# Appendix E

# MATLAB's GUI Tools Tutorial

## E.1 Introduction

Readers who are studying MATLAB may want to explore the convenience of MATLAB's **Linear System Analyzer**. Before proceeding, the reader should have studied Appendix B, the MATLAB Tutorial, including Section B.1, which is applicable to this appendix.

MATLAB Version 9.3(R2017b), MATLAB's Control System Toolbox Version 10, Simulink Version 9.0, and Simulink Control Design Version 5 are required in order to use the tools described in this appendix.

Consult the MATLAB Installation Guide for your platform for minimum system hardware requirements. The M and Simulink files for the examples in this appendix are located in the Control Systems Engineering Toolbox.

## E.2 The Linear System Analyzer: Description

The **Linear System Analyzer** is a convenient way to obtain and view time and frequency response plots of LTI transfer functions and obtain measurements from these plots. In particular, some of the graphs the **Linear System Analyzer** can create are step and impulse responses, Bode, Nyquist, Nichols, and pole-zero plots. In addition, the values of critical points on these plots can be displayed with a click of the mouse. Table E.1 shows the critical points that are available for each plot.

**TABLE E.1** Critical points available for each plot in MATLAB's Linear System Analyzer

| | Peak value: peak time or frequency | Settling time | Rise time | Steady state value | Gain/phase margins; zero dB/180° frequencies | Pole-zero value |
|---|---|---|---|---|---|---|
| Step | • | • | • | • | | |
| Impulse | • | • | | | | |
| Bode | • | | | | • | |
| Nyquist | • | | | | • | |
| Nichols | • | | | | • | |
| Pole-zero | | | | | | • |

## E.3 Using the Linear System Analyzer

In this section we give you steps you may follow to use the **Linear System Analyzer** to plot time and frequency responses. If you have trouble, help is available on the **Linear System Analyzer** window menu bar. Help is also available from the **MATLAB** window by typing **Linear System Analyzer** in the **Search Documentation** tab. The following summarize the steps you may take to obtain plots from the **Linear System Analyzer**.

1. **Access the Linear System Analyzer** The **Linear System Analyzer**, shown in Figure E.1, may be accessed by typing **linearSystemAnalyzer** in the **MATLAB Command Window** or by executing this command in an M-file. The **Linear System Analyzer** can be obtained from the APPS tab in the **MATLAB** window.
2. **Create LTI transfer function** Create LTI transfer functions for which you want to obtain responses. The transfer functions can be created in an M-file or in the **MATLAB Command Window**. Run the M-file or **MATLAB Command Window** statements to place the transfer function in the MATLAB workspace. All LTI objects in the MATLAB workspace can be exported to the **Linear System Analyzer**.
3. **Select LTI transfer functions for the Linear System Analyzer** Choose **Import**... under the **File** menu in the **Linear System Analyzer** window and select all LTI objects whose responses you wish to display in the **Linear System Analyzer** sometime during your current session.
4. **Select the LTI objects for the next response plot** Right-click anywhere in the **Linear System Analyzer** plot area to produce a pop-up menu as shown in Figure E.1. Under **Systems,** select or deselect the objects whose plots you want or do not want to show in the **Linear System Analyzer**. More than one LTI transfer function may be selected.
5. **Select the plot type** Right-click anywhere in the **Linear System Analyzer** plot area to produce a pop-up menu as shown in Figure E.1. Under **Plot Types,** select the type of plot you want to show in the **Linear System Analyzer**.
6. **Select the characteristics** Right-click anywhere in the **Linear System Analyzer** plot area to produce a pop-up menu as shown in Figure E.1. Under **Characteristics,**

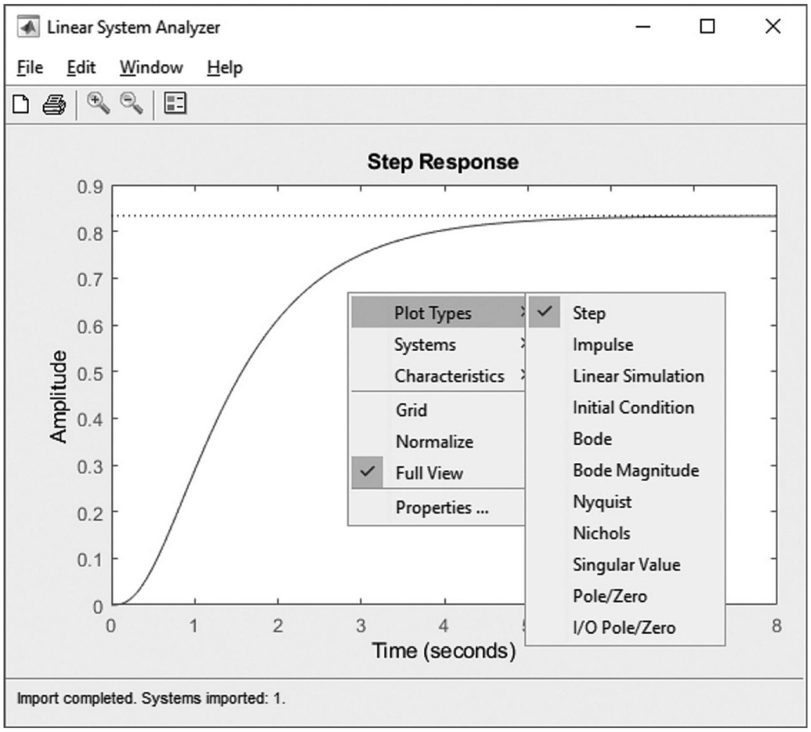



**FIGURE E.1** **Linear System Analyzer** showing right-click pop-up menu select the characteristics of the plot you want displayed. More than one characteristic may be selected. For each characteristic chosen, a point will be placed on the plot at the appropriate location.

**7. Interact with the Plot:**

**Zoom in** Select the **Zoom In** button (with the + sign) on the tool bar. Hold the mouse button down and drag a rectangle on the plot over the area you want to enlarge. Let go of the mouse button. You may also click the mouse. Each click zooms you in closer.

**Zoom out** Select the **Zoom Out** button (with the − sign) on the tool bar. Click on the plot. Each click widens your view.

**Grid** Select **Grid** in the right-click menu to toggle the grid on and off. The right-click menu will not work if any zoom button on the tool bar is selected.

**Normalize** Select **Normalize** in the right-click menu to normalize all curves in view.

**Full view** Select **Full View** in the right-click menu to return to the full view of your plot after zooming.

**Characteristics** Read the values of the characteristics by placing the mouse on the characteristics point on the plot. Left-click the mouse to keep the values displayed.

**Properties** Select **Properties** in the right-click menu to change the appearance of the graph. You can change the title, axis labels, $x$ and $y$ limits, font size and styles, colors, and response characteristics definitions.

**Coordinates and curve** Left-click the mouse at any point on the plot to read the system identification and the coordinates. Right-click to manipulate the identification display.

**Add text and graphics** Under the **File** menu, choose **Print to Figure**. The tool bar of this figure has additional tools for adding text, arrows, and lines.

**Additional plot-edit capabilities** The **Edit** menus of the **Linear System Analyzer** and the figures created by selecting **Print to Figure** offer a wide variety of control over the plot presentation.

# E.4 Linear System Analyzer Examples

This section presents five examples of the use of the Linear System Analyzer taken from Chapters 4, 10, and 13. The examples will show the M-files along with the resulting Linear System Analyzer window.

## Example E.1

### Step Response

**PROBLEM:** This example, taken from Example 4.8 in the text, shows the use of the Linear System Analyzer to display simultaneously three step responses as well as their peak time, settling time, rise time, and steady-state values. Let us follow the steps listed in Section E.3.

**Access the Linear System Analyzer and create the LTI objects** Follow Steps (1) and (2) in Section E.3 to access the Linear System Analyzer and generate the LTI transfer functions. Figure E.2(*a*) shows the M-file used to generate the three transfer functions.

**Select transfer functions for viewing responses** After running the M-file, follow Steps (3) and (4) in Section E.3 and select T1, T2, and T3.

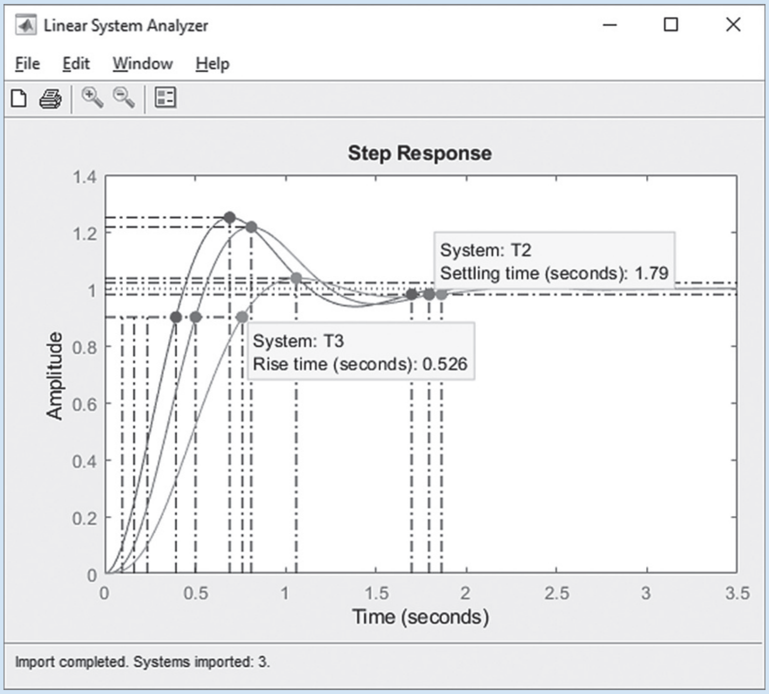
**Select the plot type** Follow Step (5) in Section E.3 and select **Step**.

**Select the Characteristics** Follow Step (6) in Section E.3 and select **Peak Response, Settling Time, Rise Time,** and **Steady State**.

**Interact with the plot** Follow Step (7) in Section E.3 and interact with the plot. In particular, read the peak value and peak time of T3's step response. Figure E.2(*b*) shows the **Linear System Analyzer** window with the responses, system T3's rise time, and system T2's settling time.

```
'(ch4apE1) Example E.1'                          %Display label.
'Linear System Analyzer for Chapter 4, Example 4.8'   %Display label.
'Step response'                                  %Display label.
'T1(s)'                                          %Display label.
T1=tf(24.542,[1 4 24.542])                       %Create T1.
'T2(s)'                                          %Display label.
T2=tf(245.42,conv([1 10],[1 4 24.542]))          %Create T2.
'T3(s)'                                          %Display label.
T3=tf(73.626,conv([1 3],[1 4 24.542]))           %Create T3.
linearSystemAnalyzer                             %Call up Linear System Analyzer.
```

(*a*)




(*b*)

**FIGURE E.2** **Linear System Analyzer** used for step response: **a**. M-file; **b**. **Linear System Analyzer**

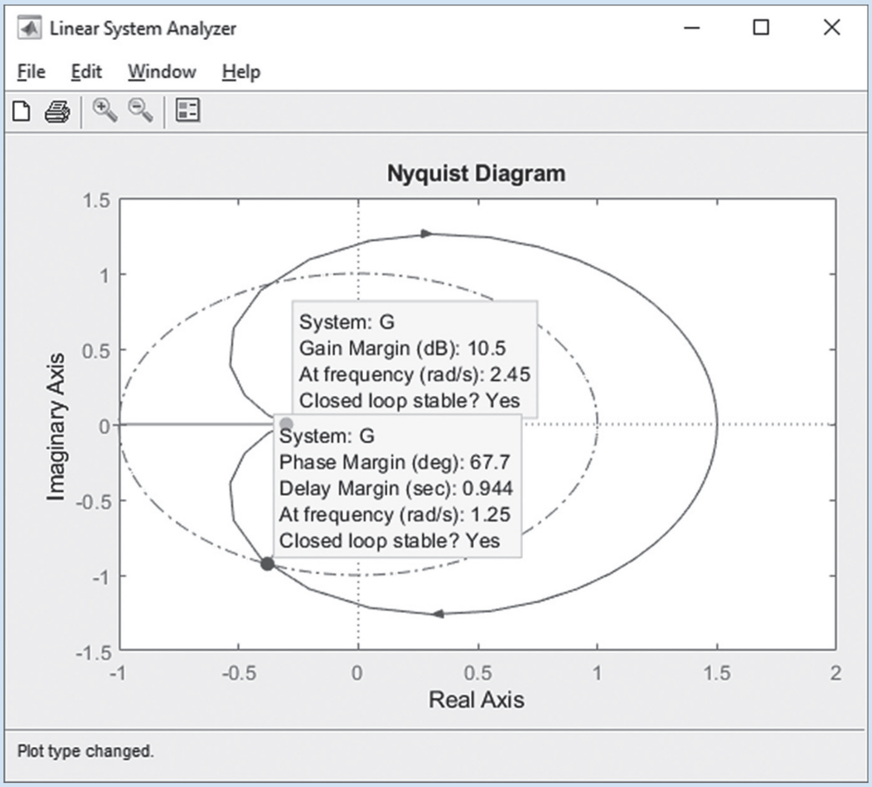
## Example E.2

### Nyquist Diagram and Gain/Phase Margins

**PROBLEM:** This example, taken from Example 10.8 in the text, shows the use of the Linear System Analyzer in plotting a Nyquist diagram and obtaining gain margin, phase margin, zero dB frequency, and 180° frequency. To create this plot follow Step (1) through (4) in Section E.3 using the M-file shown in Figure E.3(*a*). Then use the right-click menu and select **Nyquist** under **Plot Type**. To find the gain and phase margins as well as the gain and phase margin frequencies, use the right-click menu and select **All Stability Margins** under **Characteristics**. Figure E.3(*b*) shows the resulting **Linear System Analyzer** window. The system's gain margin and 180° frequency are displayed along with the phase margin and zero dB frequency.

```
'(ch10apE1) Example E.2'                    %Display label.
'Linear System Analyzer for Chapter 10 Example 10.8'
                                            %Display label.
'Nyquist diagram'                           %Display label.
numg=6;                                     %Create numerator of G(s).
deng=conv([1 2],[1 2 2]);                   %Create denominator of G(s).
'G(s)'                                      %Display label.
G=tf(numg,deng)                             %Create and display G(s).
linearSystemAnalyzer(G)                     %Call up Linear System Analyzer.
```

(*a*)




(*b*)

**FIGURE E.3** **Linear System Analyzer** used for Nyquist diagram: **a**. M-file; **b**. **Linear System Analyzer**

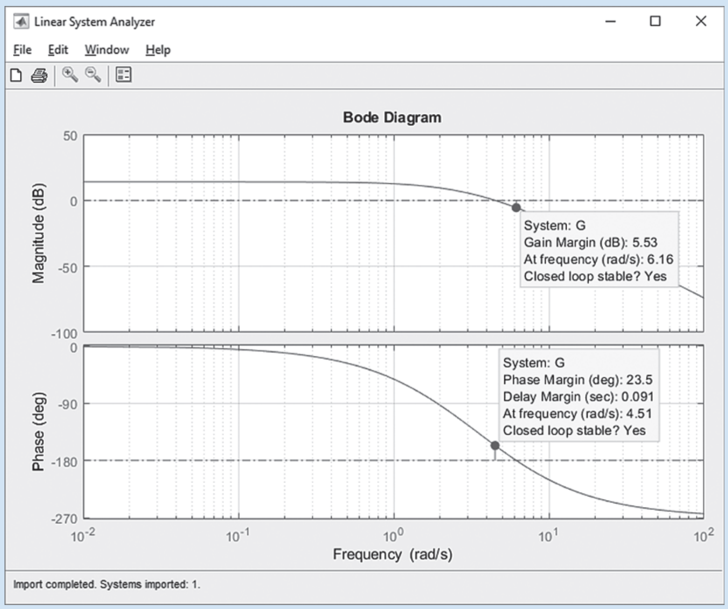
## Example E.3

### Bode Plots and Gain/Phase Margins

**PROBLEM:** This example, taken from Example 10.10 in the text, shows the use of the **Linear System Analyzer** in making a Bode plot and obtaining gain margin, phase margin, zero dB frequency, and 180° frequency. To create this plot, follow Steps (1) through (4) in Section E.3 using the M-file shown in Figure E.4(*a*). Then use the right-click menu and select **Bode** under **Plot Type**. To find the gain and phase margins as well as the gain and phase margin frequencies, use the right-click menu and select **All Stability Margins** under **Characteristics**. Use the right-click menu and select **Grid**. Figure E.4(*b*) shows the resulting **Linear System Analyzer** window. The system's phase margin and 0 dB frequency are displayed along with the gain margin and 180° frequency.

```
'(ch10apE2) Example E.3'               %Display label.
'Linear System Analyzer for Chapter 10, Example 10.10'
                                       %Display label.
'Bode plot'                            %Display label.
numg=200;                              %Create numerator of G(s).
deng=poly([-2 -4 -5]);                 %Create denominator of G(s).
'G(s)'                                 %Display label.
G=tf(numg,deng)                        %Create and display G(s).
linearSystemAnalyzer                   %Call up Linear System Analyzer.
```

(*a*)




(*b*)

**FIGURE E.4 Linear System Analyzer** used for Bode plot: **a**. M-file; **b**. **Linear System Analyzer**

Since Example 10.10 used asymptotic approximations to determine the characteristics, such as gain and phase margin, there will be some discrepancy between the characteristics found using the **Linear System Analyzer**, which uses the exact frequency response, and the results of Example 10.10.

## Example E.4

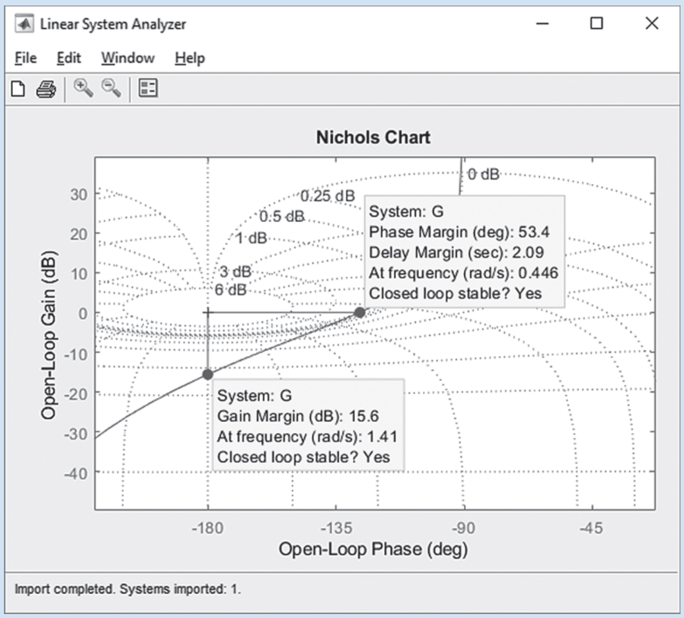
### Nichols Chart and Gain/Phase Margins

**PROBLEM:** This example, which reproduces Figure 10.47 in the text, shows the use of the **Linear System Analyzer** in making a Nichols chart and obtaining gain margin, phase margin, zero dB frequency, and 180° frequency. To create this plot follow Step (1) through (4) in Section E.3 using the M-file shown in Figure E.5(*a*). Then use the right-click menu and select **Nichols** under **Plot Type**.

To find the gain and phase margins as well as the gain and phase margin frequencies, use the right-click menu and select **All Stability Margins** under **Characteristics**. Use the right-click menu to select **Grid**. Finally, select **Zoom In** from the toolbar and drag your mouse over a portion of the Nichols plot to create the close-up view shown in Figure E.5(*b*). Figure E.5(*b*) also shows the points from which gain and phase margins and frequencies can be read.

```
'(ch10apE3) Example E.4' %Display label.
'Linear System Analyzer for Chapter 10, Figure 10.47'
                         %Display label.
'Nichols chart'          %Display label.
numg=1;                  %Create numerator for G(s).
deng=poly([0 -1 -2]);    %Create denominator for G(s).
'G(s)'                   %Display label.
G=tf(numg,deng)          %Create G(s).
linearSystemAnalyzer     %Call up Linear System Analyzer.
```

(*a*)




(*b*)

**FIGURE E.5** **Linear System Analyzer** used for Nichols chart: **a**. M-file; **b**. **Linear System Analyzer**

## Example E.5

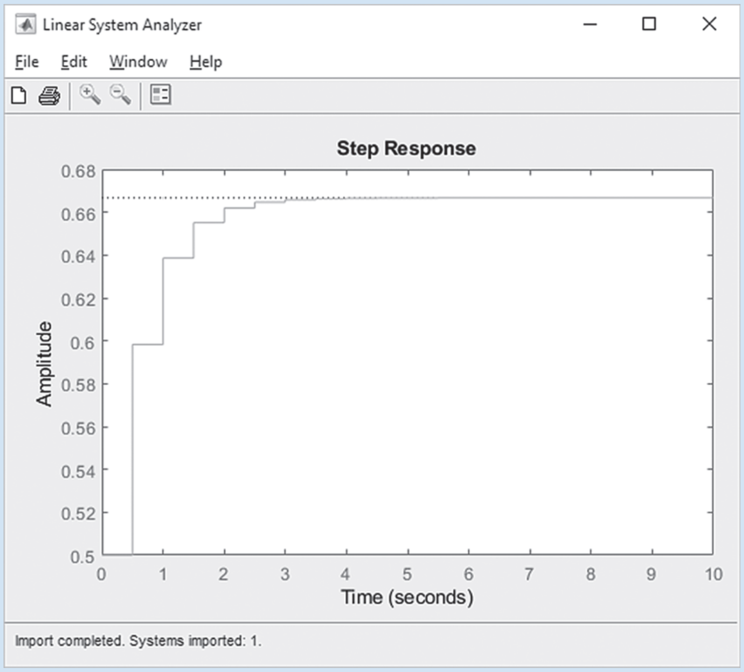
### Step Response for Digital systems

**PROBLEM:** This example shows the use of the **Linear System Analyzer** to produce step responses for digital system. To create this plot follow Steps (1) through (4) in Section E.3 using the M-file shown in Figure E.6(*a*). Then use the right-click menu and select **Step** under **Plot Type**. Figure E.6(*b*) shows the **Linear System Analyzer** window with the digital step response.

```
'(apEex5) Example E.5'              %Display label.
'Linear System Analyzer for Chapter 13'     %Display label.
'Digital step response'             %Display label.
'G(z)'                              %Display label.
G=tf([1 -0.214],[1 -0.607],0.5)     %Create sampled transfer funtion.
'T(z)'                              %Display label.
T=G/(1+G)                           %Calculate closed-loop sampled
                                    %transfer function for unity
                                    %feedback sampled system.
linearSystemAnalyzer                %Call Linear System Analyzer.
```

(*a*)

**FIGURE E.6** **Linear System Analyzer** used for digital step response:
**a**. M-file; (*figure continues*)




(*b*)

**FIGURE E.6** (*continued*)
**b. Linear System Analyzer**

## E.5 Simulink and the Linear Analysis Tool

Readers who are using Simulink may use the **Linear Analysis Tool** to obtain responses and their characteristics directly from Simulink models. All of the response plots and characteristics available to you in the **Linear Analysis Tool** using transfer functions generated in MATLAB and placed in the MATLAB workspace are available to you from your Simulink model. Any nonlinear blocks in your Simulink model are linearized by the Simulink **Linear Analysis Tool** before presenting the requested response curve. You will be able to:

1. Set a point on your Simulink model where the input signal will be applied.
2. Set output points on your Simulink model where responses will be obtained.
3. Specify operating conditions, such as initial conditions and input value.

## E.6 Using the Linear Analysis Tool with Simulink to Analyze a Response

In this section we present the steps you may follow to use the **Linear Analysis Tool** with **Simulink** in order to analyze a response. Help is available on the tabs bar of the **MATLAB** Window. Type **Linear Analysis Tool** in the **Search Documentation** box. In the resulting window select the tool for documentation. The following summarize the steps you may take to use the **Linear Analysis Tool** with **Simulink**. We use the system from Example C.3 to demonstrate.

1. **Access a Simulink Model** Start with your **Simulink model** window shown in Figure E.7
2. **Define the input and output of your linearized model** Right click on the selected input point and choose **Linear Analysis Points** then **Open-loop input** on the drop-down menu. Right click on the selected output point and choose **Linear Analysis Points** then **Open-loop output** on the drop-down menu. The input and output points are shown on the Simulink model of Figure E.7.

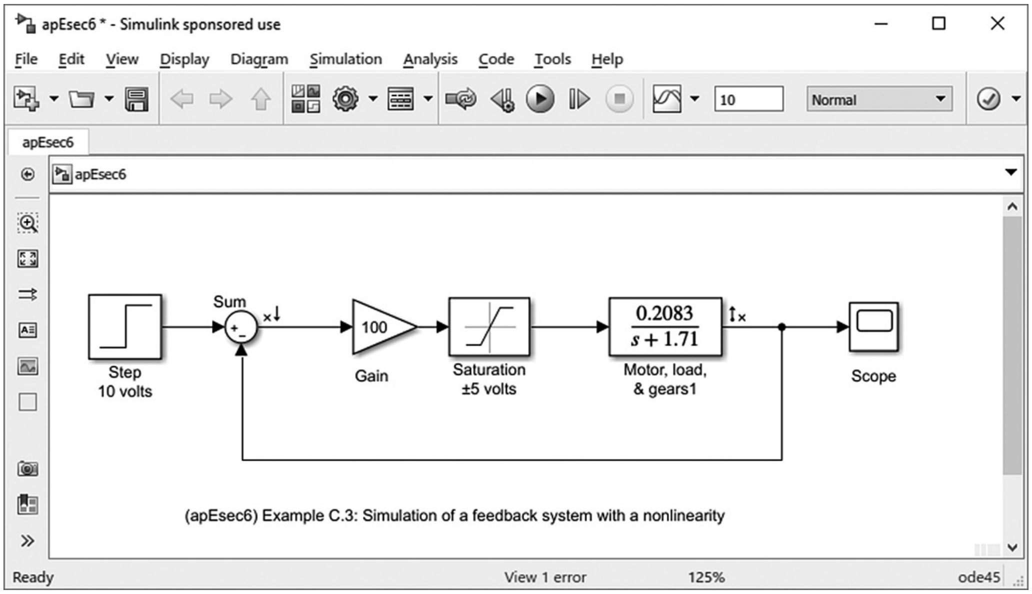



**FIGURE E.7** **Simulink model** window showing **Input Point** and **Output Point**

3. **Open Linear Analysis Tool** Under the **Analysis** menu select **Control Design** followed by **Linear Analysis. . . .** In response, MATLAB opens the **Linear Analysis Tool** Window, Figure E.8.
4. **Specify the Operating Conditions** Any nonlinear blocks in your Simulink model must be linearized about an equilibrium point. The default setting for the equilibrium points are the initial values used in your Simulink model. Typically these values are zero unless you changed them in your Simulink model. Thus, if you agree with the default

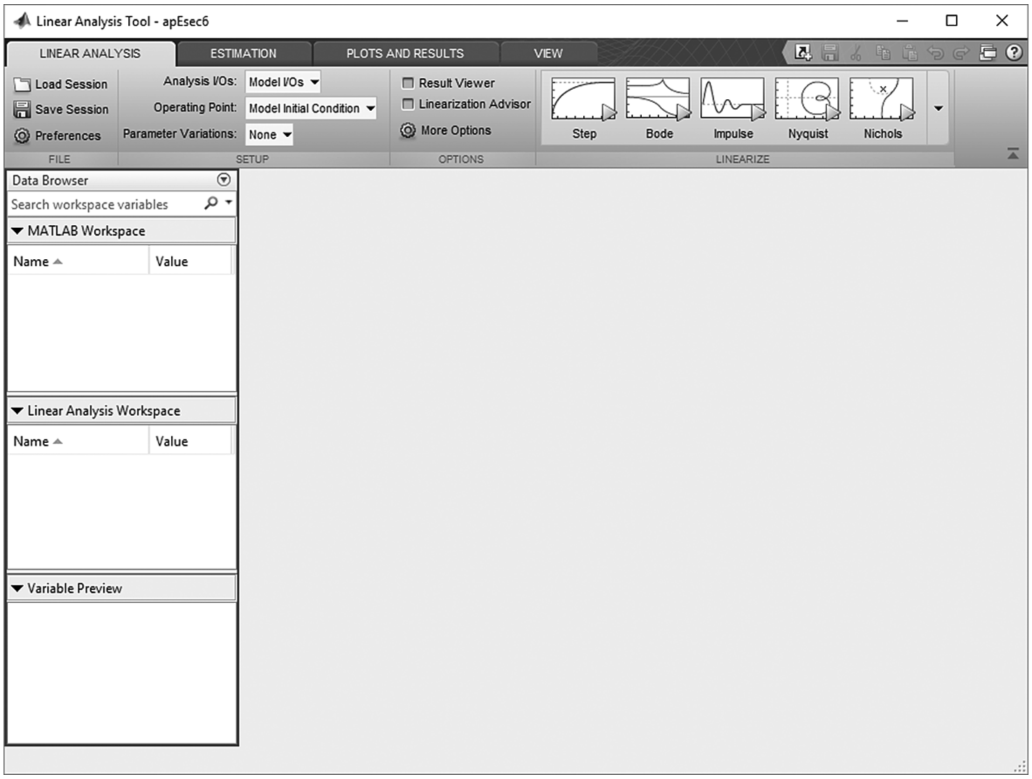



**FIGURE E.8** **Linear Analysis Tool** window

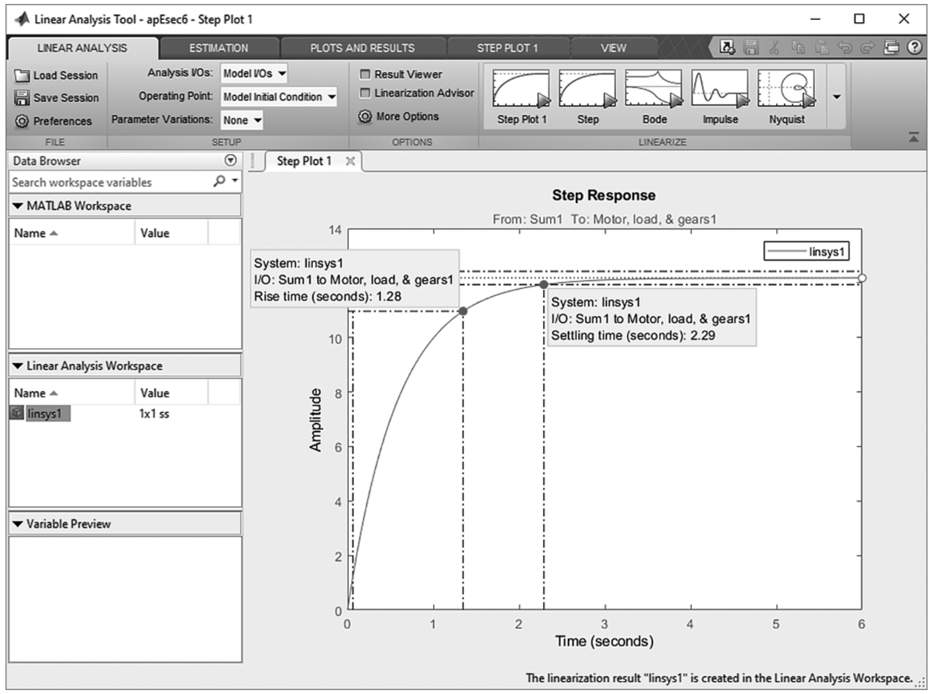



**FIGURE E.9** Simulink **Linear Analysis Tool** showing response and characteristics

initial conditions, then go immediately to Step 5. However, if you wish to change the initial conditions, select the drop-down menu under the **Linear Analysis** tab marked **Operating Point** and change the value. Consult **Help** for more details.

5. **Generate the Response to Be Analyzed** For this example click on **Step**. In response the system is linearized, placed in the **Linear Analysis Workspace**, and plots of the closed-loop step response are generated. Right-click the response and choose **Characteristics**. Select desired characteristics on the drop-down menu. In response, MATLAB puts dots on the plot. The final result is shown in Figure E.9

# E.7 The Control System Designer: Description

The **Control System Designer** is a convenient and intuitive way to obtain, view, and interact with a system's root locus and Bode plots. The tool also has the option of using a Nichols chart. After the tool produces these plots, you can do the following with the root locus: (1) drag closed-loop poles along the root locus and read gain, damping ratio, natural frequency, and pole location, (2) view immediate changes in the Bode plots, and (3) view immediate changes in the system's closed-loop response via the **New Plot** drop-down menu. You can add poles, zeros, and compensators, which can be interactively changed to see the immediate effects on the root locus, Bode plots, and time response.

You can do the following with the Bode plots: (1) effect a gain change by moving the Bode magnitude curve up and down and reading the gain, gain margin, gain margin frequency, phase margin, phase margin frequency, and whether the loop is stable or unstable, (2) view immediate changes on the root locus, and (3) view immediate changes in the system's closed-loop response via the **New Plot** drop-down menu. You can add poles, zeros, and compensators, which can be interactively changed to see the immediate effect on the Bode plots, root locus, and time response.

Finally, you can add root locus or Bode plot design constraints that are then displayed on the respective plot.

## E.8 Using the Control System Designer

How to use the **Control System Designer** is covered in detail in Appendix C. The reader is referred to Appendix C, Section C.4 for detailed instruction and an example. To call up the **Control System Designer** in MATLAB use the command *controlSystemDesigner*.

## Summary

This appendix described three MATLAB GUI tools: the Linear System Analyzer, the Simulink Linear Analysis Tool, and the Control System Designer, for which you were referred to Appendix C for details.

We described how to use MATLAB's Linear System Analyzer to obtain time and frequency response plots, as well as critical points on those plots, for transfer functions within the MATLAB workspace. Several examples covering step responses for continuous and sampled systems, Nyquist diagrams, Bode plots, and Nichols charts were given.

In addition, several preferences that we did not describe are available from the Linear System Analyzer **Edit** menu. Within that menu, choose **Plot Configurations**... to select a response layout. **Line Styles**... allows you to change the color, marker, and line style orders. The interested reader should consult the Control System Toolbox reference listed in the Bibliography of this appendix for more details about options not covered in this appendix as well as additional instruction about the Linear System Analyzer.

The Simulink Linear Analysis Tool extends the usefulness of the Linear System Analyzer to Simulink diagrams. Simulink models are linearized before presenting the response curves in the Simulink Linear Analysis Tool. You may set the input and output points at any appropriate place on the Simulink diagram. You may make changes to the Simulink diagram and simultaneously display the response of each mode in the Simulink Linear Analysis Tool.

The Control System Designer is a convenient and intuitive way to obtain, view and interact with a system's root locus, Bode plot, and Nichols plot. You can move closed-loop poles along the root locus and immediately read the values of gain, locations of closed-loop poles, and characteristics of performance, Furthermore, you can see the changes in the open-loop frequency response as well as the closed-loop response if you have those responses selected. Gain also can be adjusted on the open-loop frequency response plots, and the effect can be seen immediately on the root locus and closed-loop responses. Finally, you can add compensators and see the immediate effect on the root locus, open-loop frequency response plots, and the closed-loop responses.

In conclusion, it should be pointed out that results obtained from the GUIs might be different from the analysis presented in the chapters. For example, the GUIs use non-asymptotic frequency response plots to obtain results, while our analysis and design may have used asymptotic Bode plots. Another example is settling time. In Chapter 4 we approximated the settling time so that it was measured at the peaks. With the GUIs the actual settling time is used, that is, the time the curve first enters and stays within the $\pm 2\%$ boundary.

## Bibliography

MathWorks. *Control System Toolbox™ Getting Started Guide R2017b.* MathWorks, Natick, MA, 2000–2017.

MathWorks. *MATLAB® Primer R2017b.* MathWorks, Natick, MA, 1984–2017.

MathWorks. *Simulink® User's Guide R2017b.* MathWorks, Natick, MA, 2004–2017.

MathWorks. *Simulink® Control Design™ Getting Started Guide R2017b.* MathWorks, Natick, MA, 2004–2017.