海交通大学 Shanghai Jiao Tong University

# System Simulation by Simulink ACLab2\_3.slx

## Model Construction

- How to build a simulation model based on TF
- How to control the signal phase

![](_page_31_Figure_5.jpeg)

![](_page_32_Picture_0.jpeg)

## Simulation Result Analysis ACLab2\_3.slx

![](_page_32_Figure_2.jpeg)

### 上海交通大学 Shanghai Jiao Tong University

# System Simulation by Simulink ACLab2\_4.slx

## Model Construction

- How to build a simulation model based on TF
- How to manipulate variable parameters

![](_page_33_Figure_5.jpeg)

![](_page_33_Figure_6.jpeg)

![](_page_34_Picture_0.jpeg)

## Simulation Result Analysis ACLab2\_4.slx

![](_page_34_Figure_2.jpeg)

![](_page_35_Picture_0.jpeg)

![](_page_35_Picture_1.jpeg)

Q&A