

SIMULINK FOR BEGINNERS*

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*These notes are revised using MATLAB and SIMULINK version 2020b.
Compared with earlier versions some modifications have occurred.

SIMULINK FOR BEGINNERS:

To begin your *Simulink* session, start by clicking MATLAB ICON



and click the *Simulink*

button (Figure 1.1).

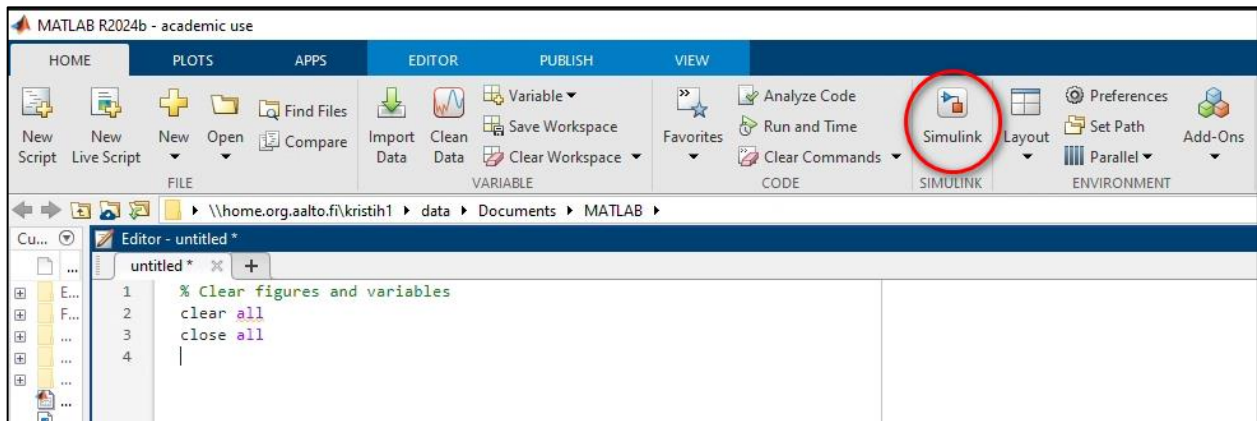


Figure 1. 1 MATLAB window is first opened. For a new Simulink session click the Simulink button.

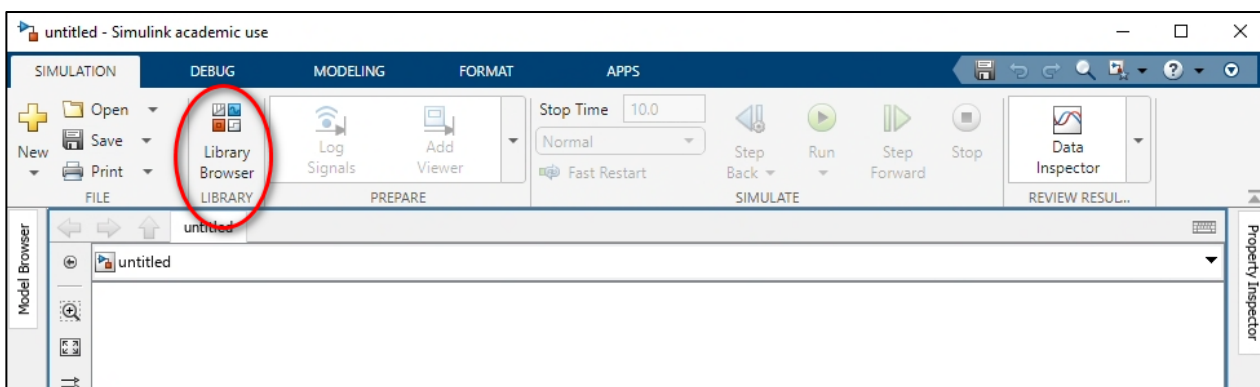
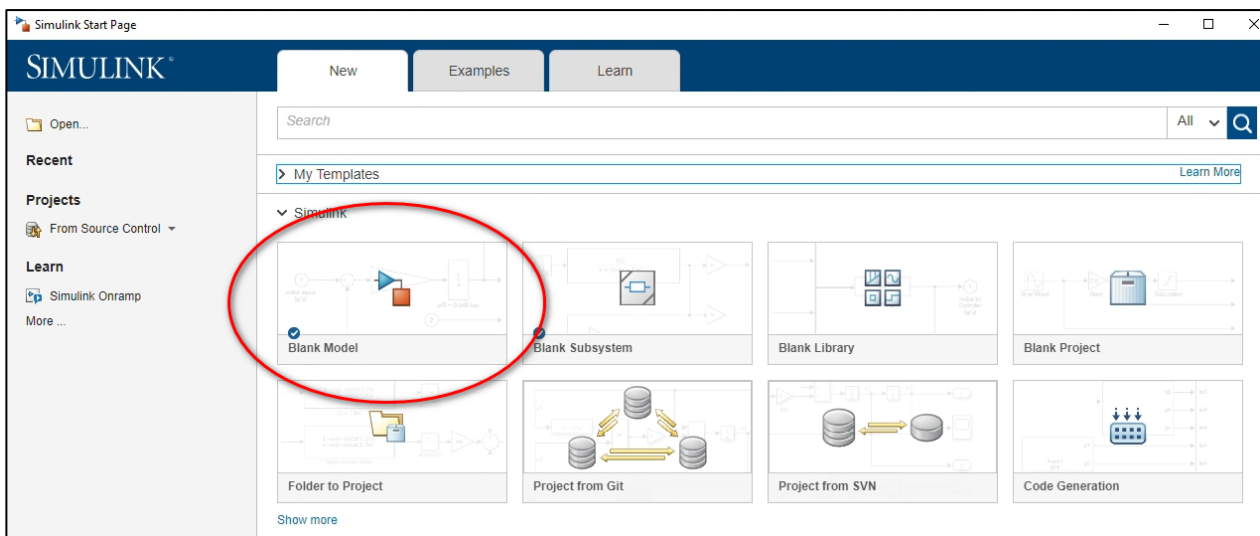


Figure 1. 1 Select Blank Model and when it opens, select the Library Browser

You will now see the whole *Simulink* block library as in Fig.1.2.

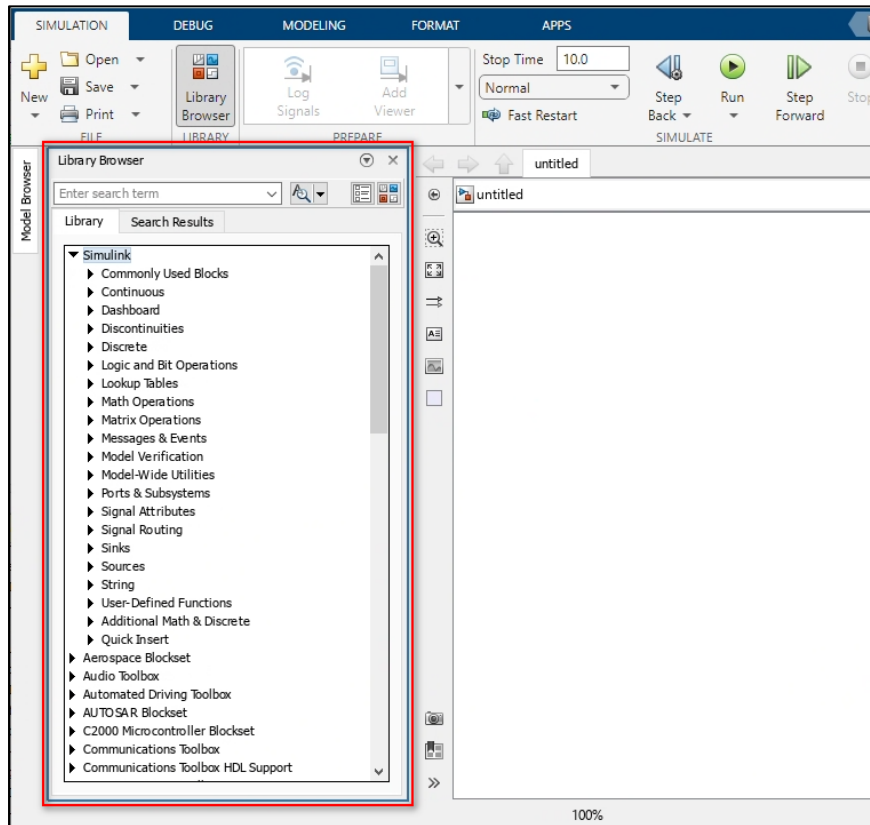


Figure 1. 2 Simulink consists of block libraries Continuous, Dashboard, Discontinuities, Discrete, etc, as shown above. Note that there is a separate Simulink Extras, where you can find special blocks.

Browse through different block libraries. E.g., if you click *Continuous*, you will see the following:

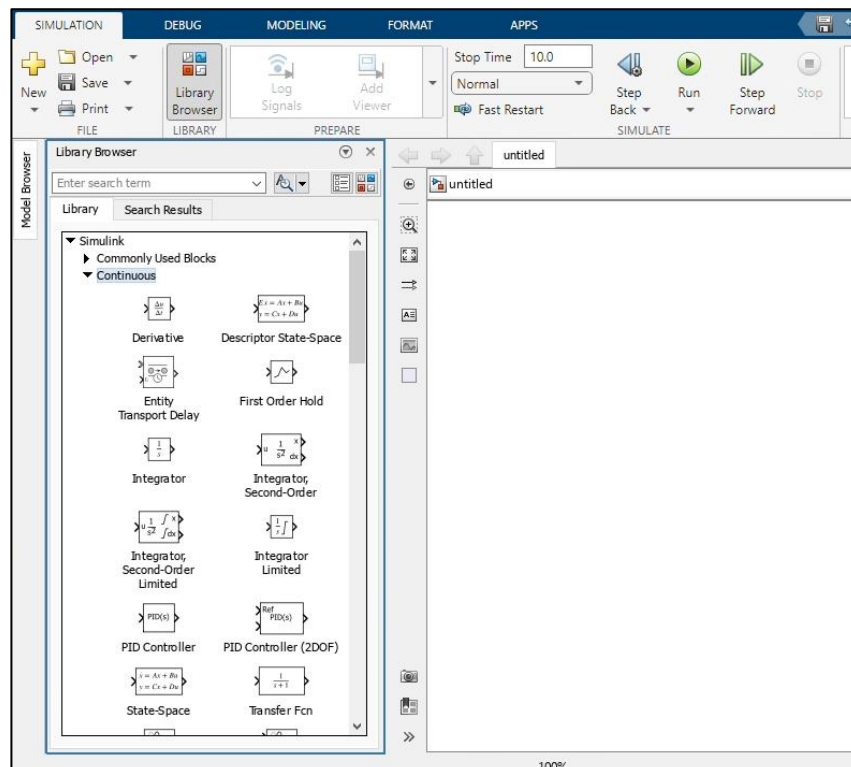


Figure 1. 3 Blocks of *Continuous* block library.

Observe the description inside the Integrator block: $\frac{1}{s}$. This operator notation comes from linear systems domain, where s represents Laplace variable. Roughly speaking, s corresponds to derivative operator $\frac{d}{dt}$, and its inverse $\frac{1}{s}$, to integration operation \int . We will discuss the differences later.

Math Operations library is shown next

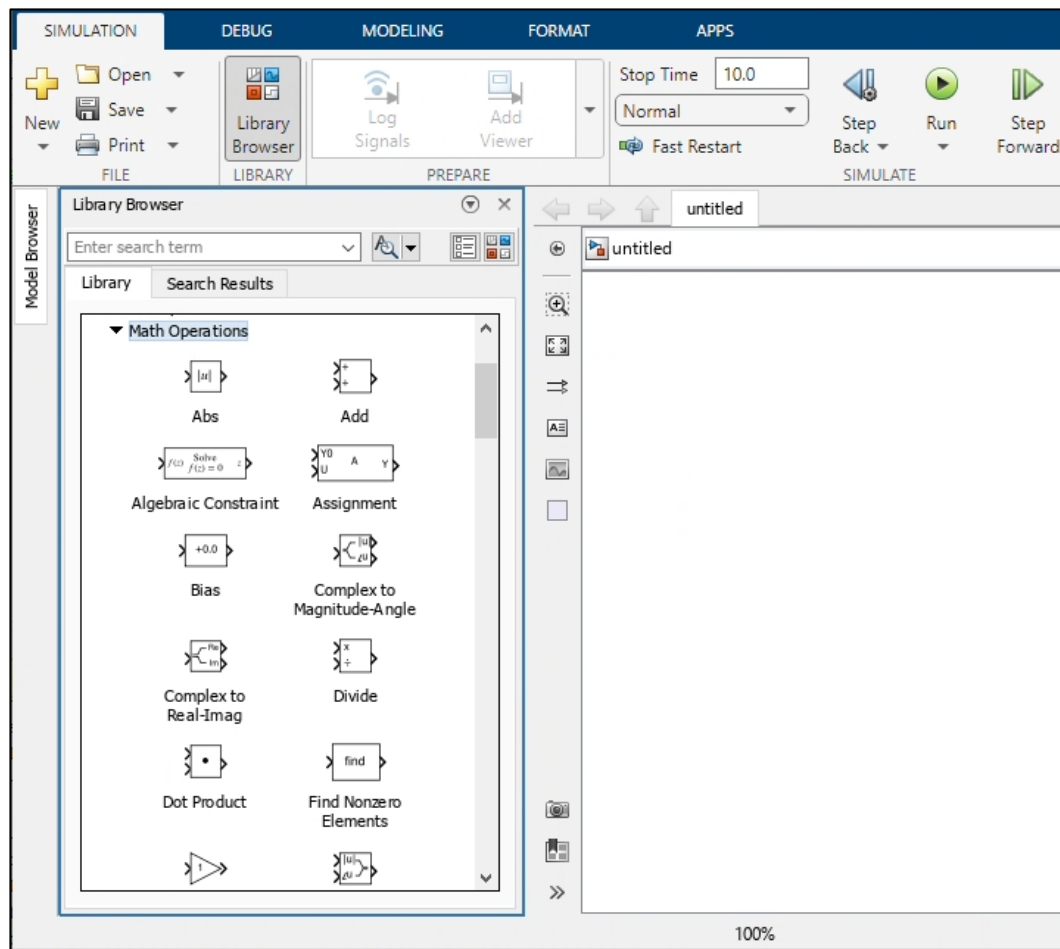


Figure 1. 4 Blocks in Math Operations block library (not all shown).

After browsing through other block libraries, we are now ready to start generating *Simulink* diagrams.

You can now construct a *Simulink* configuration of your system using different blocks in the library. You do not need to know how to solve e.g. a differential equation, *Simulink* will do it for you. After solving the problem the result is in numerical form, which can also be presented graphically.

EXAMPLE 1: Given an input signal $u(t) = \sin(t)$.
It is fed into an amplifier with gain 2. Simulate the output of the amplifier $y(t)$.
(The answer is $y(t) = 2 \sin(t)$)

Solution: First choose the amplifier block. This you can find under *Math Operations* and it is called *Gain* (Figure 1.6). Move the cursor on top of *Gain*. Press the left hand side of your mouse down and drag the *Gain* block to the **untitled** file and release it. If you fail, try again. The result is shown below.

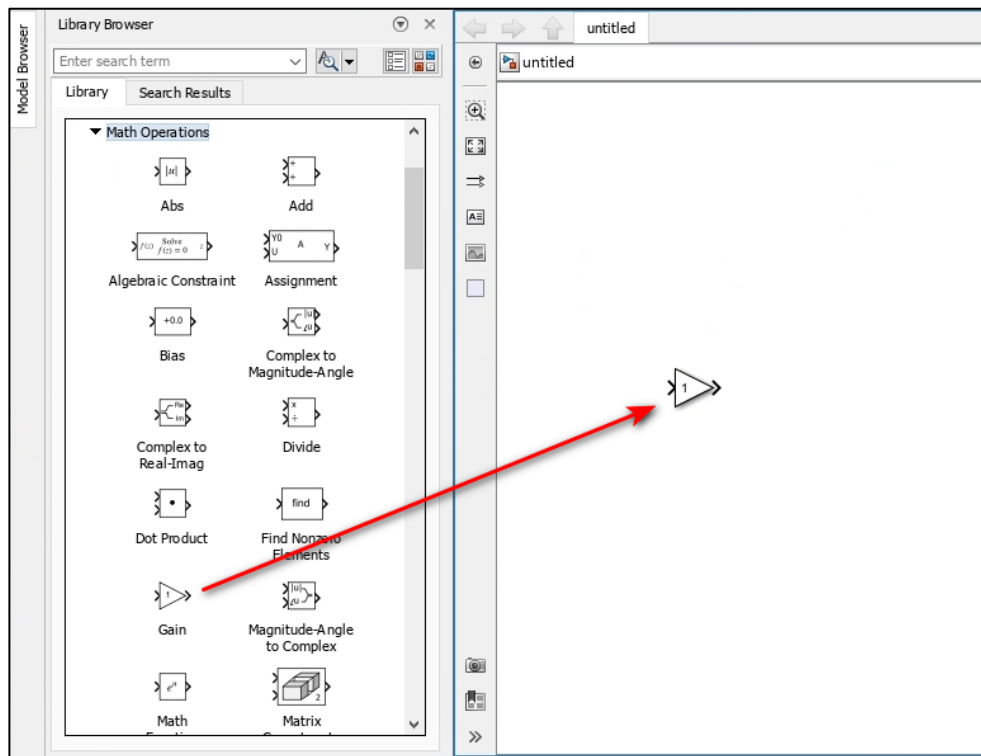


Figure 1.6 Gain block in Math Operations block library.

The Gain has only one parameter, default value of 1. Change gain to 2.

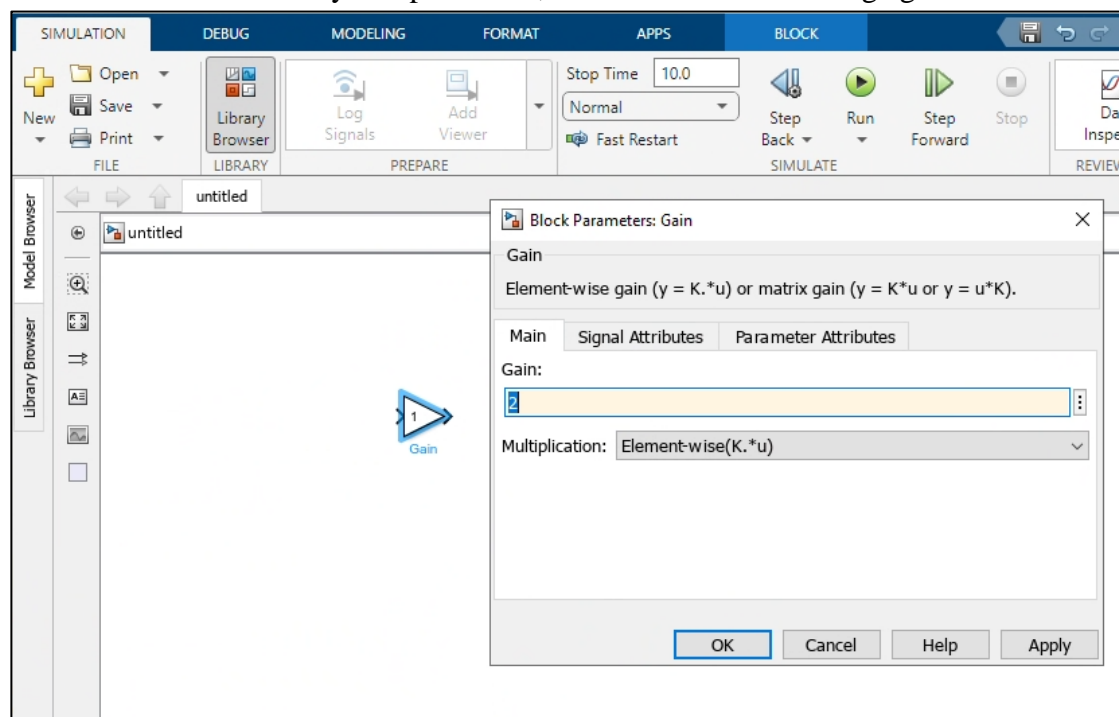


Figure 1.7 Changing the gain value in the Gain block from 1 to 2.

The gain value can be changed by double-clicking the Gain block. Once finished, click OK. If you do not, the value will not be changed. The numerical value inside the Gain block will now become 2.

Next find input signals. Input block library is called *Sources*, where you can find the needed input: *Sine Wave*. Move the cursor on top of the *Sine Wave* block, drag the block to your model (Figure 1. 9).

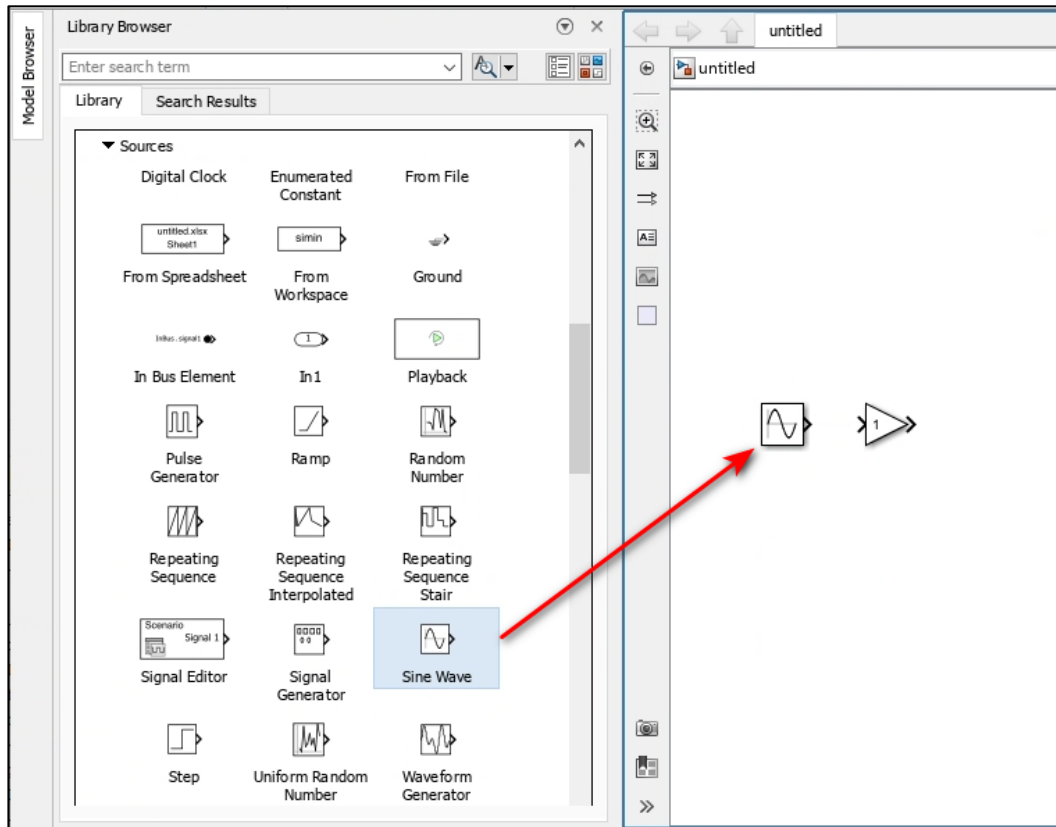


Figure 1. 9 *Sine Wave* block is taken from the *Sources* block library.

To see the result, you need to install a *Sink* from *Sinks* library. In the beginning, the easiest *Sink* device is *Scope*. Move the *Scope* block to your model in the same way as before (The result is shown below Figure 1. 10).

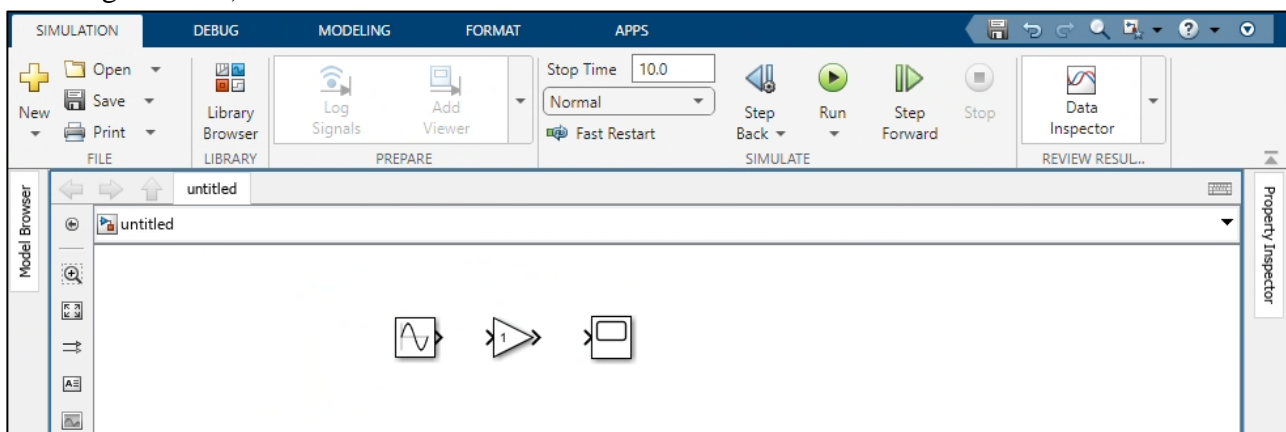


Figure 1. 10 *Scope* block is taken from the *Sources* block library.

The only thing missing from the system is to connect the subsystems together. Take the cursor to the output of the *Sine Wave* block. Cursor will change to a hairline. Now press left mouse button and drag your mouse close to the input of the Gain block. You will see a dashed black line forming from the output side of the block which you started. Once you reach the input of the other block, a solid black line is formed to indicate that connection is made. If the connection is not complete, you will see a red dotted line (Figure 1.11). To complete the connection, you can e.g. drag the receiving block so that its input will meet the arrowhead.

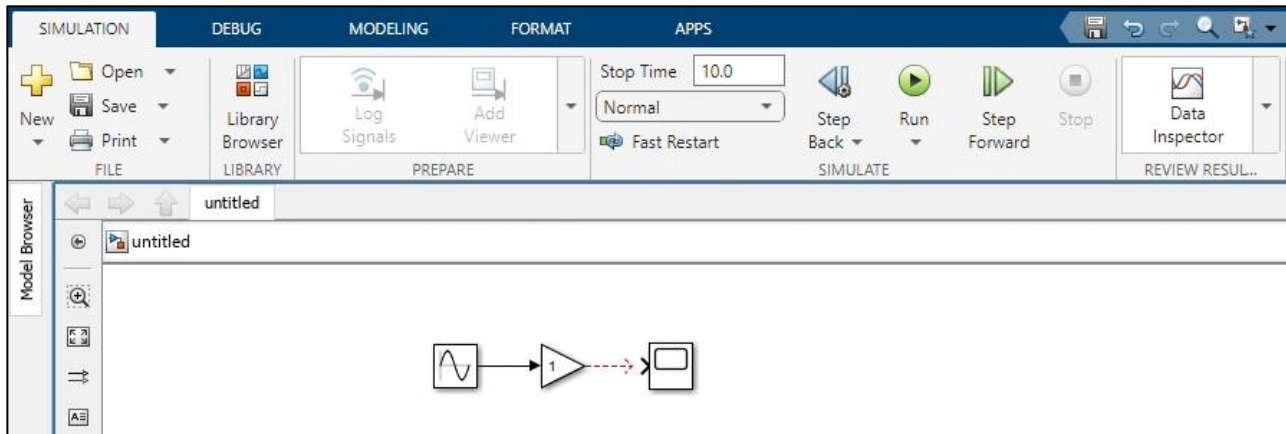


Figure 1.11 Connection from sine wave to gain is good.

The connection from gain to scope is not complete (red dashed line)

After connections your configuration of the system is complete. Before simulation, you should check that the parameter values in the *Sine Wave* block are correct. Open it by double-clicking the block.

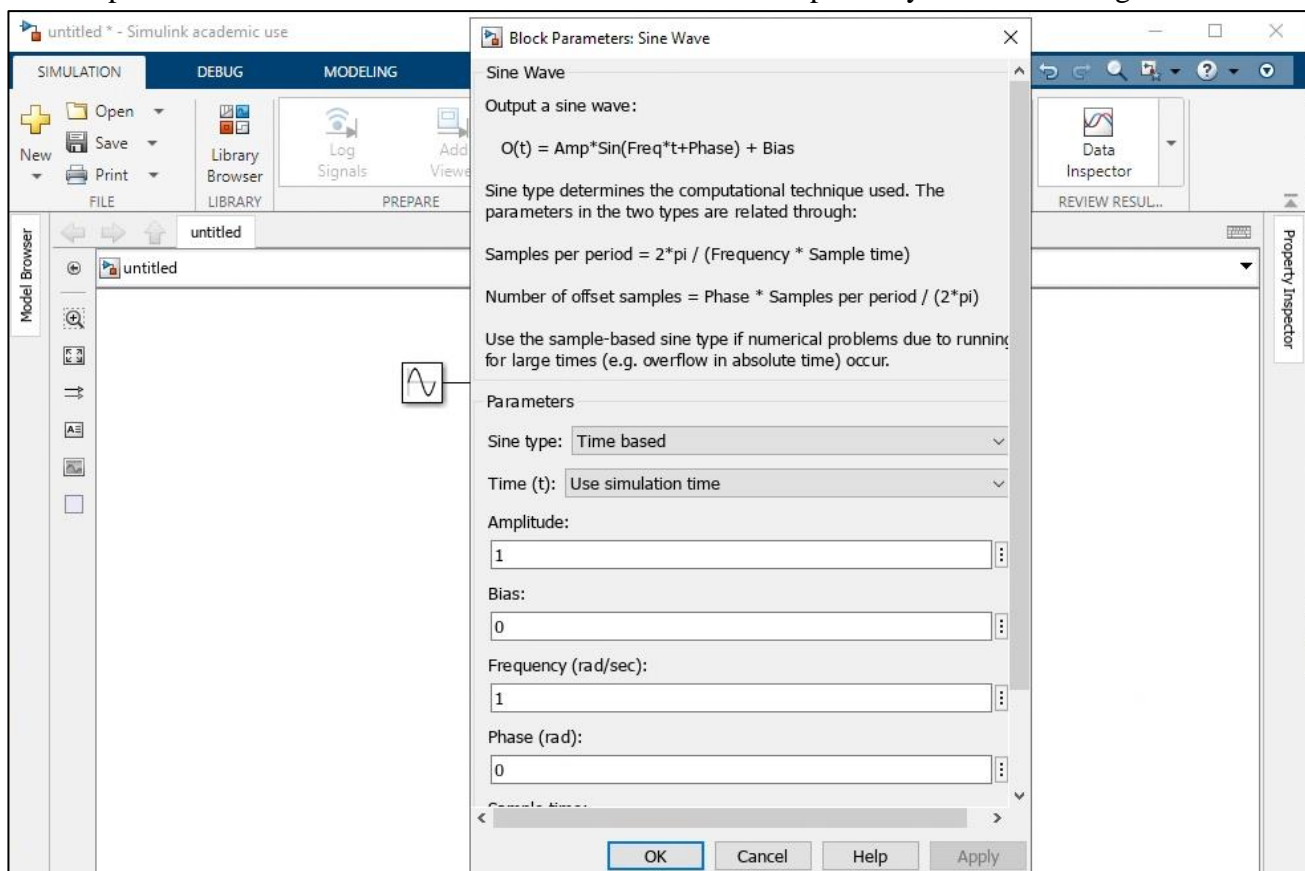


Figure 1.12 Block Parameters of the Sine Wave (last parameter: sample time, not shown).

For this example Amplitude is 1, Frequency (rad/s) is also 1, Phase and Bias are 0, so default values are OK. Sampling time is not an issue here.

Begin simulation by clicking the **Run** button (Figure 1.13).

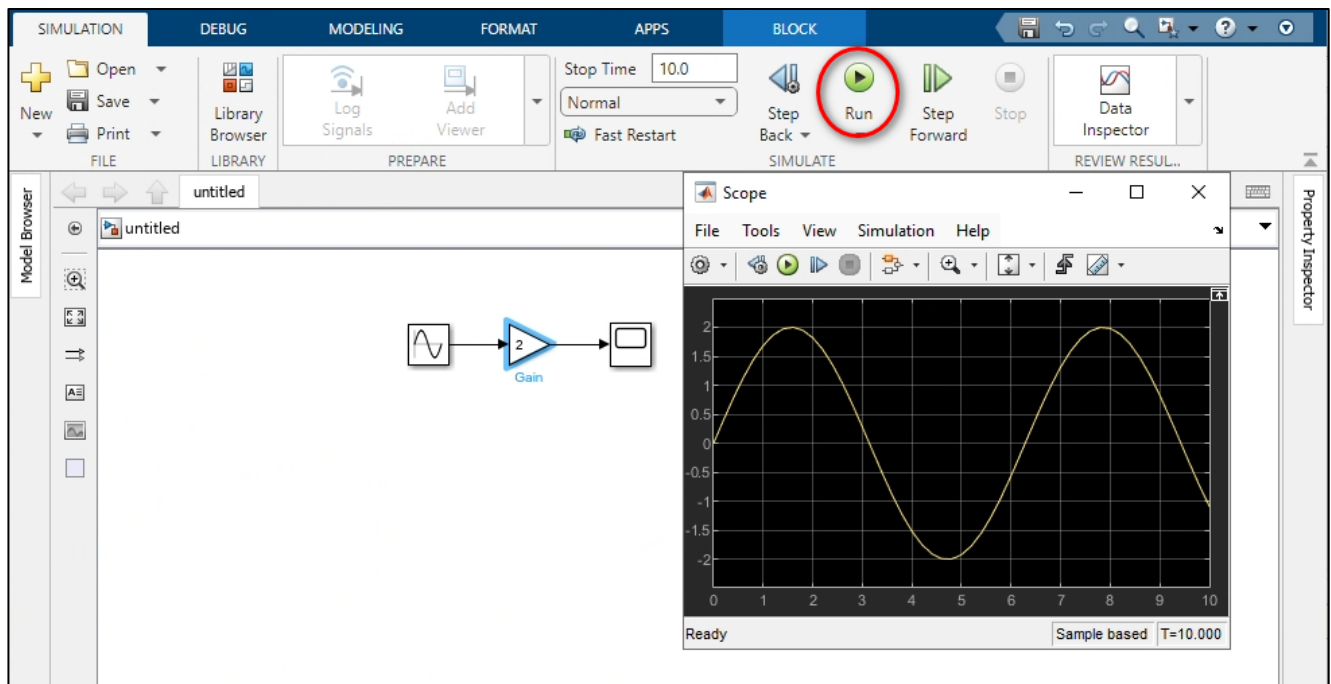


Figure 1. 13 Starting simulation with the *Run* button. The simulation result is shown in the scope. The amplitude should be equal to 2 as seen in the Figure.

The solution is seen in the *Scope*. If the *Scope* does not open automatically, double-click it. Observe from the *x*-axis that the default simulation time is 10 s. If the figure is not scaled properly, use the different scale buttons in the Menu above the figure.

An important thing in learning to use SIMULINK is to actively play and experiment!

Example 2 – First order differential equation: Solve numerically the differential equation with SIMULINK. Think also what the exact solution is.

$$\frac{dx}{dt} = -2x + 1, t > 0$$

$$x(0) = 0$$

Solution 1: Consider the integrator block in Continuous block library. The input to the block is $\frac{dx}{dt}$. The integrator integrates it from $t = 0$ s up to t . Default value is $t = 10$ s.

$$\int_0^t \frac{dx}{dt} dt = x(t) - x(0)$$

What is shown is only the input $\frac{dx}{dt}$ and output $x(t)$. The initial condition is given in the *Block parameters* (Figure 1.14).

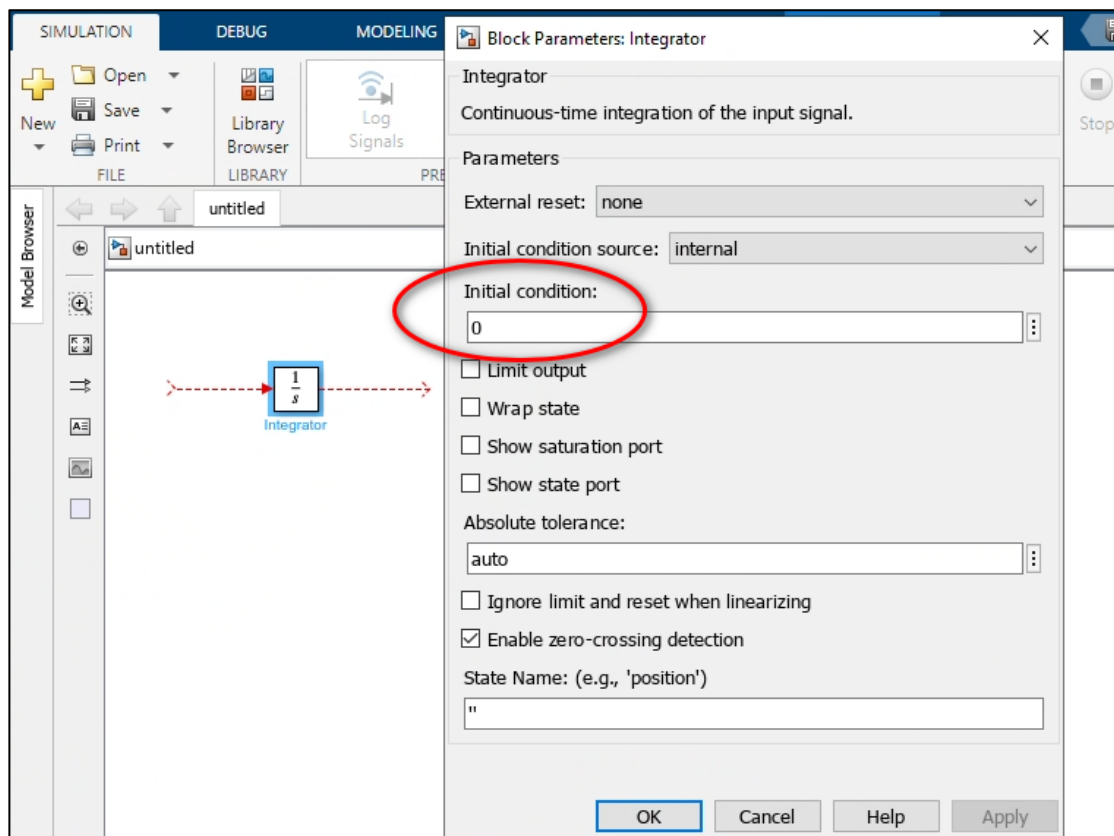


Figure 1. 14 Operation of the integrator block: Input is $\frac{dx}{dt}$ and output $x(t)$.

Initial condition $x(0)$ is given by double-clicking the block. Default value is $x(0)=0$.

Continuing our configuration we observe that in Figure 1.14 we already have the left hand side of equation (1.1), which is $\frac{dx}{dt}$. We still need to generate the right hand side of the equation $-2x+1$ and equate it with $\frac{dx}{dt}$.

The integration in Figure 1.14 produces $x(t)$. This needs to be multiplied by 2 (or -2), minus sign can also be added later to produce $-2x$. What is needed is the gain block from *Math operations* block library. Finally, a constant from the *Sources* block library is picked. For summing we need a summing block, which is found from *Math operations* block library. All the mentioned blocks are shown in Figure 1.15.

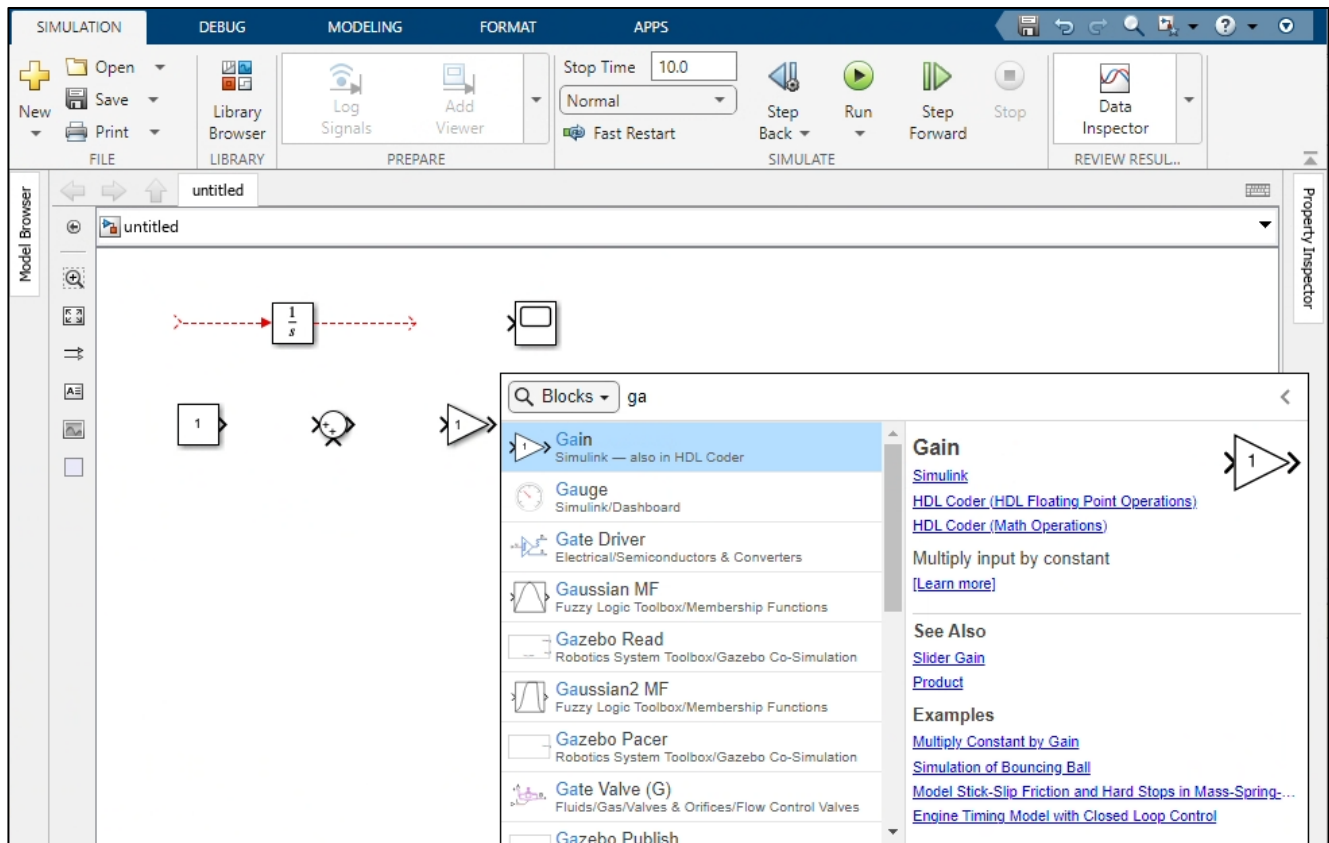


Figure 1. 15 Blocks needed to configure system (1.1).

Fastest way to add blocks is instead of Library Browser to double-click an empty area of your model and type first letters of the needed block, then select it from a list

Activate *Gain* block by clicking once and apply *Flip block*, which is found by right-clicking the block or under *Format* menu. Open the *Gain* block to change the gain value to 2. Remember to click OK. With the *Sum* block, click it open and change one sign to a minus sign. Again, remember to click OK.

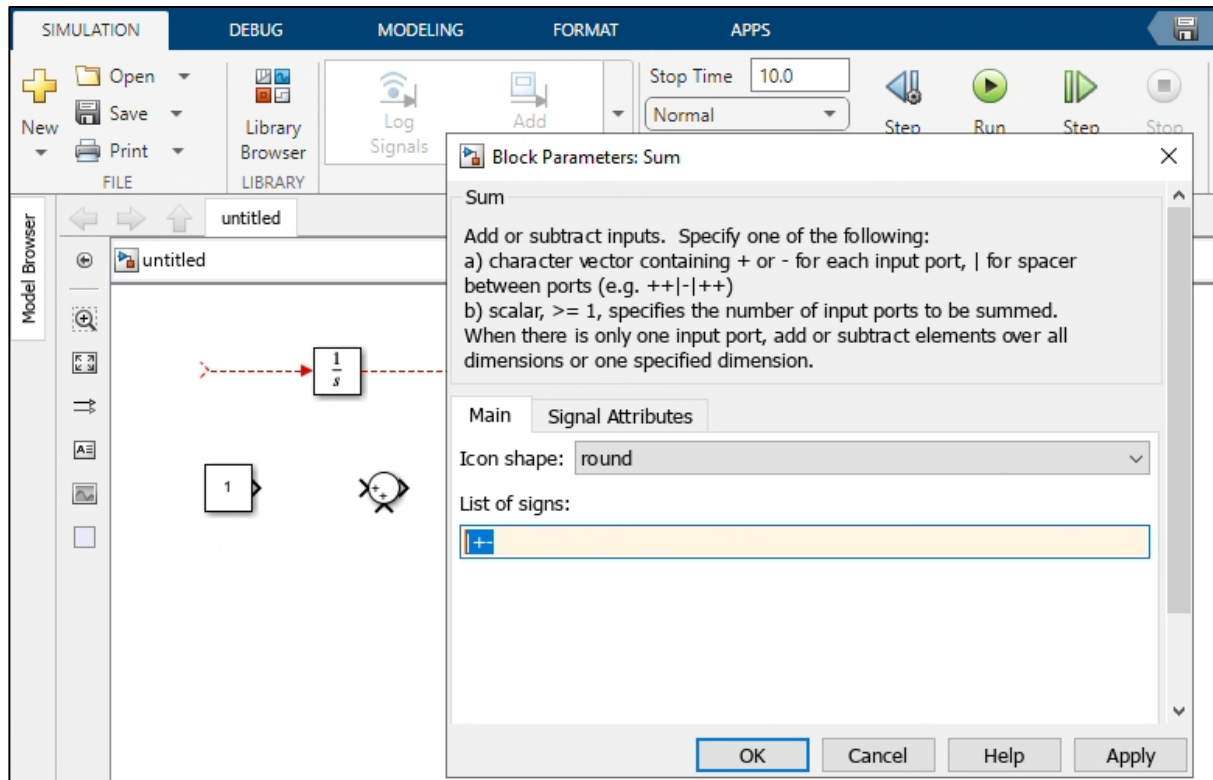


Figure 1.16 Block parameters of Sum. Change list of signs to +-.

Default value for *Integrator's Initial condition* $x(0)$ is 0, so we do not need to change it. The final configuration is given in Figure 1.17. *Scope* has been added to observe the simulation result.

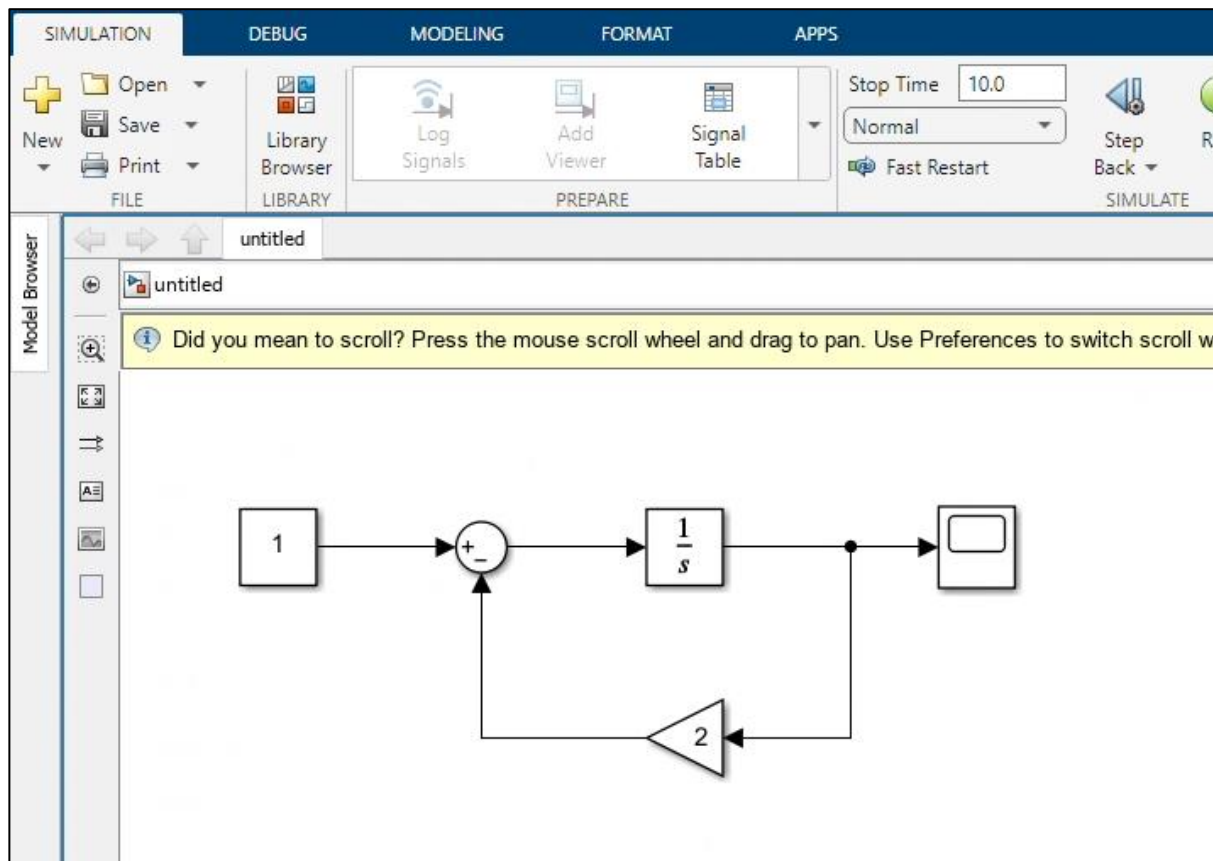


Figure 1.17 The final SIMULINK configuration of system (1.1).

Start the simulation with *Run* button. The result is shown in Figure 1.18.

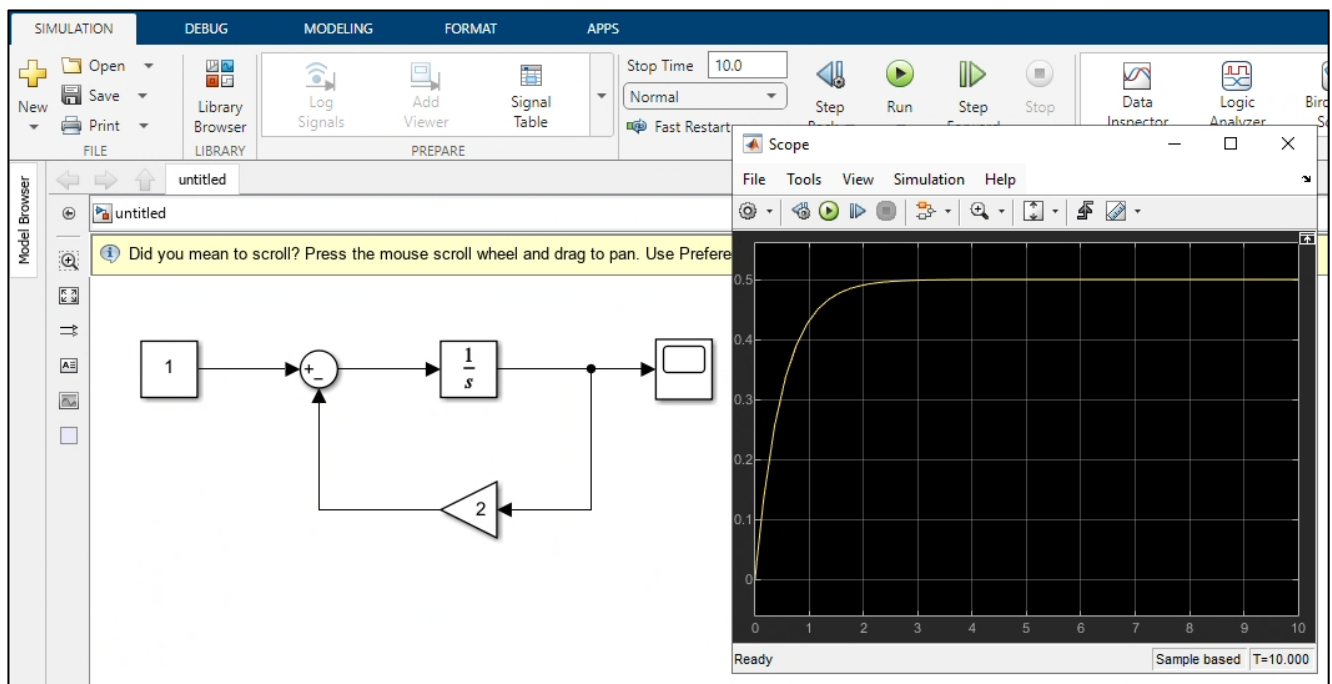


Figure 1. 18 The simulation result on scope. (after double-clicking the scope block)

The result is a typical exponential response of a forced first order linear system. You can connect several signals to the same scope as shown in Figure 1.19.

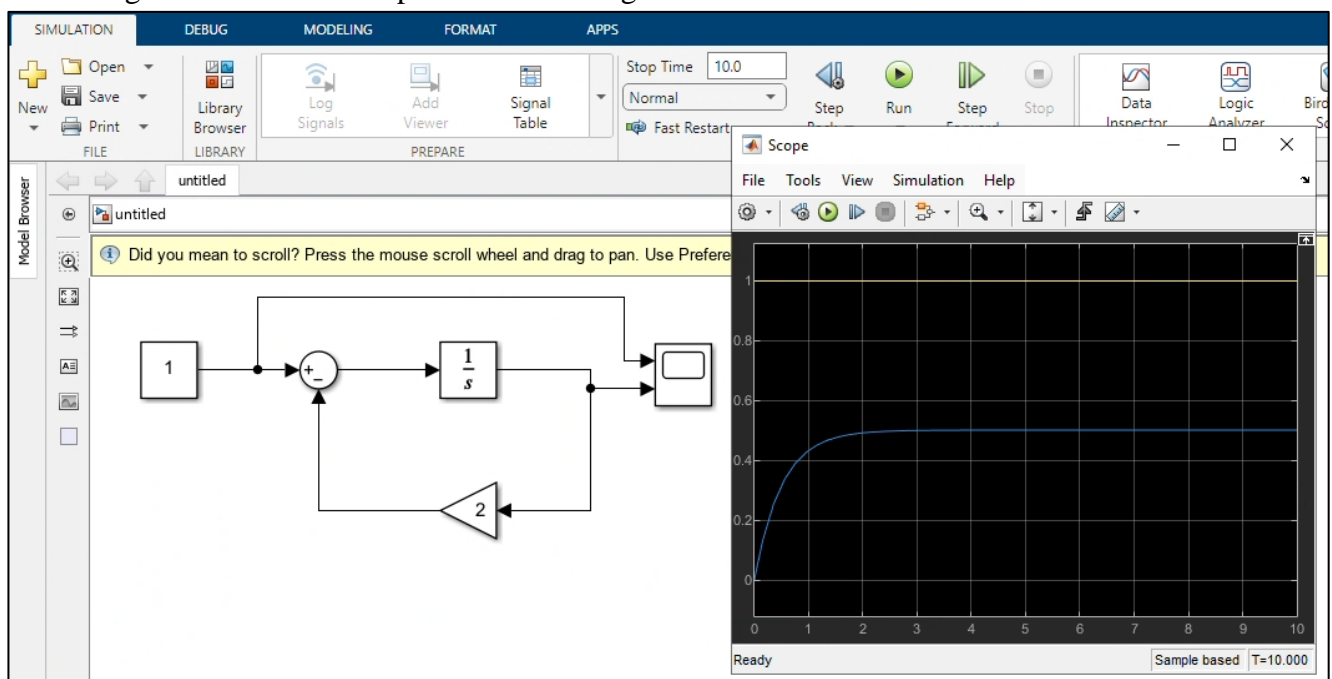


Figure 1. 19 Both input and output signals in the same Scope

Solution 2 (Transfer function):

Another way to configure system (1.1) is to use a differential operator D and derive a transfer function for the system. Let $D = \frac{d}{dt}$ and denote the input as $u(t)=1$. Then the differential equation becomes

$$Dx = -2x + u(t)$$

or

$$Dx + 2x = (D + 2)x = u$$

Solving for x leads to

$$x = \frac{1}{D + 2} u$$

output transfer f input

The configuration is now shown in Figure 1.20, where D has been replaced by s . The coefficients in the denominator polynomial are changed from default values $[1 \ 1]$ to $[1 \ 2]$

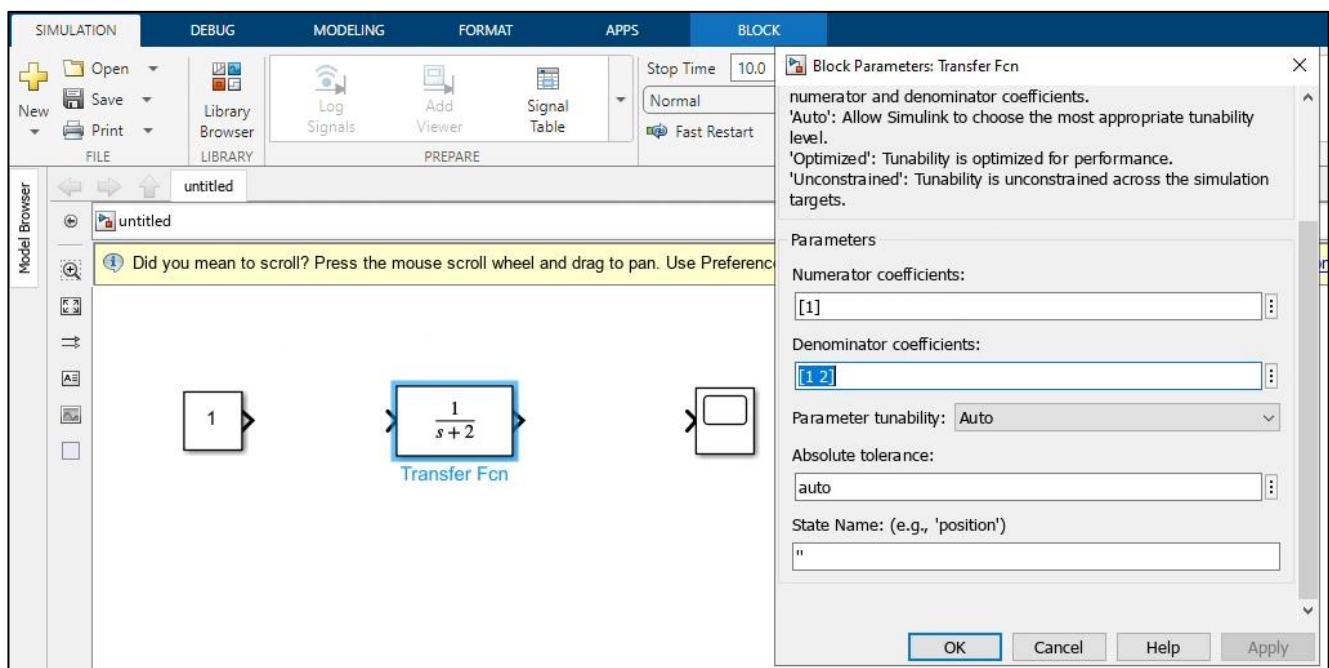


Figure 1. 20 System (1.1) in block diagram form.

The Block Parameters in Transfer Function are $[1 \ 1]$ and have to be changed: Denominator multipliers are $[1 \ 2]$. This system configuration is equivalent to that of Figure 1.17, except here the initial condition is equal to zero.

Step input: The input in system (1.1) is 1 after $t \geq 0$. A function, that first has a constant value say 0, and then at some later time instant changes to another constant value, is called a *Step function* $u(t)$. It is defined as

$$u(t) = \begin{cases} 1, & t > 0 \\ 0, & t < 0 \end{cases}$$

Here the change happens at $t = 0$ s. Note that it does not matter what value the function assumes at $t = 0$ s.

Step function can be found from the **Sources** block library as *Step* block. Note however that the default stepping time is not $t=0$ s but $t=1$ s. This can easily be changed as seen in Figure 1.21.

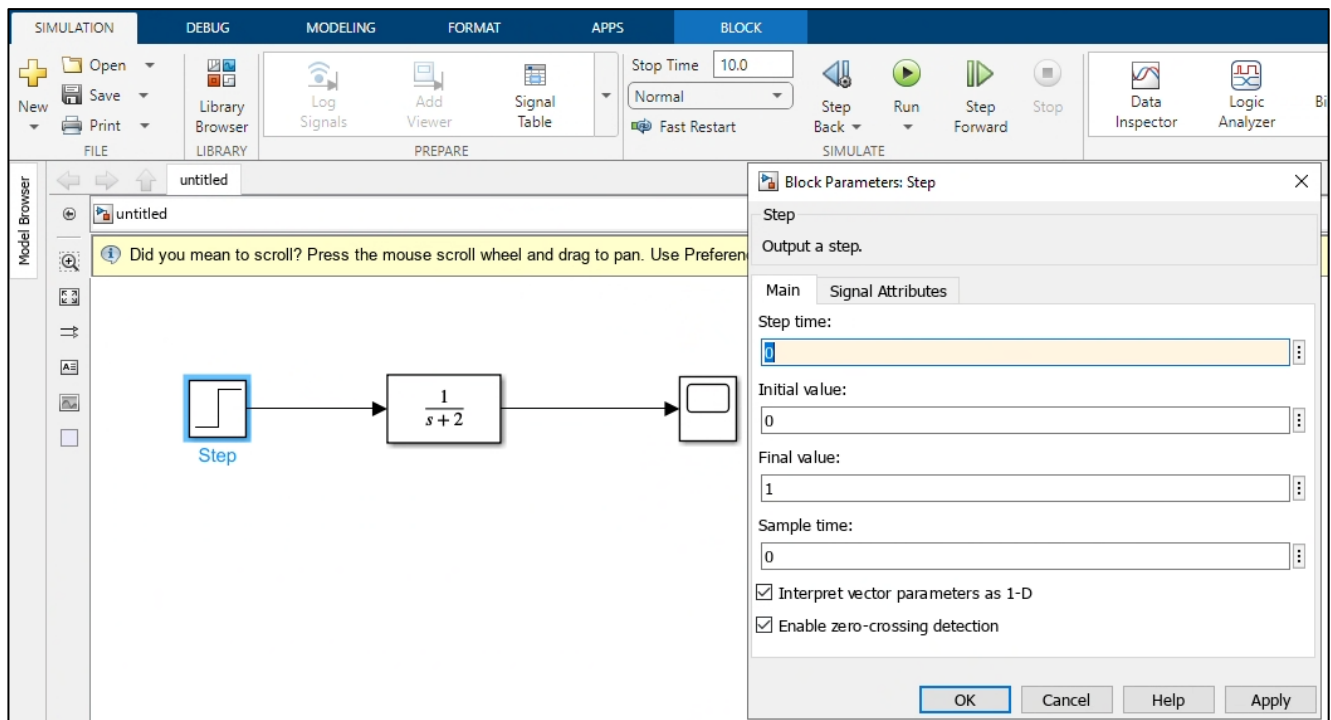
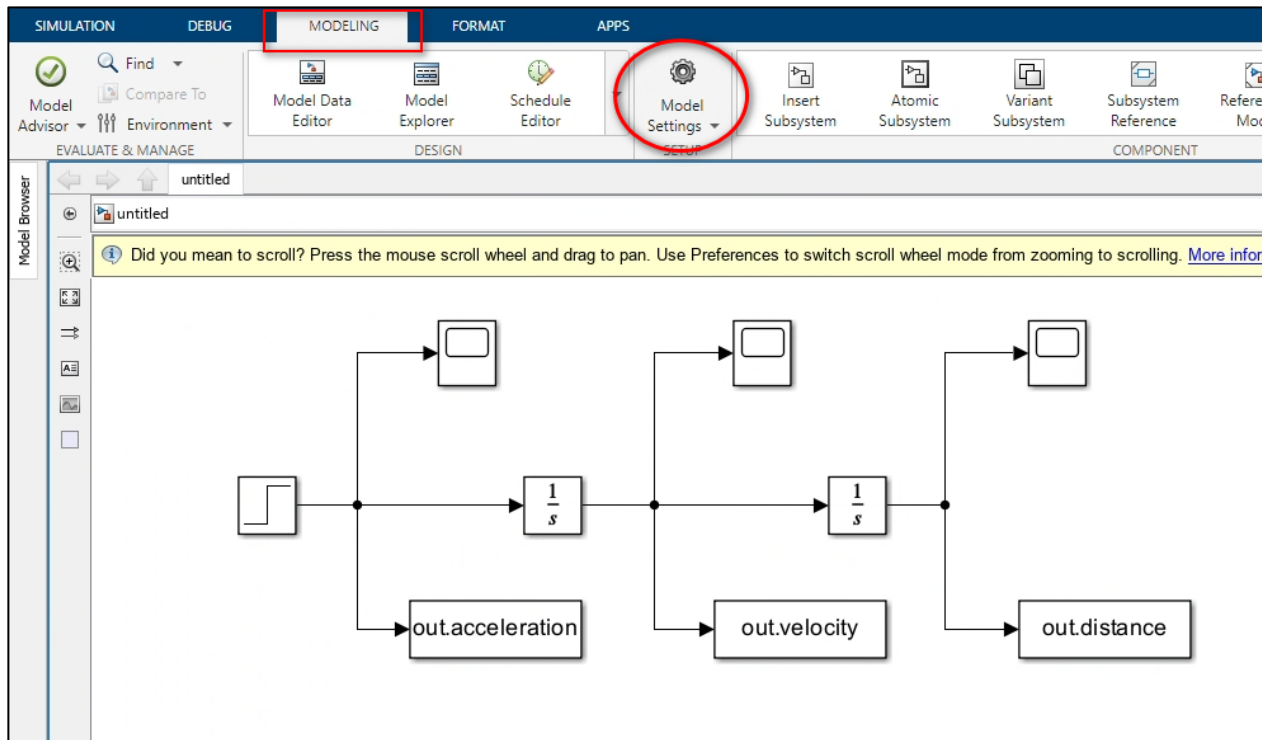


Figure 1.21 Changing *Block Parameters* in *Step Function*, especially the *Step Time*.

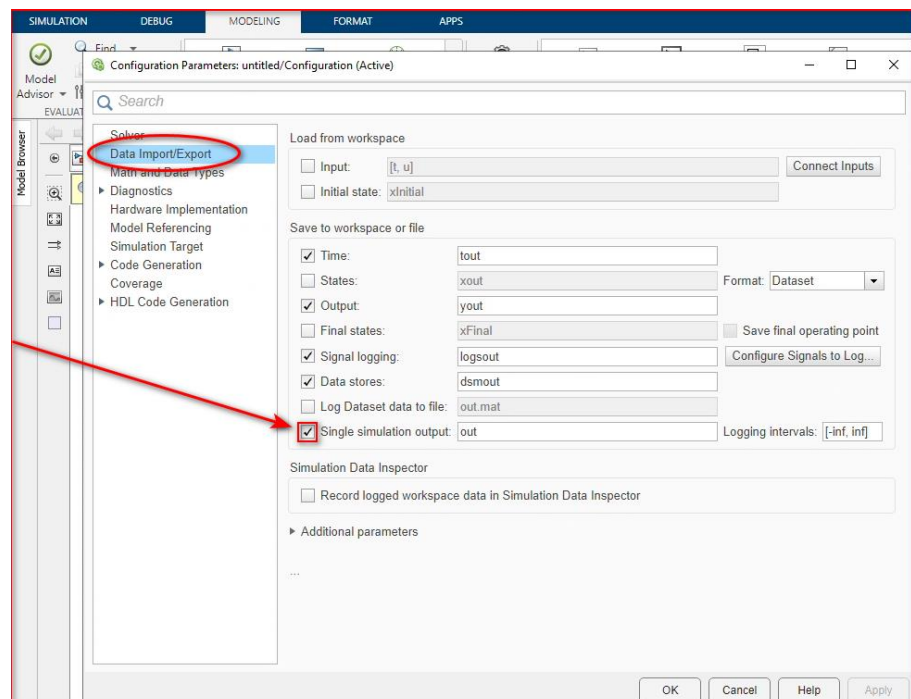
Instead of using *Constant* block, it is common to use *Step* block as shown in Figure 1.21. The simulation result is exactly the same as in Fig. 1.17, if the change of *Step time* is made.

MATLAB Command window

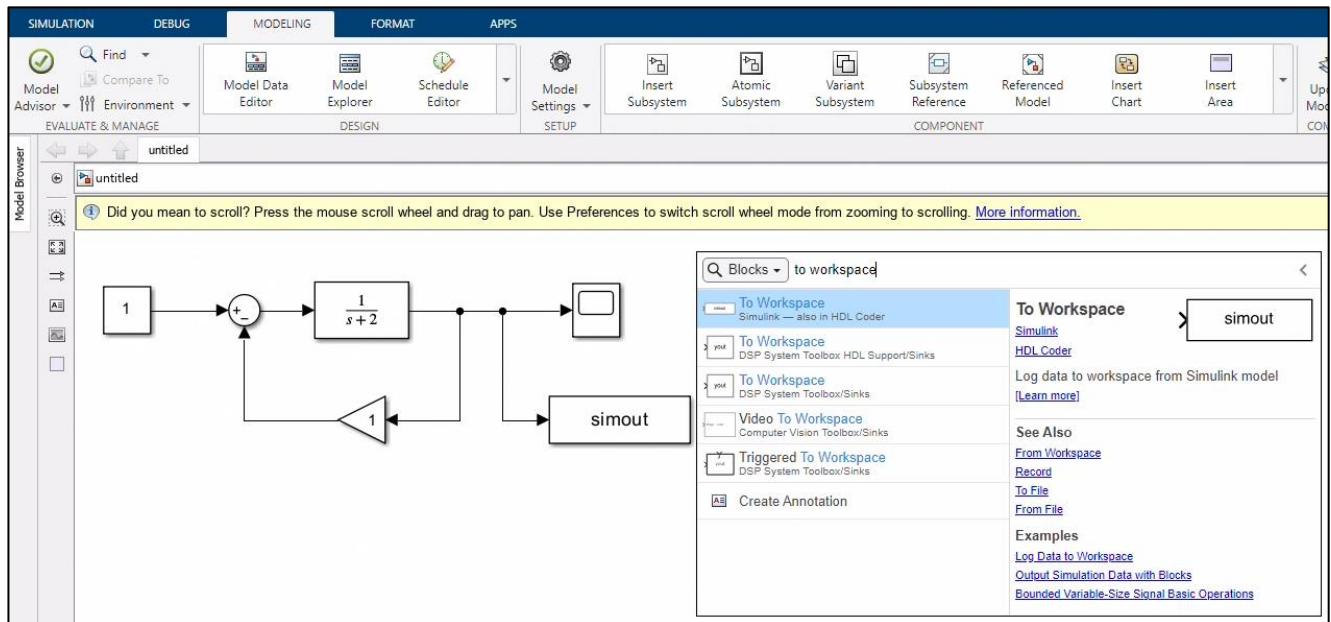
Once you have defined your system in the SIMULINK window, you can simulate it also on the MATLAB Command window. For Matlab MATLAB version 2019a or newer, the variables from Simulink will be exported differently to the workspace of MATLAB than in the older versions. Change the Simulink settings so that the provided scripts will work for newer MATLAB versions.



Under
Data Import/Export
Uncheck the box
Single simulation output



Then make an output for Matlab by adding '**to Workspace**' block. It will be named first '**simout**'. Double-click it to change name to a more meaningful one, like '**acceleration**' or '**amperes**', depending on your simulation. In this example we will just use the default '**simout**'



Save your model – it has first the name untitled, which may be used here.

Go to the MATLAB command window and type **help sim**. This will output a quick manual of sim-command. It is useful as a reference when you know the basics of using the sim-command. **help plot** is another often useful reference.

Run the simulation by typing:

```
>> sim('untitled')
```

The only thing needed here is the name of the system you want to simulate. Next you can use plot command to see the result in x (time) - y (data) graph by typing:

```
>> plot(simout.time, simout.data)
```

Or `plot(acceleration.time, acceleration.data)` etc. depending on the name you chose in Simulink for the output.

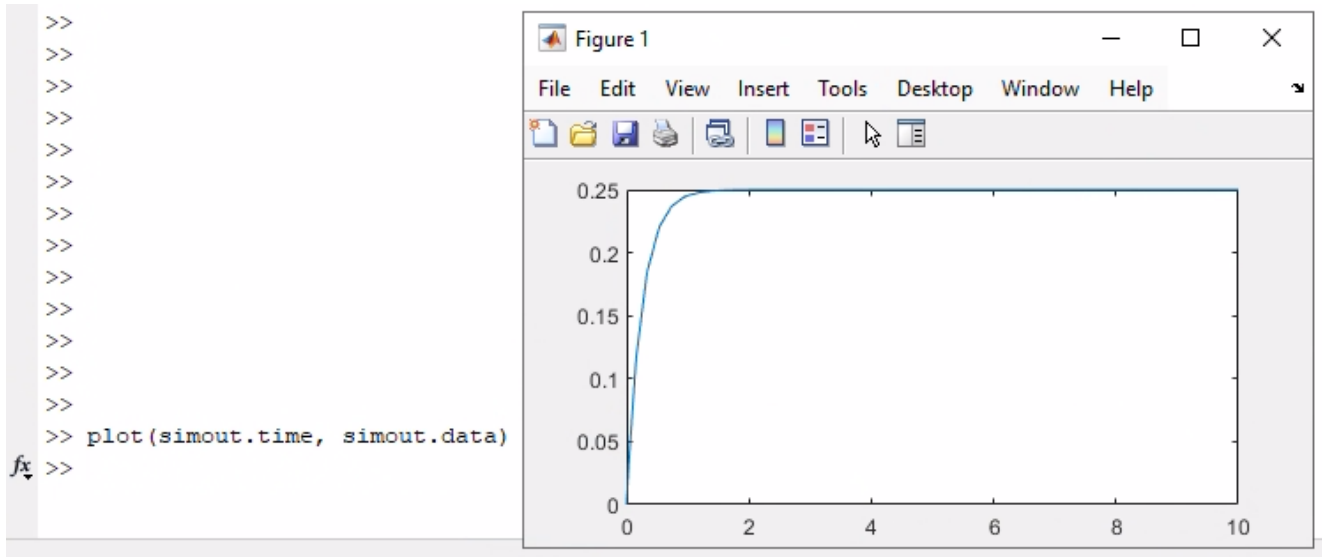


Figure 1. 23 Simulation result is plotted with *plot* command.

The default time for simulation is 10 s. If you wish to simulate longer or shorter duration you can change Simulink window's *Simulation stop time*

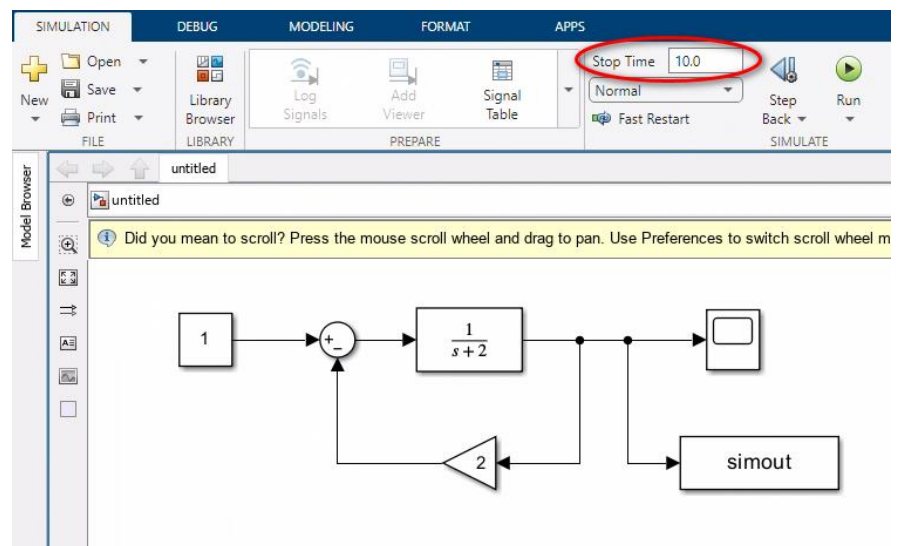


Figure 1. 24 Simulation stop time can be changed from 10 seconds to a larger or smaller non-negative value.

Complete the exercise. Run the simulation from SIMULINK and also from Command window.

Example 1.3 Damped oscillator

Solve the damped oscillator problem

$$\frac{d^2x}{dt^2} + 1 \frac{dx}{dt} + 9x = 0$$

$$\frac{dx}{dt} = -2$$

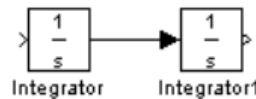
$$x(0) = 2$$

Assume that there is no input, that is, input $u(t) = 0$.

PURPOSE: To illustrate how to configure a SIMULINK diagram for a higher order differential equation and how to introduce initial conditions into it.

SOLUTION: Solve equation first with respect to the highest order derivative to obtain

$$\frac{d^2x}{dt^2} = -1 \frac{dx}{dt} - 9x$$



To set up the left-hand side two integrators are needed:

The input to the first integrator is the second derivative $\frac{d^2x}{dt^2}$

and its output is $\frac{dx}{dt}$. The latter is the input to the second integrator producing $x(t)$ at its output. In this

way we have constructed the left-hand side of the equation. Since the second derivative $\frac{d^2x}{dt^2}$

is equal to the right hand side, we collect it term by term. In order to do that we need $\frac{dx}{dt}$ from the

output of the first integrator, and $x(t)$ from the output of the second integrator. Then $x(t)$ must be multiplied by 9, so a *Gain* block is required. All the items are to be summed up so a *Sum* block is also needed. The final configuration is given below. The initial values are added to the integrators. The resulting configuration is given in Figure 1.25.

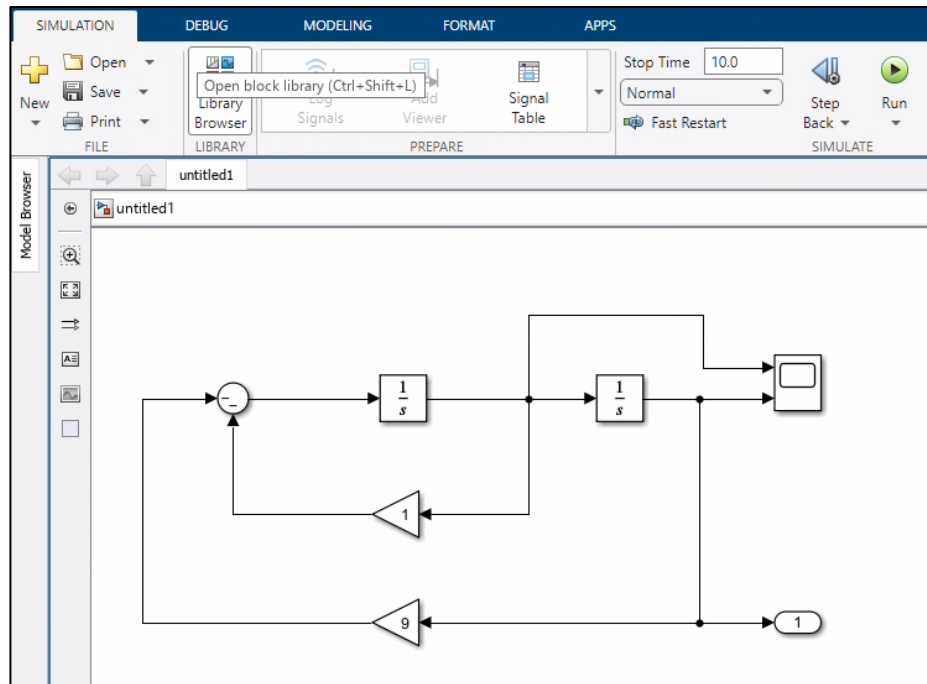
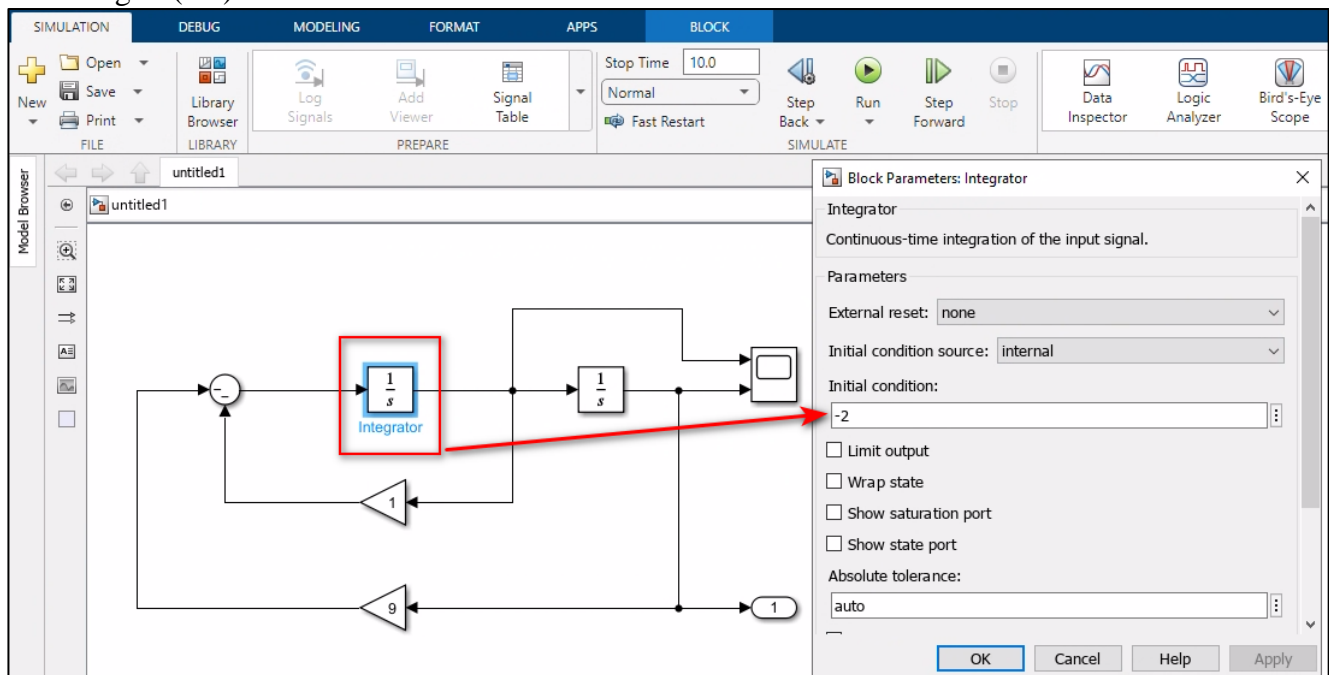


Figure 1.25 SIMULINK configuration of system (1.7)

Note that one way to take information to MATLAB command window is using Output block (See Figure 1.26 about details).

Finally, set up the initial conditions by clicking the integrators one at a time and make the changes according to (1.8)



Simulink can output results to Matlab using 'To Workspace' block or 'Output'. To Workspace is better suited for Matlab output. Output's main usage is when dividing a large Simulink model to subsystems and exchanging data between subsystems and parent systems.

To see variable names *Output* sends to *Matlab* open Simulation => Prepare => Model Settings. Select *Data Import/Export*, which is second on the list. By default Time *tout* and Output *yout* are saved to workspace and can be used in MATLAB command window (Figure 1.26).

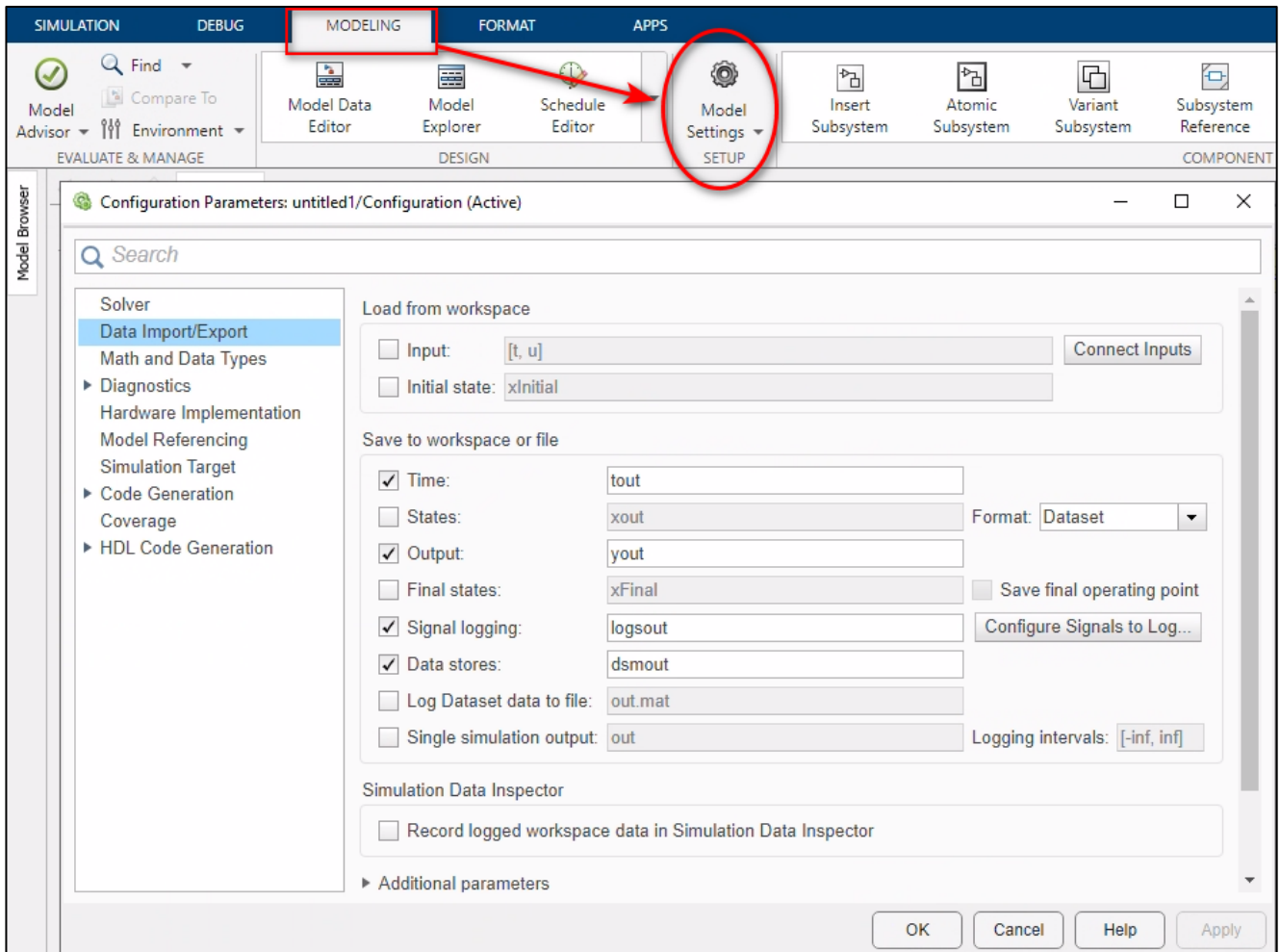


Figure 1.26 Configuration Parameters: Select *Data Import/Export* to see what is saved to workspace.

As seen from Figure 1.25, the *Outport* block corresponding to *yout*, is connected to $x(t)$ or $yout = x$. For instance, plot command can now be utilized as follows

```
>> plot(yout)
```

The result is displayed in Figure 1.27.

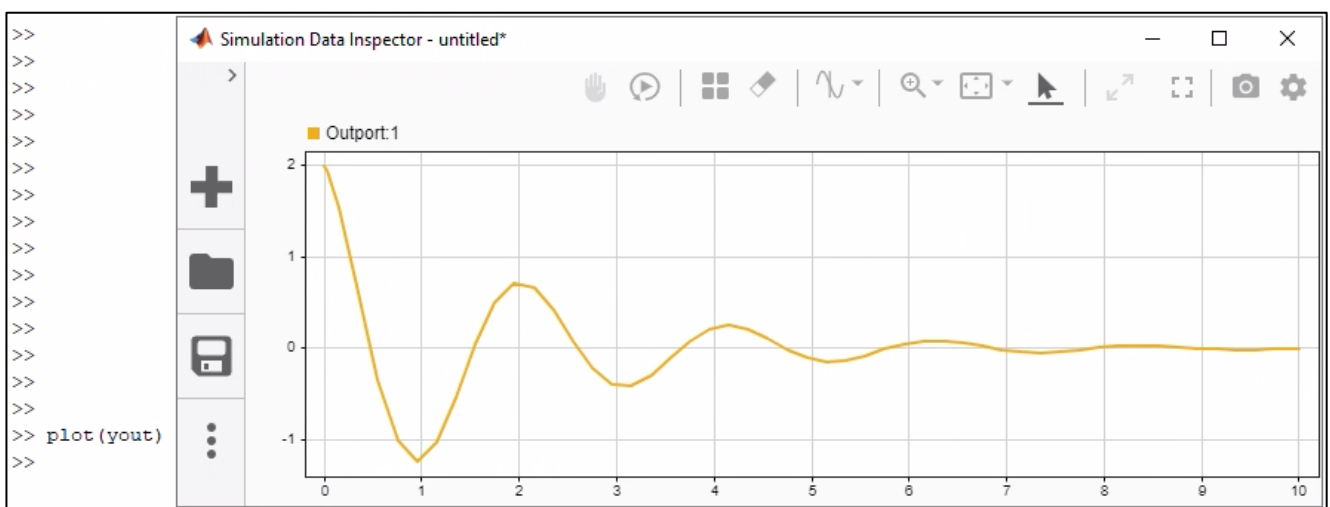


Figure 1.27 The simulation result $yout=x$ is plotted with *plot* command. The same result can be seen with SIMULINK scope. Here below with both $x(t)$ and dx/dt

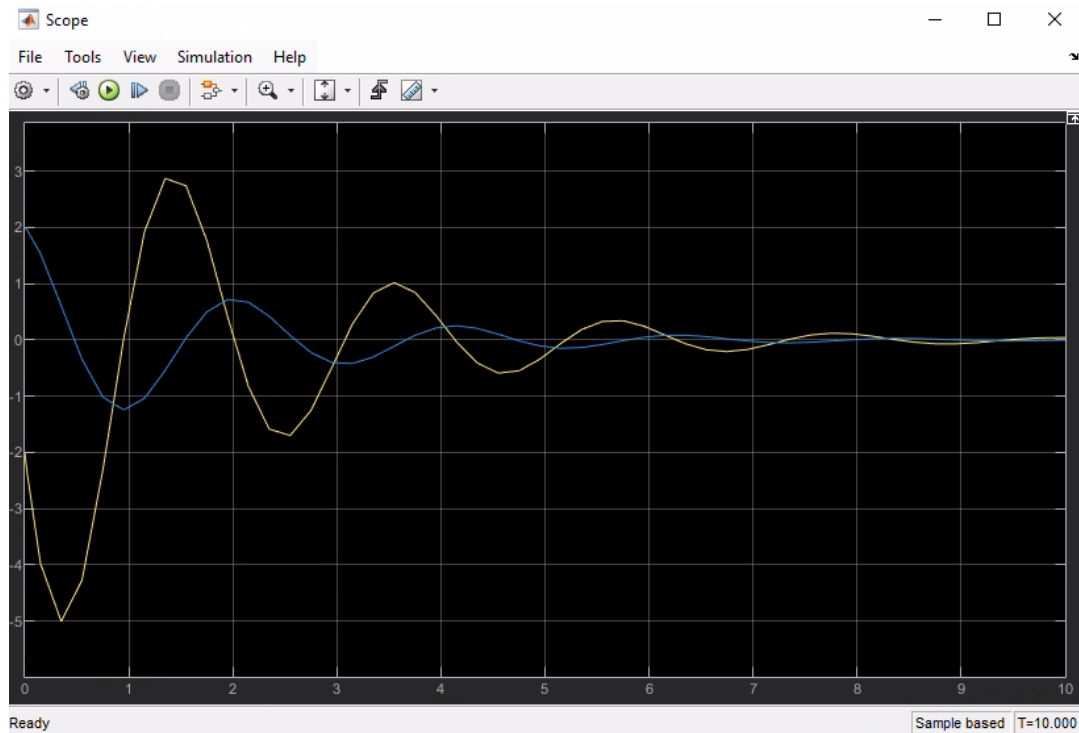


Figure 1. 28 The sharpness of the yellow curve around $t = 0.4$ s is not real, it should be smooth. First you might suspect numerical difficulties due to too large a step size. This is not the case. It is due to display graphics, i.e., not enough points have been saved to have a smooth presentation.

The damping factor can be changed by changing the coefficient to 5 in front of $\frac{dx}{dt}$. If the coefficient is zero (no damping), the result is sinusoidal. Increasing the damping will result in damped oscillations. Complete the study to obtain the following responses. Use Matlab command **'hold on'** to plot several graphs to the same window.

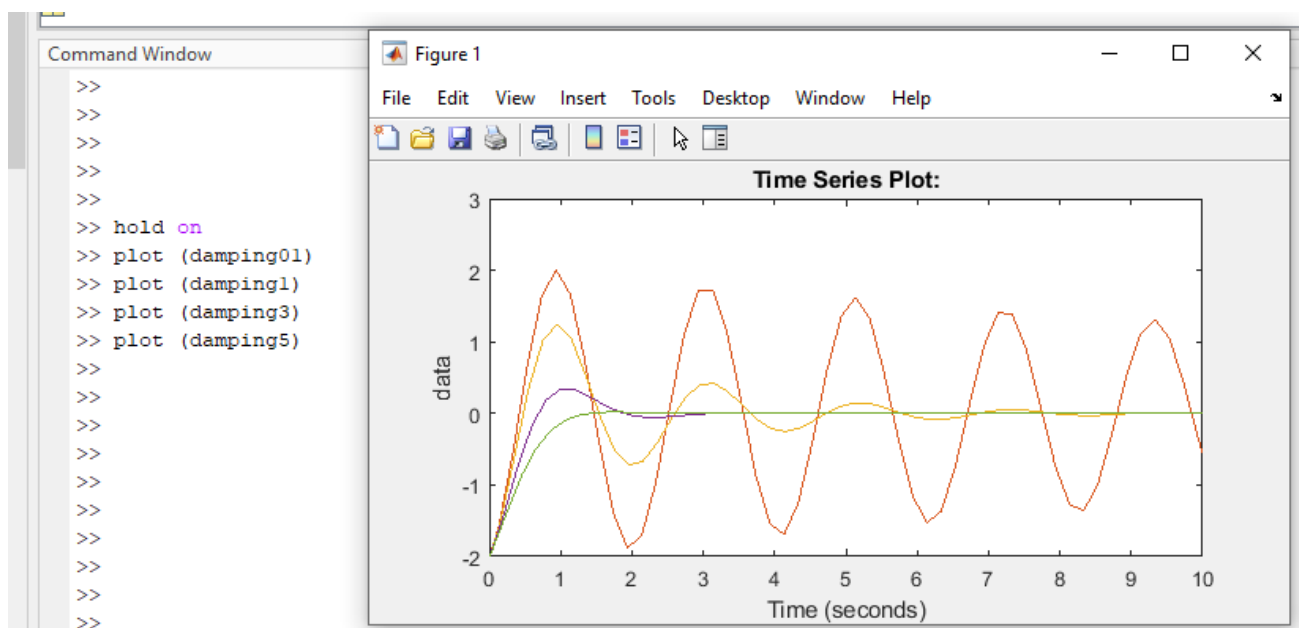


Figure 1. 29 Simulation results vary, when damping is changed. When damping constant is small, oscillation is large and when damping constant is bigger, there is no oscillation.

Let us also plot a **phase plane** plot (x vs dx/dt). Note that the time has been eliminated and it only appears as a parameter. To see the effect better, start with less damping. Change the coefficient 5 to 1.

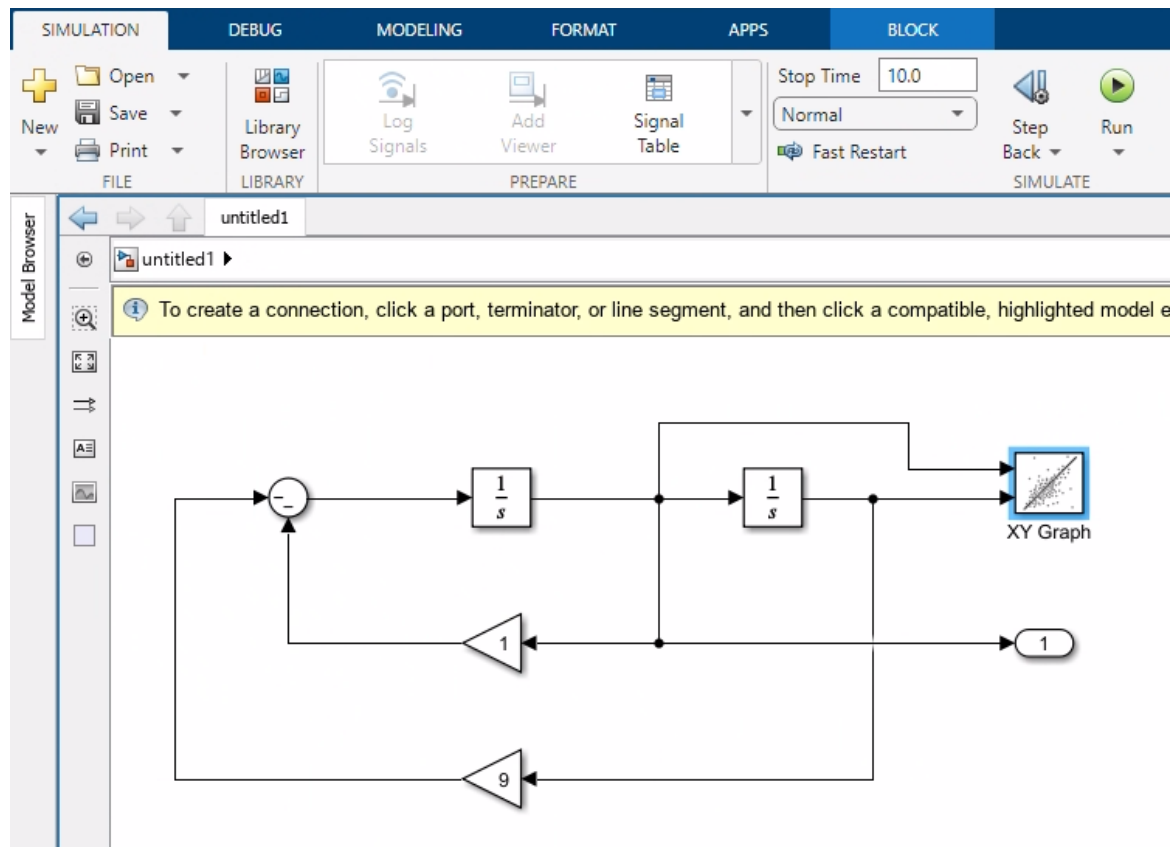


Figure 1. 30 XY Graph scope is used to draw a phase plane plot. The result is shown below.

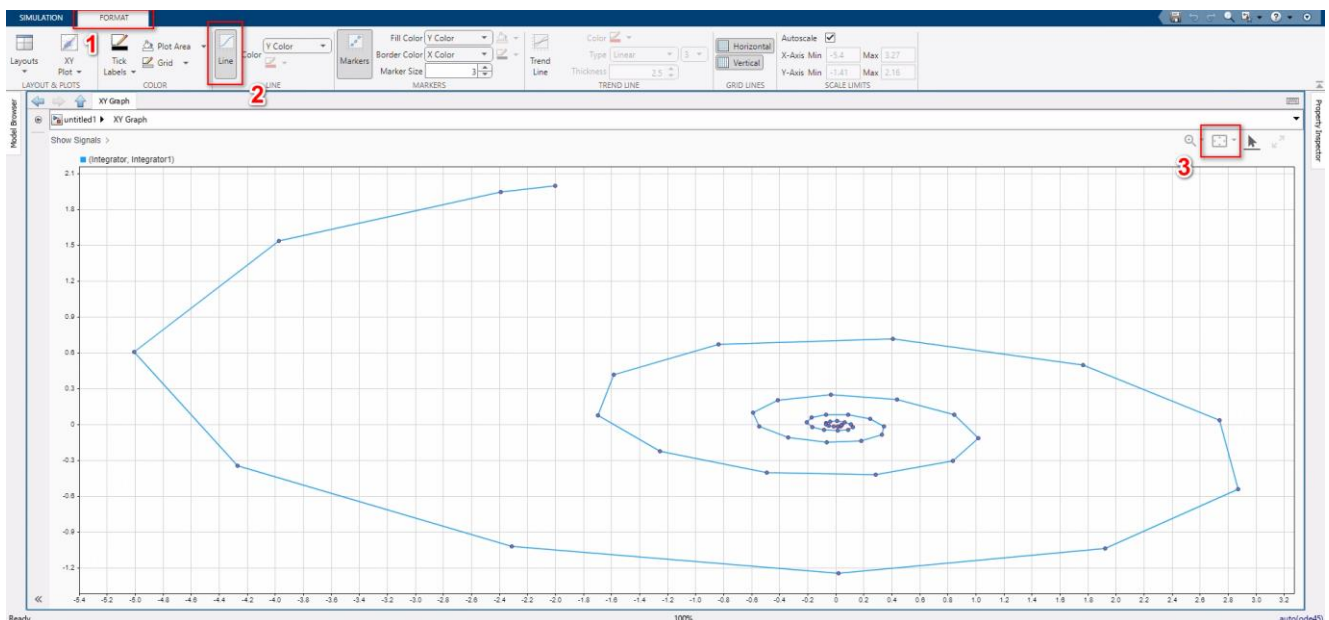


Figure 1. 31 Phase plane plot of (1.7). The resulting figure should be smooth.

XY Graph will initially show a scatter plot. Go to Format tab and then click the Line tool. The graph does not adjust the scales automatically. In order to see the whole picture in Figure 1.31, click Fit to view or press “Space bar” on your keyboard. Simulation => Model Settings => Solver => *Relative tolerance* from $1e-3$ to $1e-6$ results in a smoother Figure.

The result is shown in Figure 1.32.

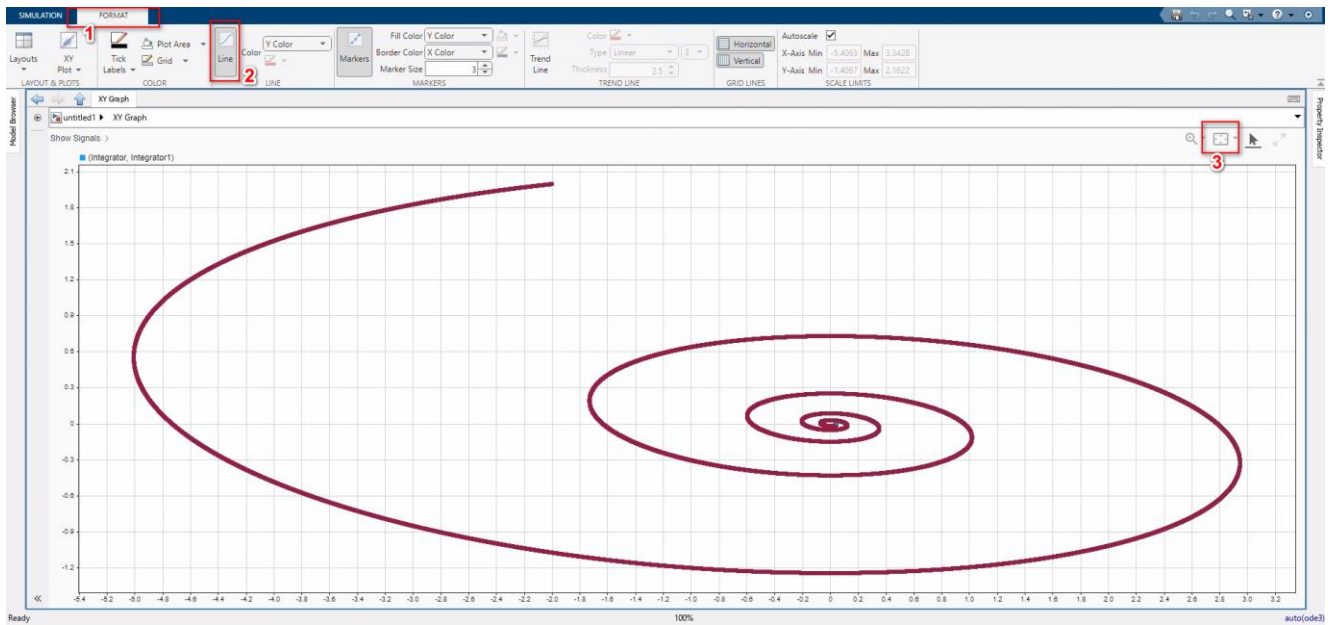


Figure 1.32 The whole, smooth phase plane plot is displayed. A stable system. It converges towards the origin. Physical interpretation: In the origin both position and velocity are zero.