CHAPTER 1

Introduction to SIMULINK

1.0 WHAT IS SIMULINK?

Simulink is a graphical user interface platform that enables users to create mathematical models instantaneously. It provides simple means for solving complex mathematical equations without writing lengthy programmes.

The typical Simulink model is shown in Figure 1.1.

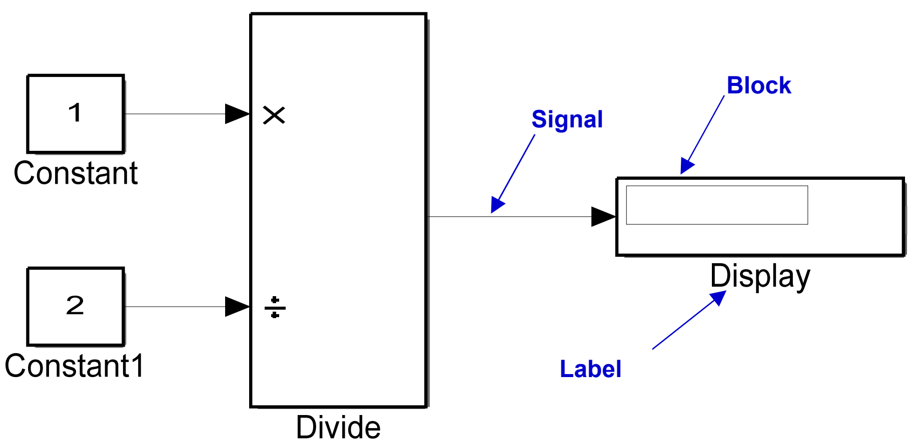

Figure 1.1 Typical Simulink model

Elements of Simulink model are given in Table 1.1.

Table 1.1 Elements of Simulink model

Blocks	Functions having input and output signals
Signals	Connects input/output between blocks
Labels	Applicable for blocks and signals They are not executable statements Useful for identification

1.1 MATLAB AND SIMULINK

Matlab and Simulink share a common platform, and hence problems can be solved in conjunction with both. Simulink needs to be initiated from MATLAB.

Example 1.1: Forced harmonic motion – Mass excitation

To obtain the response of a single degree of freedom (SDOF) system subjected to harmonic excitation with force magnitude of F_0 sin ωt shown in Figure 1.2.

To consider the following parameters.

- m = 10 kg
- c = 200 Ns/m
- k = 100 N/m
- F_0 = 50 N
- r = 2
- Time duration = 20 seconds

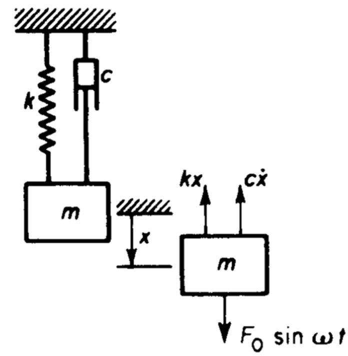

Figure 1.2 SDOF model of a system subjected to harmonic excitation

Mathematical

From the free body diagram representation of the above mentioned system, the equation of motion can be expressed as

$$m\ddot{x} + c\dot{x} + kx = F_0 \sin \omega t \qquad \text{.....(1.1)}$$

Where

m: Mass

$\ddot{x}$: Acceleration

c: Damping coefficient

$\dot{x}$: Velocity

k: Stiffness

x: Response of the system

F_o: Amplitude

ω: Excitation frequency

t: Time

The following solution can be assumed.

$$x = X \sin(\omega t - \phi) \qquad \text{.....(1.2)}$$

Where

X: Response amplitude

ϕ: Phase difference between response and excitation force

The above two response parameters can be obtained by substituting equation 1.2 in equation 1.1 as given below.

$$X = \frac{F_0}{\sqrt{(\mathrm{k} - \mathrm{m}\omega^2)^2 + (c\omega)^2}} \qquad \text{.....(1.3)}$$

$$\varphi = \tan^{-1}\left(\frac{c\omega}{\mathrm{k} - \mathrm{m}\omega^2}\right) \qquad \text{.....(1.4)}$$

Taking the equation 1.3 and equation 1.4 in non-dimensional form, i.e. by dividing both numerator and denominator with k gives

$$X = \frac{\frac{F_0}{k}}{\sqrt{\left(1 - \frac{m\omega^2}{k}\right)^2 + \left(\frac{c\omega}{k}\right)^2}} \qquad \text{.....(1.5)}$$

$$\varphi = \tan^{-1}\left(\frac{\frac{c\omega}{k}}{1 - \frac{m\omega^2}{k}}\right) \qquad \text{.....(1.6)}$$

Further

$$Natural \text{ frequency}, \omega_n = \sqrt{\frac{k}{m}}$$

Critical damping coefficient, $c_c = 2m\omega_n$

$$Damping \text{ factor}, \zeta = \frac{c}{c_c}$$

$$\frac{\mathrm{c}\,\omega}{k} = \frac{c}{c_c}\frac{c_c\,\omega}{k} = 2\,\zeta\,\frac{\omega}{\omega_n}$$

$$\text{Frequency ratio, r} = \frac{\omega}{\omega_n}$$

Substituting the above relations in equations 1.5 and 1.6 gives

$$X = \frac{\frac{F_0}{k}}{\sqrt{(1 - r^2)^2 + (2\,\zeta\,\mathrm{r})^2}} \qquad \text{.....(1.7)}$$

$$\varphi = \tan^{-1}\left(\frac{2\,\zeta\,\mathrm{r}}{1 - \mathrm{r}^2}\right) \qquad \text{.....(1.8)}$$

Substituting equation 1.7 in equation 1.2 gives the expression for a response as follows

$$x = \frac{\frac{F_0}{k}}{\sqrt{(1 - r^2)^2 + (2\,\zeta\,\mathrm{r})^2}} \sin(\omega\,\mathrm{t} - \varphi) \qquad \text{.....(1.9)}$$

Solution using MATLAB

Equations 1.8 and 1.9 are programmed in Matlab and the associated code is given below.

```
clf
clear
```

```
m=10;
c=200;
k=100;
F=50;
wn=(k/m)^0.5;
w=2*wn;
r=w/wn;
z=c/(2*m*wn);
r2=r^2;
pi=atan((2*z*r2)/(1-r2));
den=((1-r2)^2+(2*z*r)^2)^0.5;
t=0:0.1:20;
num=(F/k)*sin(w*t-pi);
x=num/den;
plot(t,x)
```

Executing the above Matlab code produces a result as shown in Figure 1.3.

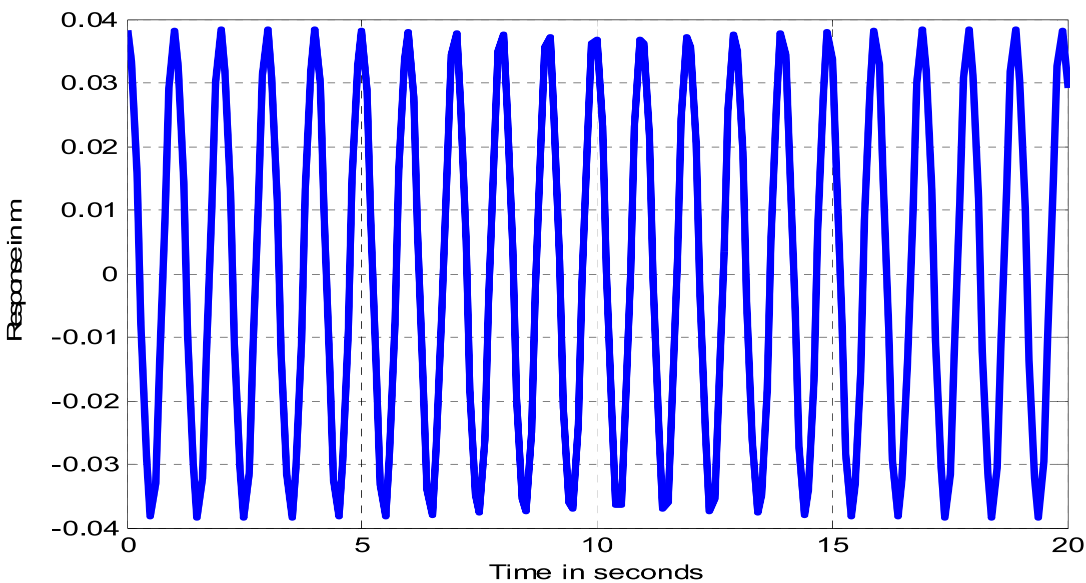

Figure 1.3 Response plot - Matlab

Solution using Simulink

Substituting the values in equation 1.1 gives.

$$10\,\ddot{x} + 200\,\dot{x} + 100\,x = 50\,\mathrm{Sin}\,\omega\,t \qquad \text{.....(1.10)}$$

Rewriting same as

$$5\,\mathrm{Sin}\,\omega\,t - 20\,\dot{x} - 10\,x = \ddot{x} \qquad \text{.....(1.11)}$$

The logic for solving equation 1.11 using Simulink is given in Table 1.2.

Table 1.2 Logic for solving equation 1.11 using Simulink

Component of equation	Operation needs to be performed	Feature needed in Simulink
Velocity, $\dot{x}$	Integration of acceleration, $\ddot{x}$	Integration
-20 $\dot{x}$	Multiplying (Gain) $\dot{x}$ with -20	Gain with a value of -20
Displacement response, x	Integration of velocity, $\dot{x}$	Integration
-10 x	Multiplying (Gain) x with -10	Gain with a value of -10
Sin (ωt)	Sinusoidal	Sine wave function
5 Sin (ωt)	Multiplying (Gain) sin (ωt) with 5	Gain with a value of 5
$5\,\mathrm{Sin}\,\omega\,t + (-20\,\dot{x}) + (-10\,x)$	Summation	Sum
$5\,\mathrm{Sin}\,\omega\,t + (-20\,\dot{x}) + (-10\,x) = \ddot{x}$	Equating evaluated LHS expression to acceleration, integrating which of same gives velocity and further integrating gives displacement response	

Simulink needs to be initiated from Matlab. After entering into Matlab main window, i.e. command window, the following command needs to be typed as shown in Figure 1.4.

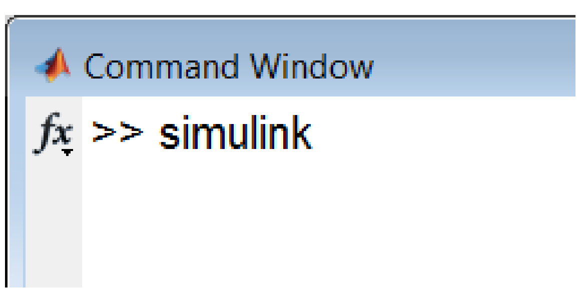

Figure 1.4 Initiating Simulink from Matlab.

Then Simulink library browser window will appear as shown in Figure 1.5.

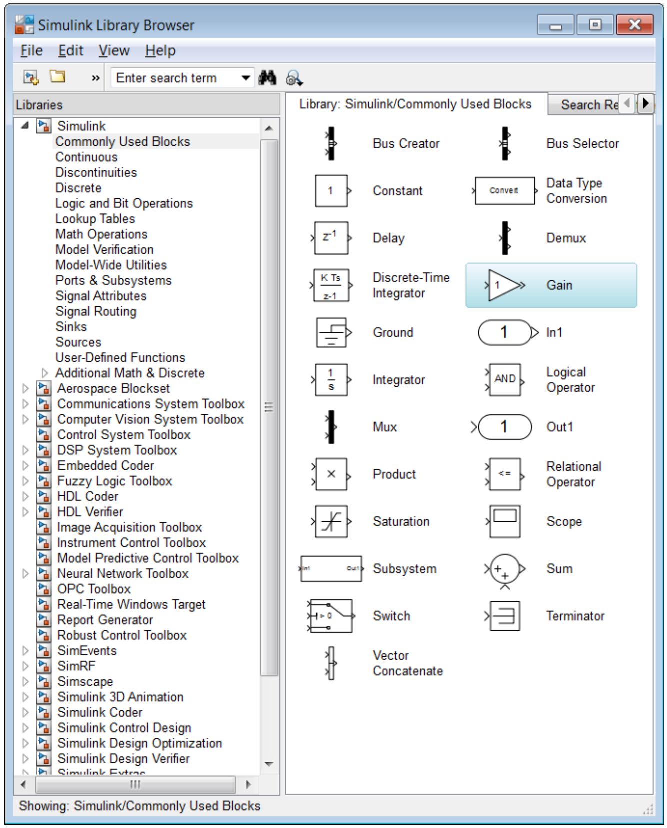

Figure 1.5 Simulink library browser window

Other way is to select Simulink library directly from Simulink on top in command window as shown in Figure 1.6.

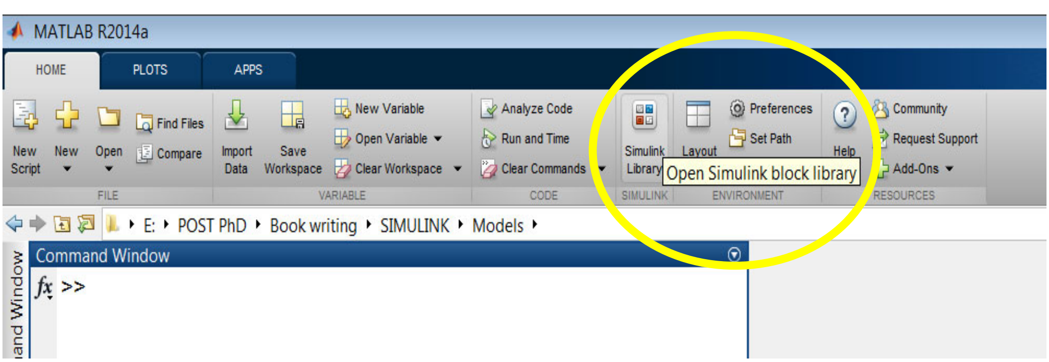

Figure 1.6 Selection of Simulink browser directly from the top menu in the command window

A New Simulink model file has to be created using the following steps.

File – New – Model

The same is shown in Figure 1.7.

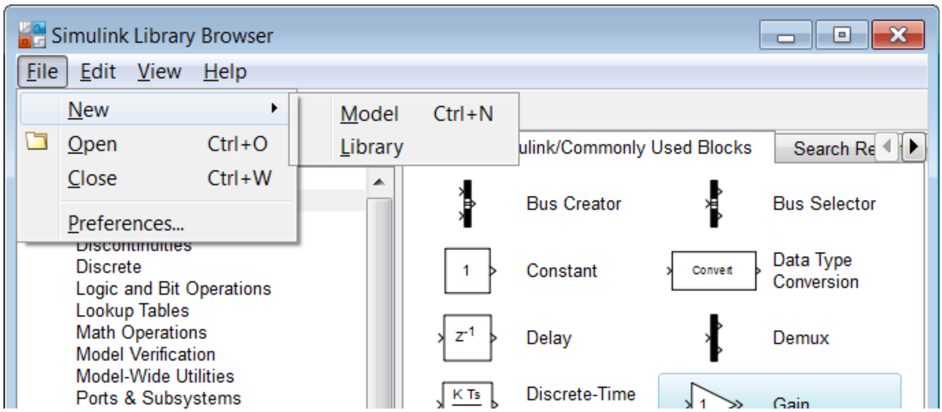

Figure 1.7 Creating new Simulink model

Then a window shown in Figure 1.8 will appear.

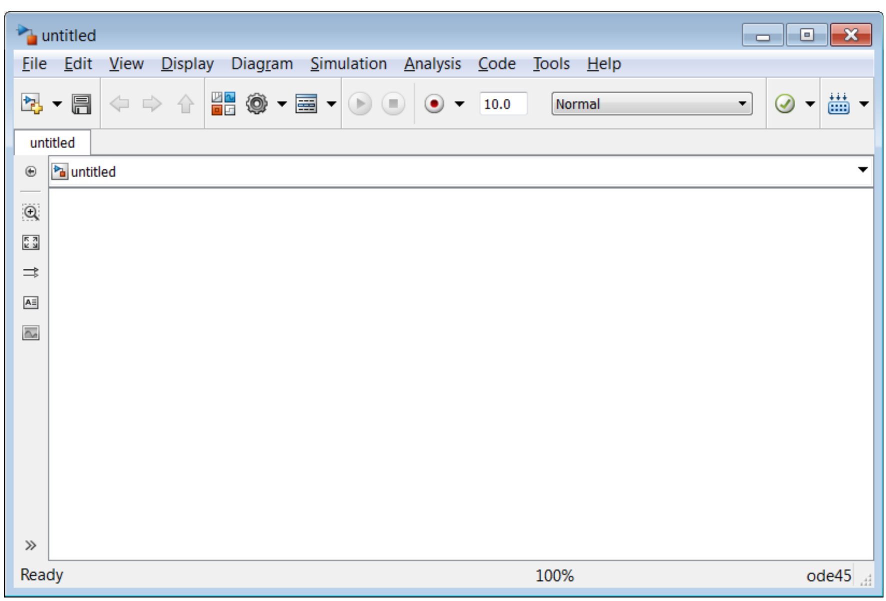

Figure 1.8 Creating new Simulink model

Select **commonly used blocks – sources – sine wave** block and drag the same using left mouse button and position it on untitled window as shown in Figure 1.9.

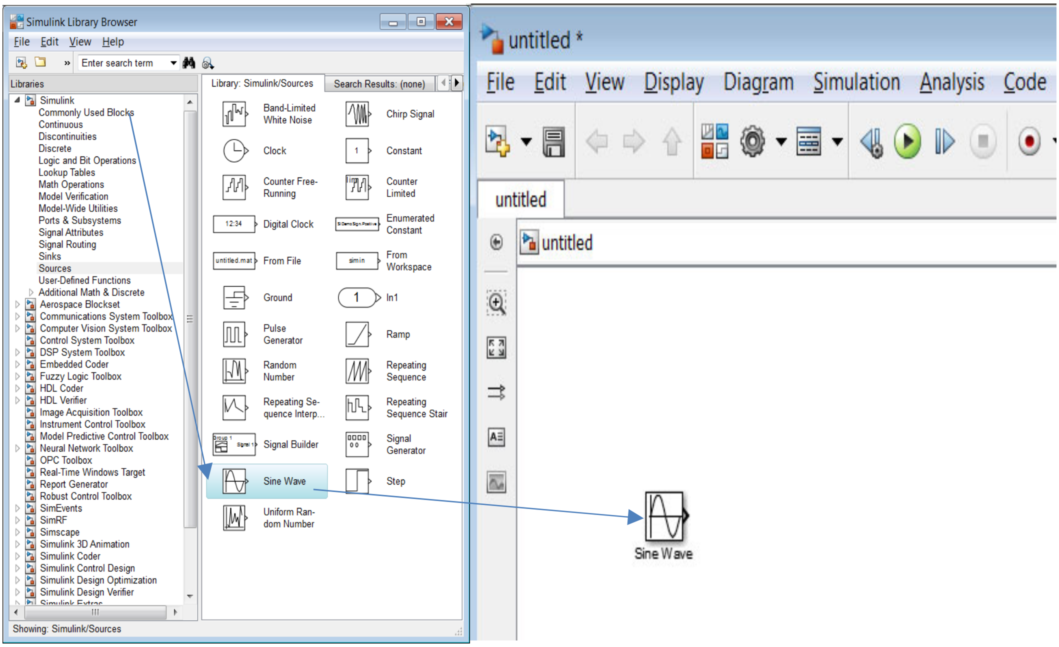

Figure 1.9 Sine wave block positioned in the model

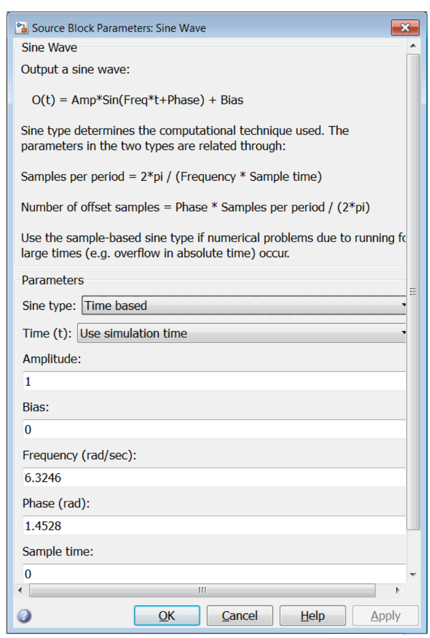

Figure 1.10 Function block parameters for sine wave block

From Matlab, the following parameters are computed, and the same is used for Simulink.

Excitation frequency, ω = 6.3246 rad/sec

Phase difference, ϕ = -1.4528 rad

Sine wave block needs to be double clicked to get associated properties window in which values **(Frequency = 6.3246 rad/sec and phase = 1.4528 rad/sec & rest are to be left with default values)** are to be entered as shown in Figure 1.10.

Note: A positive value is considered for phase as software assumes sin (ωt+ϕ) whereas formulation is in the form of sin (ωt-ϕ) with the actual value of ϕ is -1.4528.

Then three **gain** blocks from **commonly used blocks** are to be positioned as shown in Figure 1.11.

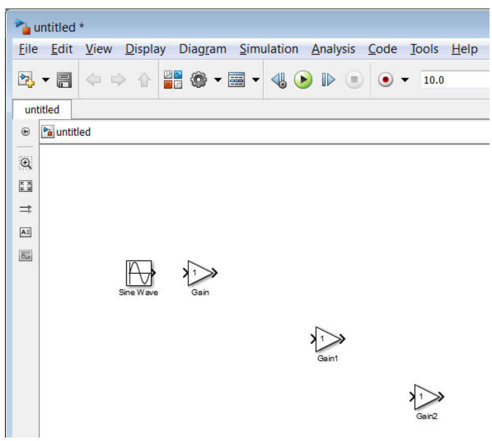

Figure 1.11 Gain blocks

Double click **gain** block (One RHS to **sine wave** block) and enter the value **(Gain = 5)** in the properties window as shown in Figure 1.12.

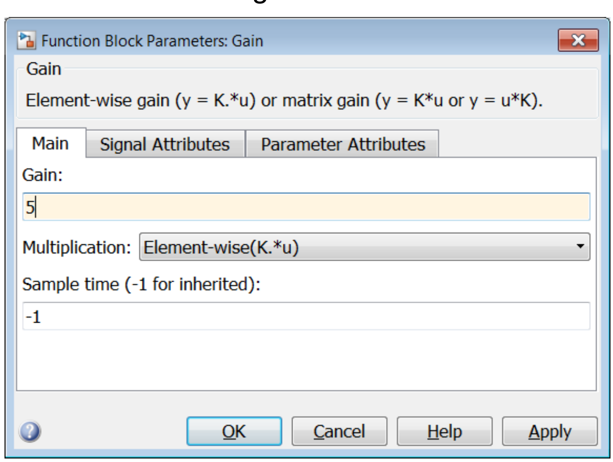

Figure 1.12 Function block parameters for gain block

Select **gain1** block (One middle bottom), then press a right mouse button and choose the options **rotate & flip - flip block** from popup menu with which orientation of **gain1** block will get changed as shown in Figure 1.13.

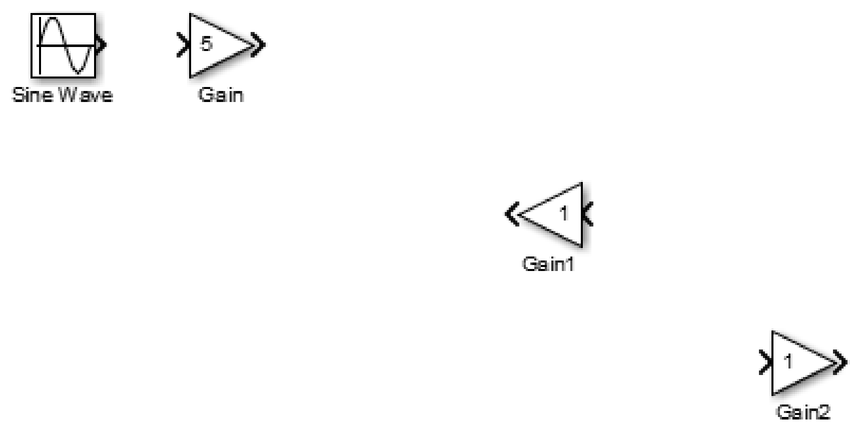

Figure 1.13 Orientation of gain1 block

Double click the **gain1** block and change its **gain** property to -20 from the resulting property window. Change the orientation of **gain2** block also the same as for **gain1** block. Change the **gain** property to -10 for **gain2** block by double clicking it.

Position **Add** block (**From math operations**) RHS to **gain** block as shown in Figure 1.14.

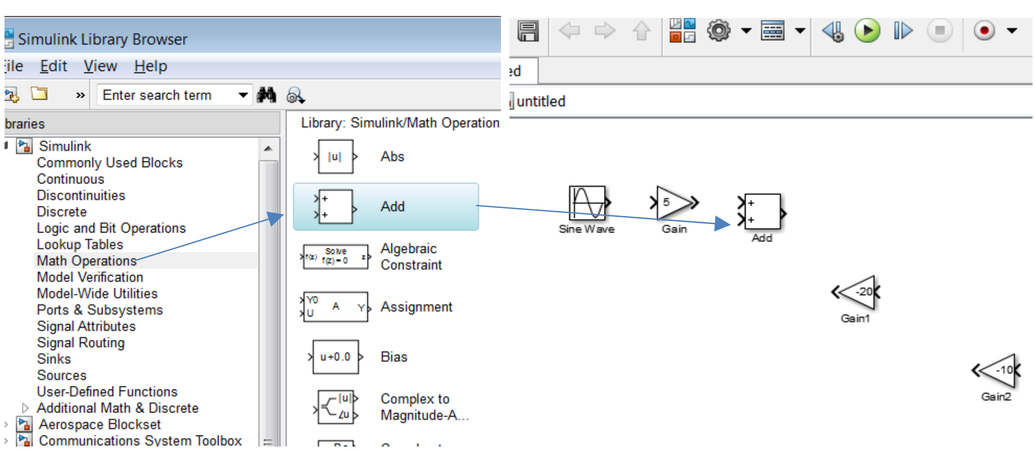

Figure 1.14 Add block

Double click **add** block and type **+++** under **list of signs** property (**+++** should appear) as shown in Figure 1.15.

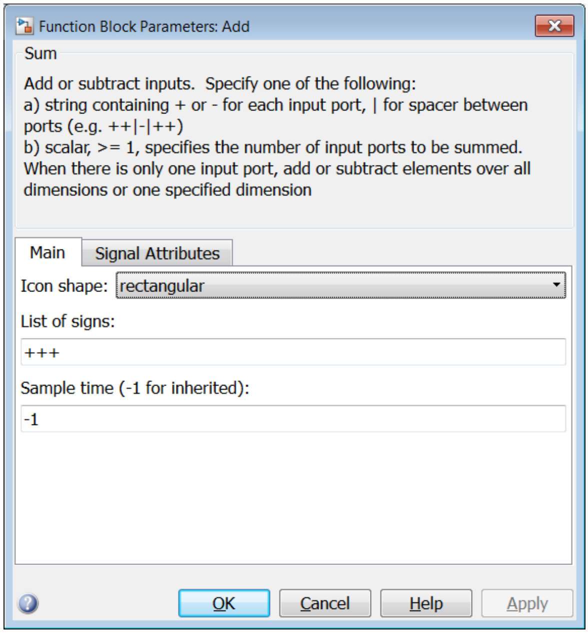

Figure 1.15 Function block parameters for add block

Position two **integrator** blocks (From commonly used blocks) RHS to gain block as shown in Figure 1.16.

Note:

- Copy-paste operations can be performed to create identical blocks from one block.

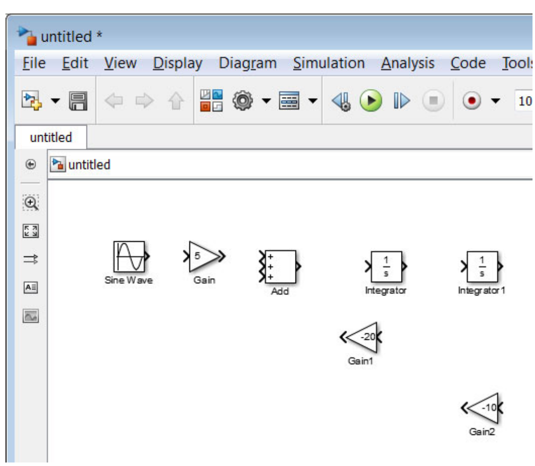

Figure 1.16 Integrator blocks

Position **scope** block (From **sinks**) RHS to **integrator1** block as shown in Figure 1.17.

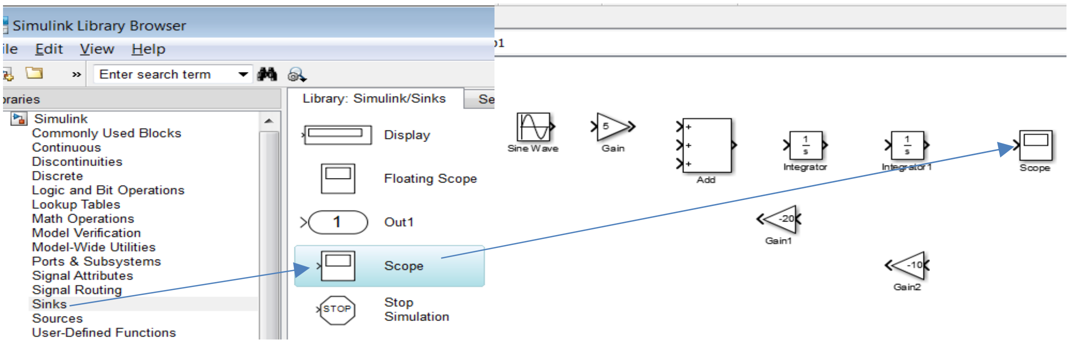

Figure 1.17 Scope block

Now all blocks need to be connected appropriately. For connecting two blocks

- The cursor needs to be positioned on the output arrow of the first block
- Press the left mouse button
- Drag the cursor on to input arrow of the second block
- Release the left mouse button

While leading cursor from input arrow of the first block to output arrow of the second block, connecting line becomes dotted red and gets converted into solid black line if a connection is established properly otherwise, it remains as a dotted red line.

Note:

- Care is to be exercised to ensure all solid black connecting lines between blocks before running the Simulink model file. While the left mouse button is pressed drag over all blocks to select them, press the right mouse button and select format and then font style so as to change the font of names of blocks as desired.

Simulink model file with all connections between blocks is shown in Figure 1.18.

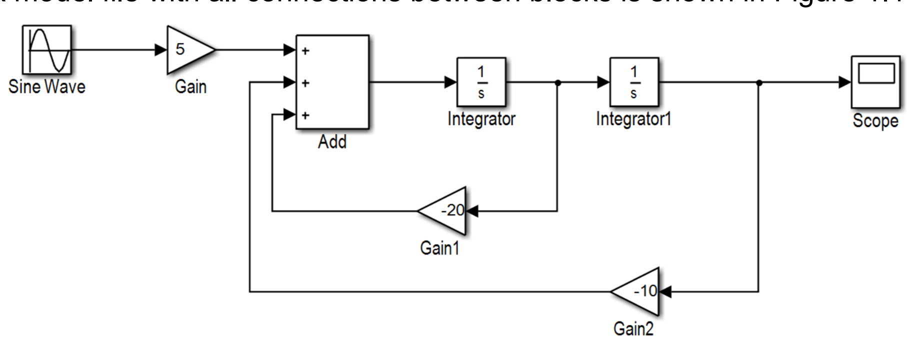

Figure 1.18 Simulink model file

Type 20 in **simulation stop time** window on top, save the model with a file name and run the model (Green arrow button) as shown in Figure 1.19.

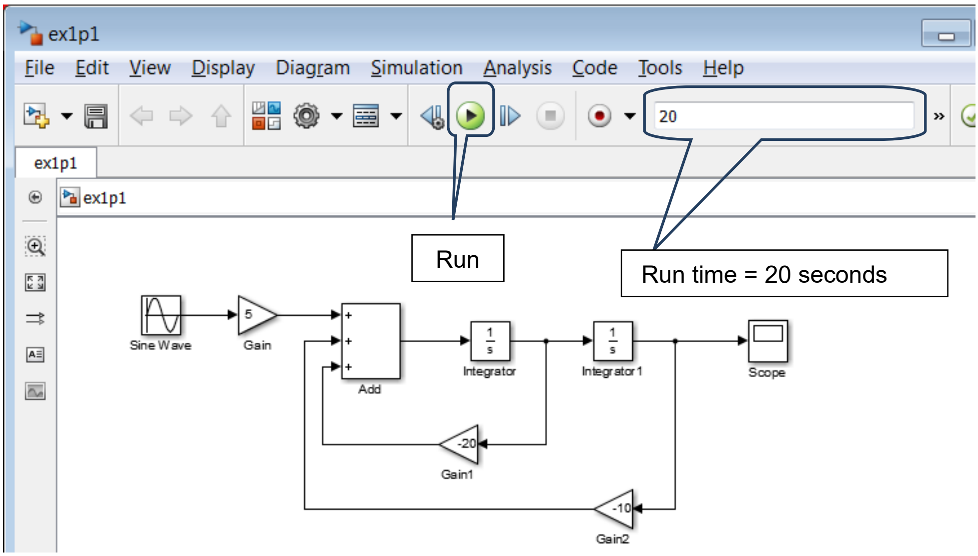

Figure 1.19 Run and Run time features

Once the run button is pressed, Simulink model file gets executed. Then double click **scope** block. A graph will be displayed which will not be fit on the screen, and hence select the auto scale icon on the top side of the graph. The final result thus produced is shown in Figure 1.20.

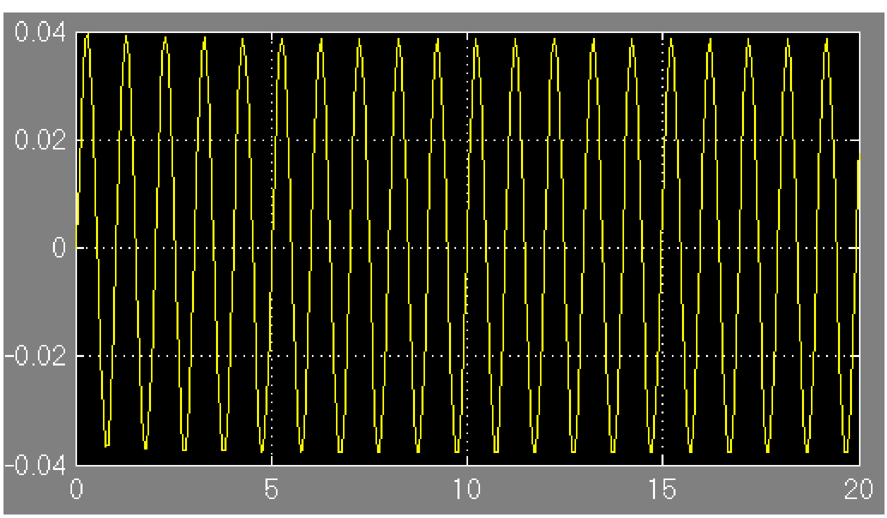

Figure 1.20 Response plot - Simulink

1.2 SIMPLIFYING COMPLEX SIMULINK MODELS

Often Simulink models will have more number of blocks with connections which may create an ambiguity. In such cases model can be simplified by bunching some blocks using **subsystem** block. Same is implemented on model shown in Figure 1.17. All blocks except **sine wave** and **scope** blocks are bunched. To implement this, the said blocks are selected by dragging the left mouse button over them. While those blocks are selected, Ctrl + G can be pressed to bring them within **subsystem** block, as shown in Figure 1.21.

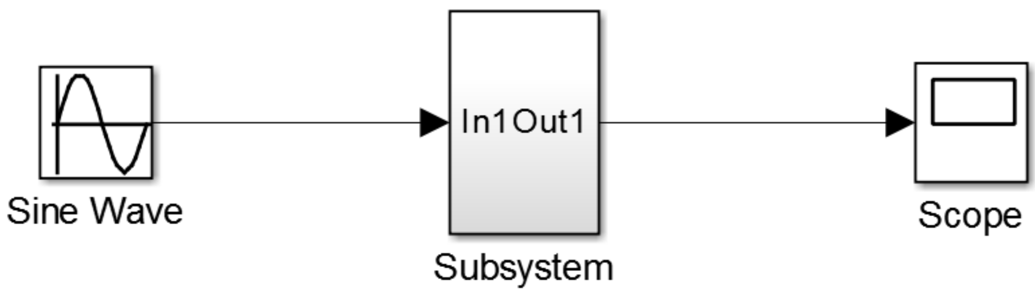

Figure 1.21 Simplified Simulink model using subsystem block

By double clicking **subsystem** block model changes with **sine wave** and **scope** blocks replaced by **In1** and **Out1,** respectively, as shown in Figure 1.22. **In1** and **Out1** represent input and output to **subsystem** block.

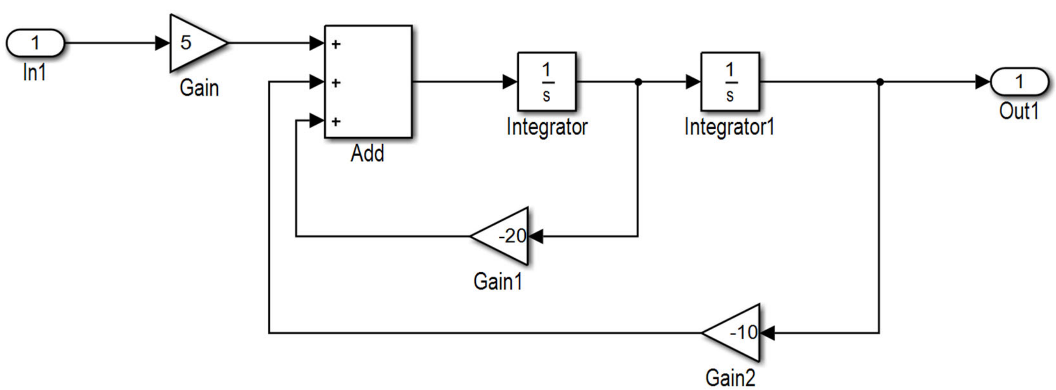

Figure 1.22 Expanded Simulink model - Subsystem block

In1, **Out1** and **subsystem** blocks can be found from **commonly used blocks**.

1.3 MANAGEMENT OF VARIABLES IN SIMULINK

Values for variables lying in Simulink blocks can be assigned from Matlab. This feature enables smooth control over changing the values for variables, and this is illustrated below.

The typical Simulink model is shown in Figure 1.23.

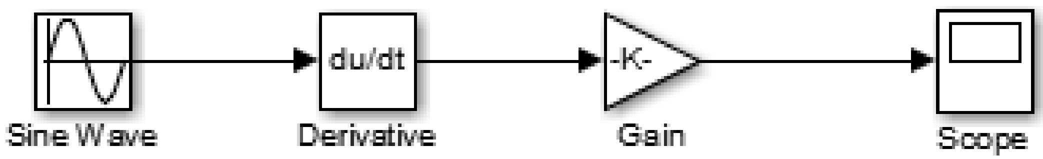

Figure 1.23 Typical Simulink model

The gain property consists of two variables 'a' and 'b'. Values for these variables have to be specified from Matlab before running Simulink model, and after that, they reside in the matlab workspace. Gain block parameters and Matlab work space are shown in Figure 1.24.

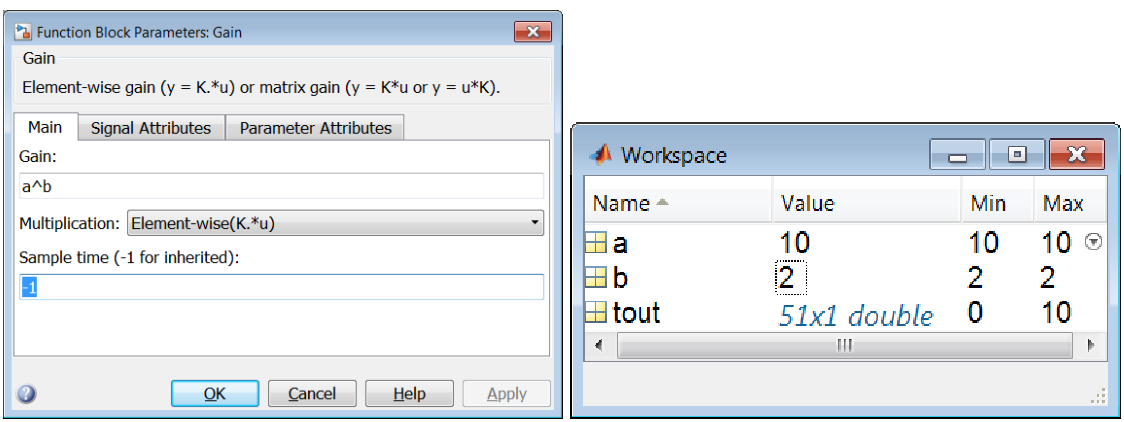

Figure 1.24 Function block parameters for gain block and matlab workspace

Values for variables can be changed comfortably from matlab workspace, and the Simulink model can be activated to study the influence of change in the values on results.

1.4 LABELLING VARIOUS ENTITIES

The simulink model, can be labelled for a description of the model. Double clicking the empty space anywhere in the model will enable a user to type the label. Alternatively, annotation icon on left side of model window also can be used to do so. Signals meant for connecting blocks also can be labelled, and signal line has to be double clicked for specifying the label. Labels can be edited by a pop up menu, which gets activated by the right mouse button. Simulink model shown in Figure 1.23 with labels to different entities is shown in Figure 1.25.

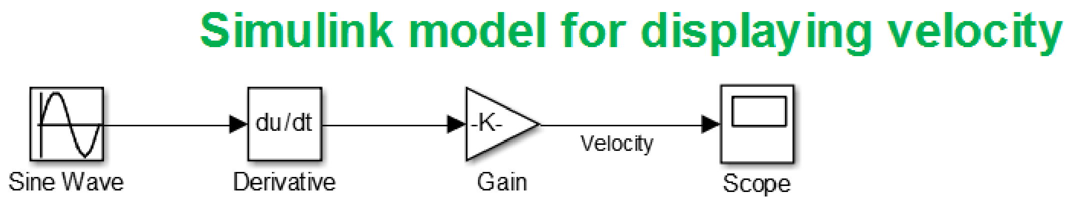

Figure 1.25 Simulink model with labels

1.5 FORMATTING BLOCKS

Blocks can be formatted by activating pop up menu. Font size, background colors and other parameters can be changed. Simulink model shown in Figure 1.23 after adding background colors to blocks is shown in Figure 1.26.

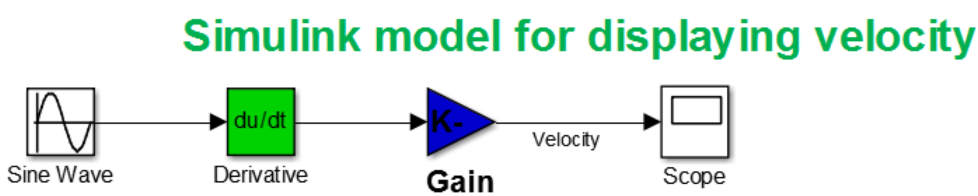

Figure 1.26 Simulink model with formatted blocks

1.6 QUICK OPTIONS

Options available in Simulink for performing quick operations on entities like blocks, signals, etc are given in Table 1.3.

Table 1.3 Options available in Simulink for performing quick operations

Sl. No.	Operation to be performed	Quick option
1.	For copying the entity	Select the entity and then drag the same with Ctrl + left mouse button
2.	For increasing/decreasing the size of block along diagonal while maintaining same width and height	Shift + Drag the block

Contd...

Sl. No.	Operation to be performed	Quick option
3.	For increasing/decreasing the size of block along width/ height	Ctrl + Drag the block
4.	To flip the block	Ctrl + Drag the block
5.	To rotate the block clockwise	Ctrl + R
6.	To rotate the block counterclockwise	Ctrl + Shift + R
7.	For connecting two blocks	Select first block, then Ctrl + select second block
8.	To create subsystem for bunch of blocks	Select the blocks Ctrl + G
9.	To move any label	To drag with left mouse button
10.	To change font of name for block	To drag with left mouse button over all blocks, right mouse button, format, font style
11.	To run simulation	Ctrl + T
12.	To stop simulation	Ctrl + Shift + T
13.	To zoom in	Ctrl + +
14.	To zoom out	Ctrl + -
15.	To zoom to 100%	Alt + 1
16.	Fit view	Press space bar
17.	To move model within screen	Space bar + drag with left mouse button

1.7 SUMMARY

This chapter brings out an overview of Simulink. Basic differences between matlab and Simulink are illustrated with the aid of an example. Methodology for simplifying complex Simulink models is elaborated. Various means for labelling different entities in a Simulink model are discussed. Procedure for formatting blocks is outlined. Further various options available for quick access of Simulink models are highlighted.