

Appendix E: MATLAB's GUI Tools Tutorial

E.1 Introduction

Readers who are studying MATLAB may want to explore the convenience of MATLAB's LTI Viewer, the Simulink LTI Viewer, and the SISO Design Tool. SISO is an acronym for single-input single-output. Before proceeding, the reader should have studied Appendix B, the MATLAB Tutorial, including Section B.1, which is applicable to this appendix.

MATLAB Version 8.3(R2014a), MATLAB's Control System Toolbox Version 9.7, Simulink Version 8.3, and Simulink Control Design Version 4.0 are required in order to use the tools described in this appendix.

The M-files in this appendix are available elsewhere on this Web site. Consult the MATLAB Installation Guide for your platform for minimum system hardware requirements.

E.2 The LTI Viewer: Description

The LTI Viewer 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 LTI Viewer 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 LTI Viewer

	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 LTI Viewer

In this section we give you steps you may follow to use the LTI Viewer to plot time and frequency responses. If you have trouble, help is available on the LTI Viewer window menu bar and on the Status Bar at the bottom of the LTI Viewer window. Help is also available on the **Quick Access Toolbar** at the top of the MATLAB R2014a window. Enter **LTI Viewer** in the search box on the right. The following summarize the steps you may take to obtain plots from the LTI Viewer.

- 1. Access the LTI Viewer** The LTI Viewer, shown in Figure E.1, may be accessed by typing `ltiview` in the **MATLAB Command Window** or by executing this command in an M-file.
- 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 LTI Viewer.
- 3. Select LTI transfer functions for the LTI Viewer** Choose **Import . . .** under the **File** menu in the **LTI Viewer** window and select all LTI objects whose responses you wish to display in the LTI Viewer sometime during your current session.
- 4. Select the LTI objects for the next response plot** Right-click anywhere in the LTI Viewer 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 LTI Viewer. More than one LTI transfer function may be selected.
- 5. Select the plot type** Right-click anywhere in the LTI Viewer 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 LTI Viewer.
- 6. Select the characteristics** Right-click anywhere in the LTI Viewer plot area to produce a pop-up menu as shown in Figure E.1. Under **Characteristics**, select the characteristics

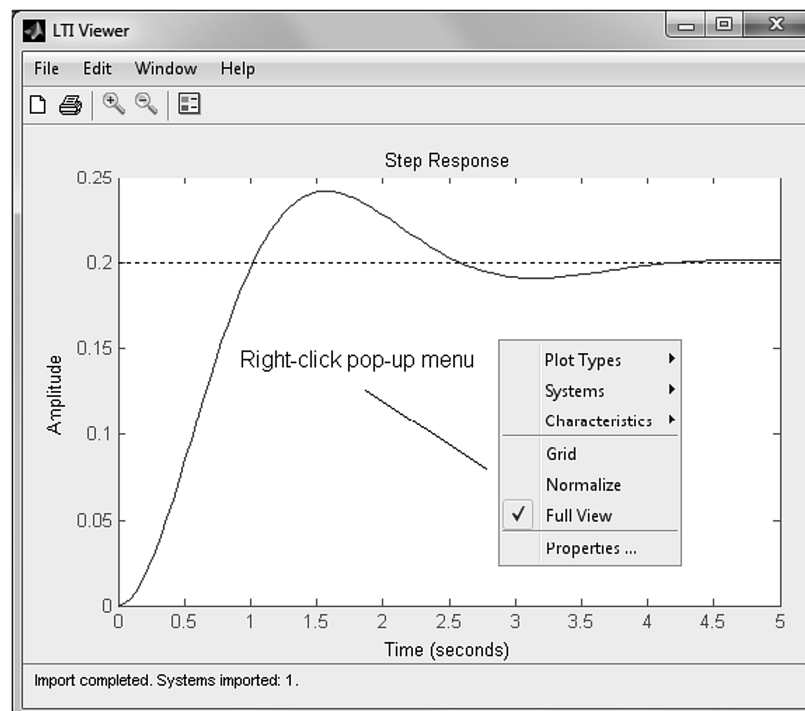


FIGURE E.1 LTI Viewer showing right click pop-up menu

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.

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 **LTI Viewer** and the figures created by selecting **Print to Figure** offer a wide variety of control over the plot presentation.

E.4 LTI Viewer Examples

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

Example E.1

Step Response

PROBLEM: This example, taken from Example 4.8 in the text, shows the use of the LTI Viewer 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 LTI Viewer and create the LTI objects Follow Steps (1) and (2) in Section E.3 to access the LTI Viewer 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**.

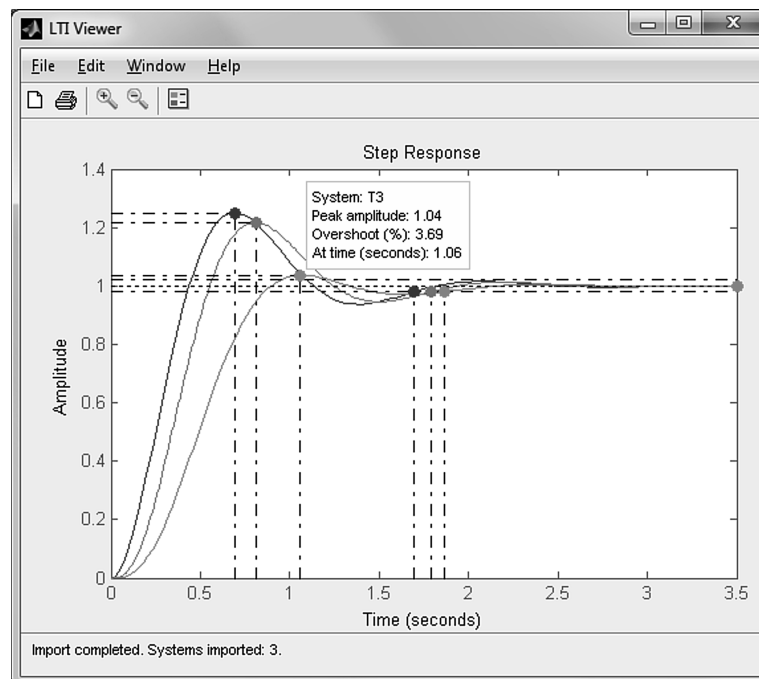
Select the Characteristics Follow Step (6) in Section E.3 and select **Peak Response**, **Settling Time**, **Rise Time**, and **Steady State**.

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 **LTI Viewer** window with the responses and system T3's peak amplitude, percent overshoot, and peak time.

```
'Example E.1' %Display label.
'LTI Viewer 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.
ltiview %Call up LTI Viewer.
```

(a)



(b)

FIGURE E.2 LTI Viewer used for step response: **a.** M-file; **b.** LTI Viewer

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 LTI Viewer 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 **LTI Viewer** window. The system's gain margin and 180° frequency are displayed along with the phase margin and zero dB frequency.

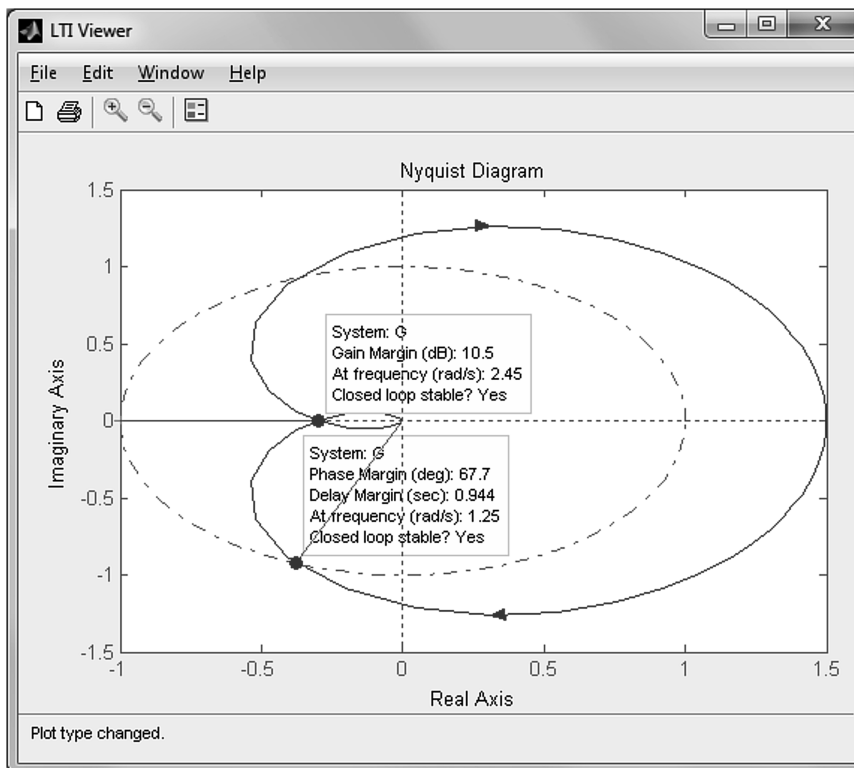
```

'Example E.2' %Display label.
'LTI Viewer 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).
ltiview %Call up LTI Viewer.

```

(a)



(b)

FIGURE E.3 LTI Viewer used for Nyquist diagram: **a.** M-file; **b.** LTI Viewer

Example E.3

Bode Plots and Gain/Phase Margins

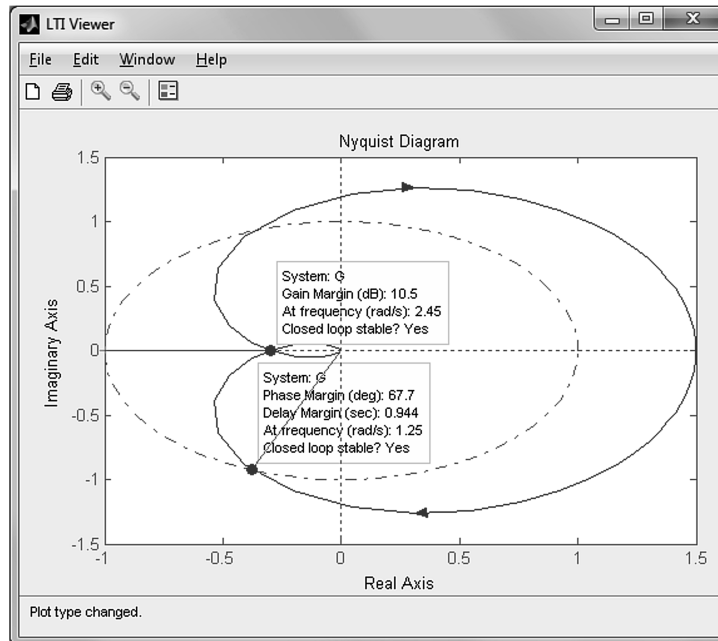
PROBLEM: This example, taken from Example 10.10 in the text, shows the use of the LTI Viewer in making a Bode plot and obtaining gain margin, phase margin, zero dB frequency, and 180° frequency. To create this plot, follow Steps (1) through (4) in Section E.3 using the M-file shown in Figure E.4(a). 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 **LTI Viewer** window. The system's phase margin and 0 dB frequency are displayed along with the gain margin and 180° frequency.

```

'Example E.3' %Display label.
'LTI Viewer 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).
ltiview %Call up LTI Viewer.

```

(a)



(b)

FIGURE E.4 LTI Viewer used for Bode plot: **a.** M-file; **b.** LTI Viewer

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 LTI Viewer, which uses the exact frequency response, and the results of Example 10.10.

Example E.4

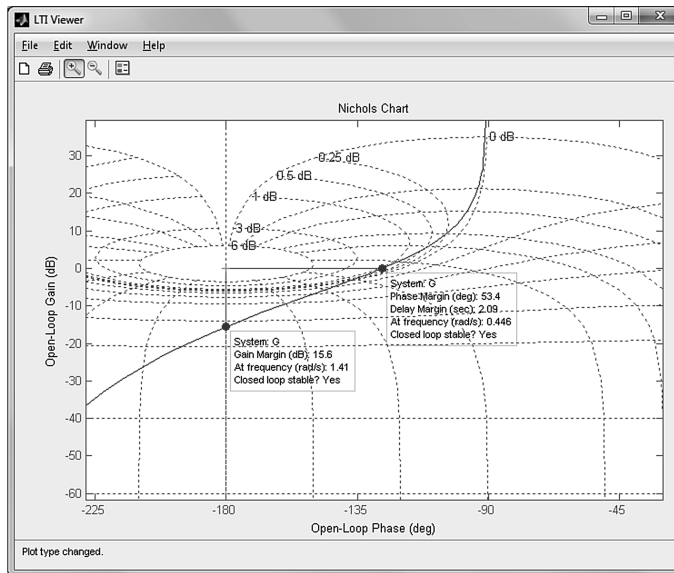
Nichols Chart and Gain/Phase Margins

PROBLEM: This example, which reproduces Figure 10.47 in the text, shows the use of the LTI Viewer 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.

```
'Example E.4'           %Display label.
'LTI Viewer 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).
ltiview                %Call up LTI Viewer.
```

(a)



(b)

FIGURE E.5 LTI Viewer used for Nichols chart: a. M-file; b. LTI Viewer

Example E.5

Step Response for Digital systems

PROBLEM: This example shows the use of the LTI Viewer 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 **LTI Viewer** window with the digital step response.

```
'Example E.5'           %Display label.
'LTI Viewer 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.
ltiview                %Call LTI Viewer.
```

(a)

FIGURE E.6 LTI Viewer used for digital step response: a. M-file; (figure continues)

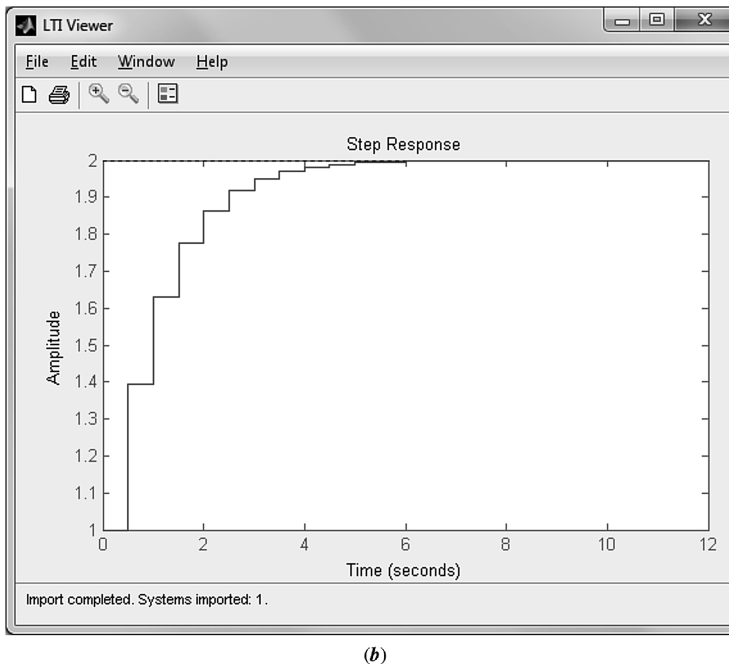


FIGURE E.6 (Continued)
b. LTI Viewer

(b)

E.5 Simulink and the LTI Viewer

Readers who are using Simulink may use the LTI Viewer to obtain responses and their characteristics directly from Simulink models. All of the response plots and characteristics available to you in the LTI Viewer 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 LTI Viewer 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 LTI Viewer with Simulink

In this section we present the steps you may follow to use the **LTI Viewer** with **Simulink**. Help is available on the menu bar of the **MATLAB** Window. Click on the encircled question mark. When the help screen is available, choose **Simulink Control Design**. Help is also available from **Help** on the menu bar of the **Control and Estimation Tools Manager** Window. From **Help** select **Simulink Control Design Help**. The following summarize the steps you may take to use the **LTI Viewer** 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 analysis model** Click on the point to apply the input. Right click on the selected point and choose **Linear Analysis Points** then **Input Perturbation** on the drop-down menu. Next, click on the point to view the output. Right click on the selected point and choose **Linear Analysis Points** then **Output**

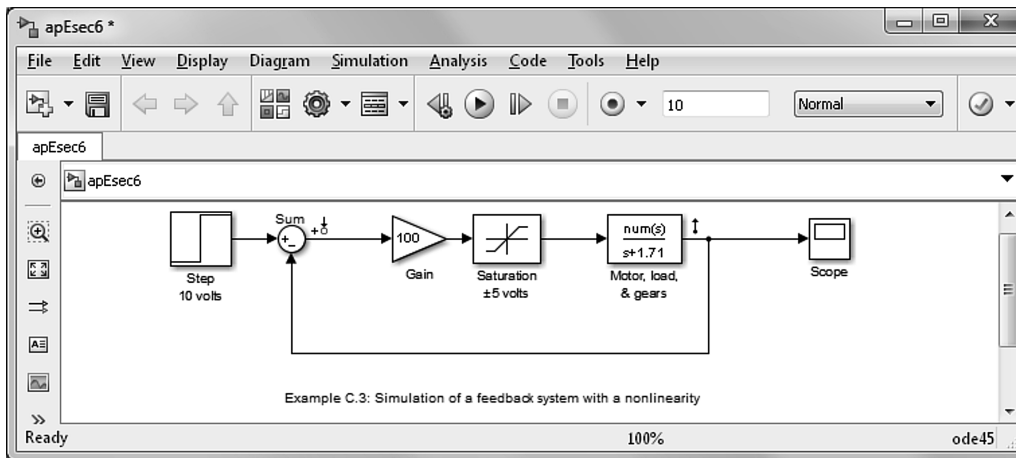


FIGURE E.7 Simulink model window showing **Input Perturbation** point and **Output Measurement** point

Measurement on the drop-down menu. The input and output points are shown on the Simulink model of Figure E.7.

3. **Linearize the model** Under the **Analysis** menu select **Control Design** followed by **Linear Analysis ...**. In response, **MATLAB** opens the **Linear Analysis Tool** Window, Figure E.8. Select the **Exact Linearization** tab followed by pressing the **Linearize** green arrow on the **Toolstrip**.
4. **Launch the LTI Viewer** After linearization, the **LTI Viewer** is launched in the **Linear Analysis Tool** window as shown in Figure E.9. All of the **LTI Viewer** functions previously described are now available.

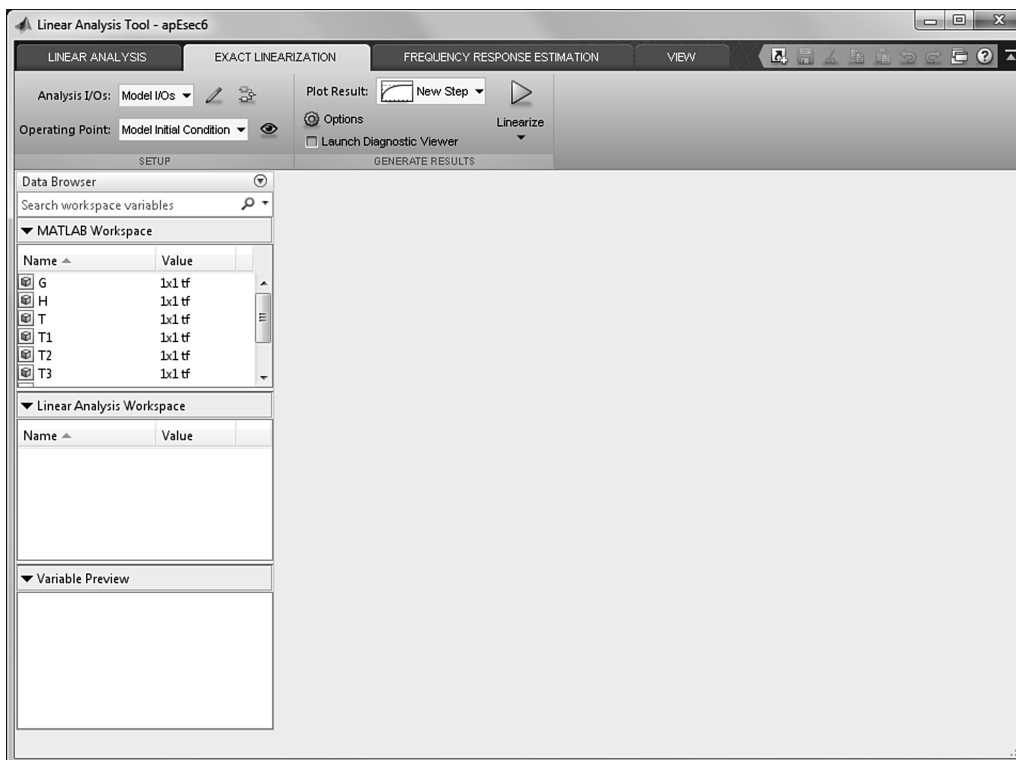


FIGURE E.8 Linear Analysis Tool window

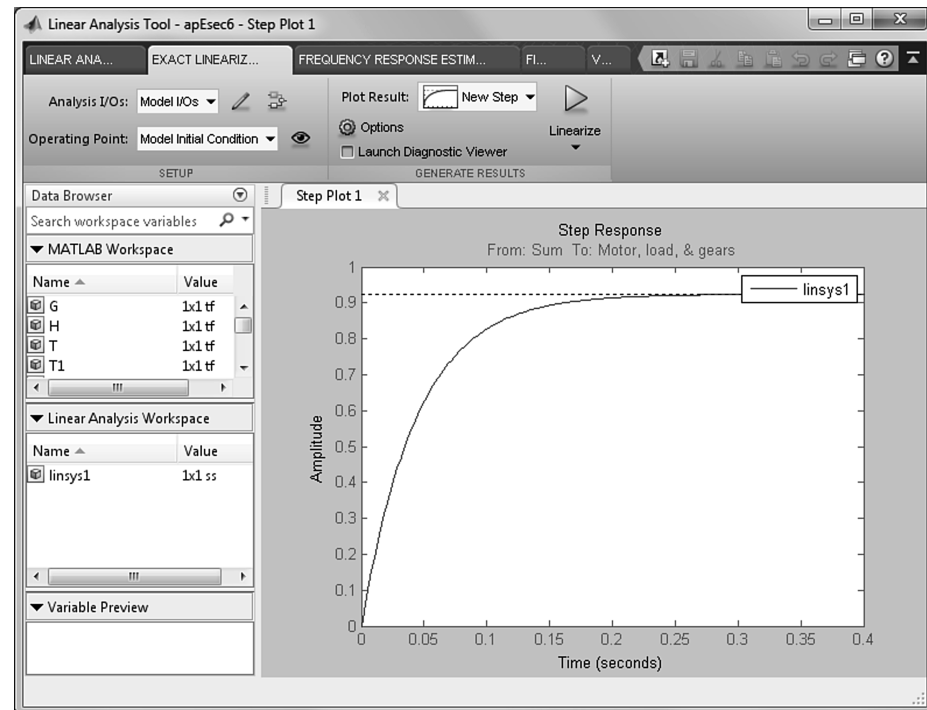


FIGURE E.9 Linear Analysis Tool window after linearization showing inserted LTI Viewer

E.7 The SISO Design Tool: Description

The SISO Design Tool 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, which can be selected under the **View** menu. 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 **LTI Viewer for SISO Design Tool** window. 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 **LTI Viewer for SISO Design Tool** window. 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 SISO Design Tool

In this section we present the steps you may follow to use the SISO Design Tool. If you have trouble, help is available by selecting **SISO Design Tool Help** under the **SISO Design for SISO Design Task** window **Help** menu. Context-sensitive help also is available. Select the

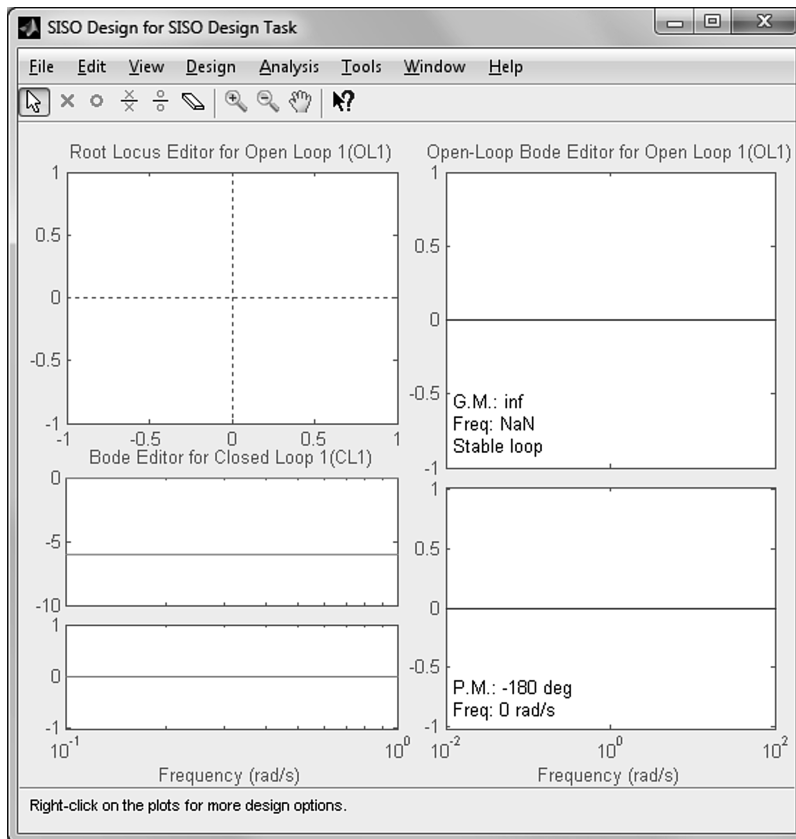
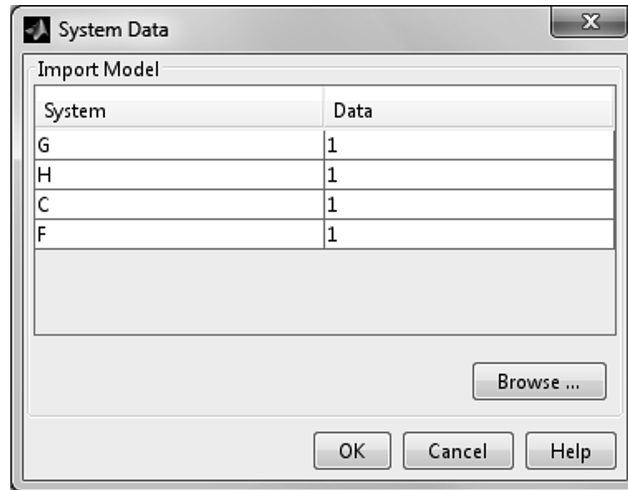


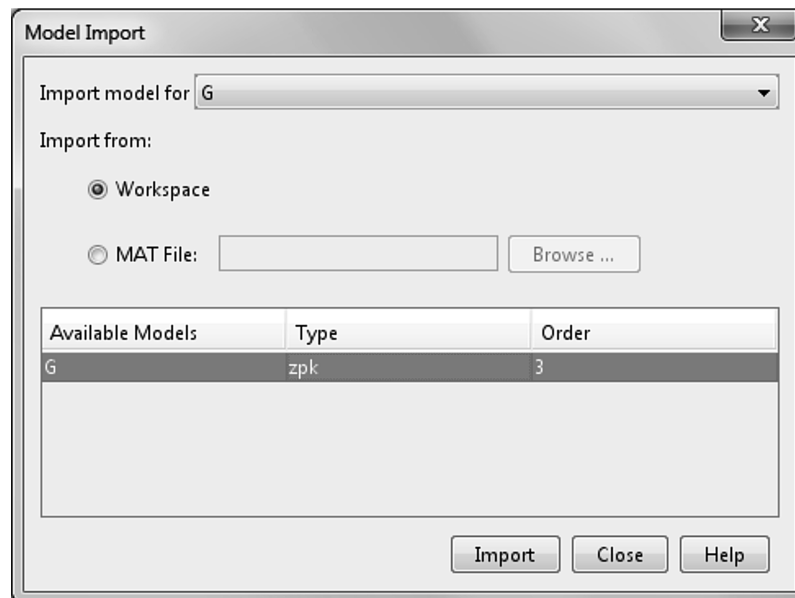
FIGURE E.10 SISO Design for SISO Design Task window

context-sensitive tool (the arrow and question mark) from the **SISO Design for SISO Design Task** window, move it to the item on the **SISO Design for SISO Design Task** window about which you have a question, and click. The explanation will appear in the **Help** window. Help is also available on the **Status Bar** at the bottom of the **SISO Design Tool** window. Finally, screen tips are available for the toolbar buttons. Let your mouse's pointer rest on the button for a few seconds to see the explanation. The following summarize the steps you may take to use the SISO Design Tool.

1. **Access the SISO Design Tool** The **SISO Design for SISO Design Task** window, shown in Figure E.10, may be accessed by typing `sisotool` in the **MATLAB Command Window** or by executing this command in an M-file.
2. **Create LTI transfer functions** Create open-loop LTI transfer functions for which you want to analyze closed-loop characteristics or design compensators. 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 functions in the MATLAB workspace. All LTI objects in the MATLAB workspace can be exported to the SISO Design Tool. For this example we run an M-file and generate the LTI object for $G(s) = (s + 8)/[(s + 3)(s + 6)(s + 10)]$.
3. **Create the closed-loop model for the SISO Design Tool** Choose **Import . . .** under the **File** menu in the **SISO Design for SISO Design Task** window to display the **System Data** window shown in Figure E.11(a).



(a)



(b)

FIGURE E.11 a. The **System Data** window b. The **Model Import** window

Type the LTI transfer function in the **Data** column. Alternately, click the **Browse . . .** button and select the function you want to analyze in the resulting **Model Import** window shown in Figure E.11(b). Click **Import** followed by **Close** in the **Model Import** window. Click **OK** in the **System Data** window.

4. Interact with the SISO Design Tool After the **System Data** window closes, the **SISO Design for SISO Design Task** window now contains the root locus and Bode plots for the system as shown in Figure E.12.

You can now add the window to your desktop from which you can immediately view closed-loop responses as you make changes to the root locus or Bode plot. Under the **Analysis** menu select the desired response to open the **LTI Viewer for SISO Design Task** window. Be sure to right-click on the **LTI Viewer for SISO Design Task** and choose **Systems** to display the system response you desire. See the earlier Task sections of this appendix for information on the **LTI Viewer**.

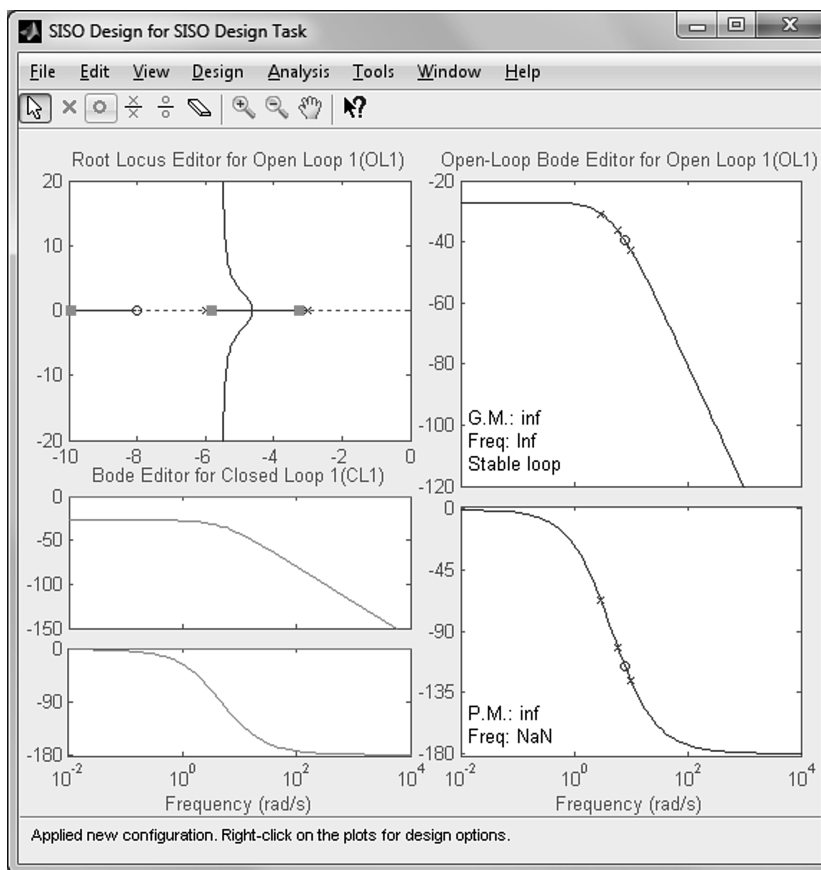


FIGURE E.12 SISO Design for SISO Design Task window

Changing gain You may change the loop gain in three ways. (1) Grab a closed-loop pole (red squares) on the root locus. When the arrow cursor changes to a hand, hold down the left button of your mouse and drag the closed-loop pole along the root locus. You will see immediate changes on the Bode plot and the closed-loop response in the **LTI Viewer for SISO Design Task** window. The value of gain will be displayed in the **Status Bar** at the bottom of the **SISO Design for SISO Design Task** window. (2) The loop gain can also be changed by positioning the cursor over the open-loop Bode magnitude plot until it changes to a hand. Hold down the left button of your mouse and drag the Bode magnitude plot up or down. You will see immediate changes on the root locus and closed-loop response. (3) Finally, the gain can also be changed by choosing **Design** in the **SISO Design for SISO Design Task** menu bar and then selecting **Edit Compensator . . .** When the **Control and Estimation Tools Manager** window appears, type the desired gain in the **Compensator Editor** section and hit enter. As you change the gain, notice that you can read the gain and phase margins and the gain and phase margin frequencies at the bottom of the Bode magnitude and phase plots. Also, at the bottom of the Bode magnitude plot you are told whether or not your closed-loop system is stable.

Grids You may toggle the root locus and Bode plot grids on and off by right-clicking in the respective plot's window and selecting or deselecting **Grid**. The root locus grids are damping ratio and natural frequency.

Zoom See the instructions for zooming in Section E.3, using the LTI Viewer.

Design constraints You may add design boundaries on your plots. For example, if you want the settling time to be less than 2 seconds, a vertical gray bar immediately to the right of -2 will signify the boundary for that portion of the root locus where the settling

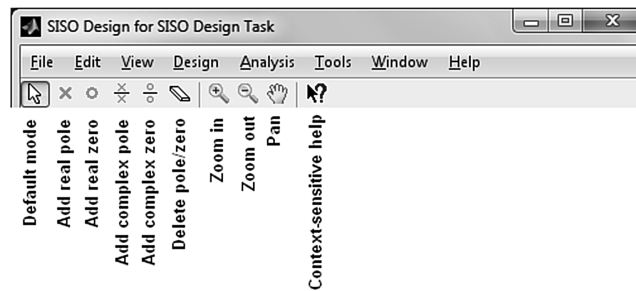


FIGURE E.13 SISO Design for SISO Design Task window toolbar

time does not meet the requirements. These constraints may be selected by right-clicking a respective plot and selecting **Design Requirements**. Choose whether you want a **New . . .** constraint or you want to **Edit . . .** an existing constraint. Constraints may also be edited on the plots. Position your cursor at the boundary of the constraint. Left click and when it turns into a four-pointed arrow, you can drag the boundary to a new position. The values of the constraints are displayed in the Status Bar at the bottom of the plots.

Properties Right-clicking in a plot's window and selecting **Properties . . .** displays the **Property Editor** window. From this window you can control some properties of the plot, such as axis labels and limits. There are other options available. For instance, you may change the damping ratio grids to show percent overshoot by right-clicking in the root locus window and selecting **Properties . . .**. Once the **Property Editor** window is displayed, click the **Options** tab and select **Display damping values as % peak overshoot**. You may want to explore other options available for the root locus and Bode plots.

Add poles, zeros, and compensators Poles and zeros may be added from the **SISO Design Tool for SISO Design Task** window toolbar shown in Figure E.13. Use the **SISO Design for SISO Design Task** toolbar and select the desired compensator pole or zero. Your cursor shows that a pole or zero was selected. Point your cursor arrow to the point on the root locus or Bode plot where you want to add the compensator and click. The compensator is shown in the **Control and Estimation Tools Manager** window under the **Compensator Editor** tab. The effect of adding the compensator is immediately seen in the root locus, Bode plots, and **LTI Viewer for SISO Design Task** windows. You may change the way the compensator is represented by going to **SISO Tool Preferences . . .** under the **Edit** menu. Select the **Options** tab and choose the compensator format you want.

Editing compensators The pole and zero values of the compensators can be edited in several ways. (1) Place your cursor over a compensator zero or pole on the root locus or Bode plot. When the cursor changes to a hand, hold down the left button of your mouse and drag the pole or zero to a new position. (2) Choose **Design** then **Edit Compensator . . .** on the **SISO Design for SISO Task** window menu bar. In response, MATLAB produces the **Control and Estimation Tools Manager**. Under the **Compensator Editor** tab you can type in another location for compensator zeros and poles. (3) Poles and zeros can be erased using the eraser on the tool bar in Figure E.13. Select the eraser with your mouse and click on the pole or zero you wish to erase. The effect of editing the compensator is immediately seen in the root locus, Bode plots, and **LTI Viewer for SISO Design Task** response window.

Other options and windows There are other options and windows available that may be important to your project. You are encouraged to explore other menu items not discussed in this section.

Summary

This appendix described three MATLAB GUI tools: the LTI Viewer, the Simulink LTI Viewer, and the SISO Design Tool.

We described how to use MATLAB's LTI Viewer 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 LTI Viewer **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 LTI Viewer.

The Simulink LTI Viewer extends the usefulness of the LTI Viewer to Simulink diagrams. Simulink models are linearized before presenting the response curves in the Simulink LTI Viewer. 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 LTI Viewer.

The SISO Design Tool 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 the LTI Viewer for SISO Design Task open. 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.

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