EE 105 Simulink Lab : Simulation as an Engineer's Problem Solving Tool (Linear State Space Block)

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Abstract

The objective of this lab is to practice linear system simulation in Matlab's Simulink using the State Space Block.

1 Prelab

Complete the following steps prior to lab.

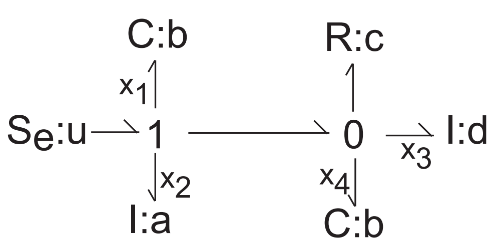

Figure 1: Bond graph.

Fig. 1 shows the bond graph (BG)[1] for a fourth order system with the state variables labeled. The output is the flow through the I-element with parameter d.

1. Walk the causal strokes and the state variables through the BG. Represent the state vector by the symbol $x(t)$. The components of $x(t)$ are labeled on the bond graph.

2. Define the A, B, C, and D matrices in terms of the design parameters: a, b, c, and d, so that the linear state space model is:

$$\begin{aligned} \dot{x}(t) &= A\,x(t) + B\,u(t) \\ y(t) &= C\,x(t) + D\,u(t). \end{aligned}$$

[1] Just for fun, not required for a grade, can you draw a circuit that yields this bond graph?

2 Simulink in Lab Procedure

For the remainder of this lab,the system parameters are

$$a = 1.0,\ b = 10,\ c = 0.5,\ d = 1.0.$$

At each location indicated, meet with the TA so that the TA can check and record your progress.

1. Review your Prelab with the TA.

   ________Show results to TA to record approval. ________

2. In this step, you are determining information about the system that you will use later. Create an m-file (script, not a function) that does each of the follow.

   (a) Computes the A, B, C, and D matrices.

   (b) Finds the poles[2] of the system, using eig(A).

   (c) Find the dominant time constant of the system[3]. How long should it take for the transient response to decay away? This is the settling time T_s.

   (d) Uses the function '[nun,den]=ss2tf(A,B,C,D)' to find the transfer function for the system where *num* is the numerator polynomial and *den* is the denominator polynomial.

   (e) Use the 'roots' function on *den* and *num* to find the poles and zeros. Confirm that the poles found here match the eigenvalues of A found earlier.

   It is important that your m-file is a script. At this point, use the command 'who' in the command window to check that the that variables A, B, C, and D exist in memory.

   ________Show results to TA to record approval. ________

[2] Later in the course we will show that the poles of the transfer function are the same as the eigenvalues of the state-space matrix A.

[3] When all poles are complex, the dominant time constant is computed using the pole that has real part nearest to the origin.

3. In this step, you will use the Bode plot to choose five frequencies to simulate.
   (a) Type 'help bode' in the command window to see what it does.
   (b) Use the Matlab function 'bode(num,den)' to plot the Bode plots for the system. It may also be useful for turn on the grid (i.e., 'grid on'). The top plot is the magnitude response. It should exhibit two frequencies where the magnitude has a local maximum. These are the frequencies at which where the output steady-state response will have the maximum magnitude, call them ω_{p_1} and ω_{p_2}, with $\omega_{p_1} < \omega_{p_2}$. Determine these two frequencies, being careful to note the units.
   (c) Select three other frequencies: ω_1, ω_2, and ω_3, such that
   $$0 < \omega_1 < \omega_{p_1} < \omega_2 < \omega_{p_2} < \omega_3.$$
   Determine the magnitude and phase shift at these five frequencies.

______Show results to TA to record approval. ______

4. In this step, you create a Simulink simulation[4] to analyze the system response for each sinusoidal input. Reference Fig. 2 while reading the following method.
   (a) Click the Simulink icon on the Matlab menu bar. Open a blank model.
   (b) Open the Simulink library browser (see green S1 on Fig. 2). In the 'continuous' folder, copy the 'State-Space' block to the Simulink window. Also copy a 'sine wave' source input from the sources folder and a 'scope' output from the sinks folder. Connect them up as shown in the bottom of Fig. 2 to represent the system.[5]
   (c) Double click the 'State-space' block to open it up (see green S2 on Fig. 2).
      i. Enter the names 'A', 'B', 'C', and 'D' into the appropriate menu slots. Do not type in the whole matrix, just the matrix names. Simulink will read the data from the workspace for you.
      ii. Enter an appropriately sized column vector of zero initial conditions.
      iii. Close the 'State-space' block.
   (d) Near the top middle of the Simulink main window is an item labeled 'Stop time' (see green S3 on Fig. 2). Change the value of the stop time to be approximately three times the settling time. This allows T_s seconds for the transient response and $2\,T_s$ seconds for the steady-state response.
   (e) Complete the following steps to simulate the system and analyze the response for each of the five frequencies selected in Step 3c.
      i. Double click the sine wave to open it. Edit its frequency to match one of the values above. The amplitude should be one.
      ii. Click the button with the green arrow to perform the simulation (see green S4 on Fig. 2).
      iii. Double click the scope to open it and see the results (see green S5 on Fig. 2). The scope displays both the input signal (sine wave) and the output response.
      iv. Determine the settling time T_s. For the steady-state response, measure the change in amplitude and phase of the output relative to the input.
      v. Compare the gain and phase shift information from the Bode plot with the simulated response. They should match.[6]

   Repeat these steps for each of the frequencies from Step 3c.

______Show results to TA to record approval. ______

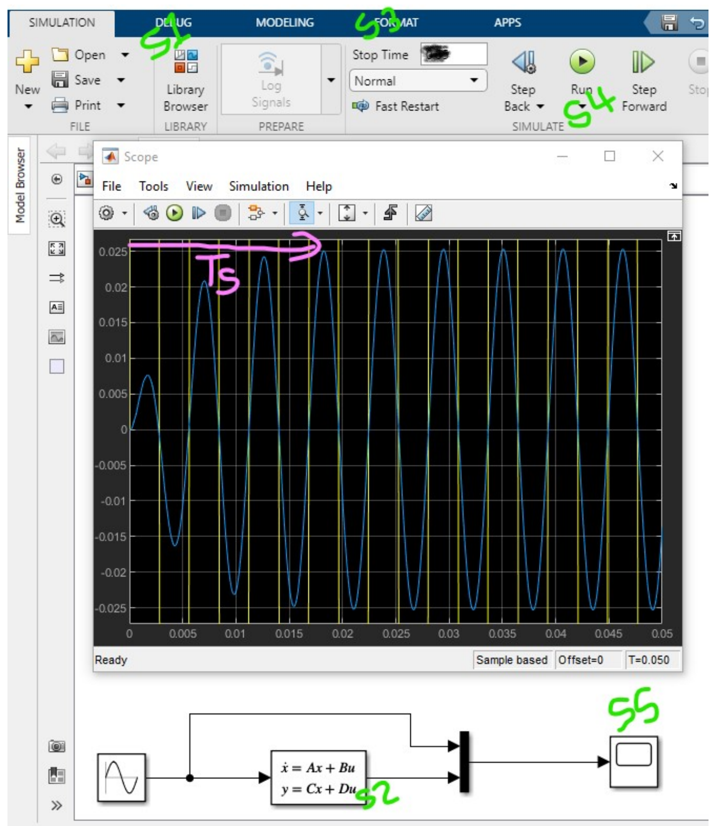

Figure 2: Simulink Setup. The time response may not match that for the design parameters used this year.

[4] See the Simulink guide attached to the previous lab.

[5] It is also convenient to use the 'mux' block to cause the scope to plot both the sinusoidal input and the output on one scope. This makes it easy to compare them.

[6] See the 'Frequency Response: Physical Meaning' section of the lecture notes.

3 Report Writing Guidance

Your goal in any report is clear communication of results. This requires labeled figures, equations showing sample calculations, and text with good grammar that describes what the reader should conclude.

For this lab report, consider:

1. Your complete BG and the state-space model equations that you extract from it.
2. Your definitions of the A, B, C, and D matrices.
3. A figure showing your simulink block diagram.
4. Marked-up figures for *one* of the frequencies that help you explain how you compute the phase and gain of the output relative to the input. Note:
   - A figure marked to show how you determined T_s, with discussion comparing it to your expectations.
   - The input magnitude, output magnitude (marked on a figure) and their ratio, with discussion comparing it to your expectations.
   - A figure showing how you computed the phase shift between the input and output.

   Each figure should have a name (e.g., Fig. 6) and the discussion should refer to it by name (e.g., Fig. 6 shows ...). You only need these figures for one of the frequencies, to demonstrate your method of calculation.
5. A table showing, for each of the five frequencies, the theoretical and simulated T_s, input amplitude, output amplitude, amplitude gain, theoretical phase shift and simulated phase shift. This Table should have a name and should be discussed by name.