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.

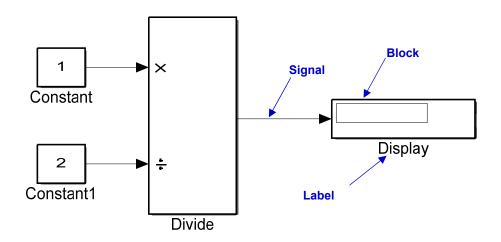


Figure 1.1 Typical Simulink model

Elements of Simulink model are given in Table 1.1.

Table 1.1 El	ements of Simulink model
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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 $F_0 \sin \omega t$ shown in Figure 1.2.

To consider the following parameters.

- m = 10 kg
- c = 200 Ns/m
- k = 100 N/m
- F₀ = 50 N
- r = 2
- Time duration = 20 seconds



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

$$m\ddot{\mathbf{x}} + \mathbf{c}\dot{\mathbf{x}} + \mathbf{k}\mathbf{x} = \mathbf{F}_0 \sin \omega \mathbf{t} \qquad \dots \dots (1.1)$$

Where

m: Mass

```
x: Acceleration
```

- c: Damping coefficient
- *x*: Velocity
- k: Stiffness
- x: Response of the system
- F_o: Amplitude
- ω: Excitation frequency

t: Time

The following solution can be assumed.

 $x = X \sin(\omega t - \phi)$

Where

X: Response amplitude

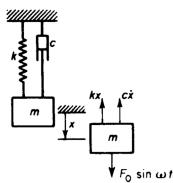


Figure 1.2 SDOF model of a system subjected to harmonic excitation

.....(1.2)

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

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

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

$$X = \frac{\frac{F_0}{k}}{\sqrt{\left(1 - \frac{m\omega^2}{k}\right)^2 + \left(\frac{c\omega}{k}\right)^2}} \qquad \dots (1.5)$$
$$\varphi = \tan^{-1}\left(\frac{\frac{c\omega}{k}}{1 - \frac{m\omega^2}{k}}\right) \qquad \dots (1.6)$$

Further

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

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

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

 $\frac{c \,\omega}{k} = \frac{c}{c_c} \frac{c_c \,\omega}{k} = 2 \,\zeta \,\frac{\omega}{\omega_n}$
Frequency ratio, $r = \frac{\omega}{\omega_n}$

Substituting the above relations in equations 1.5 and 1.6 gives

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

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

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

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.

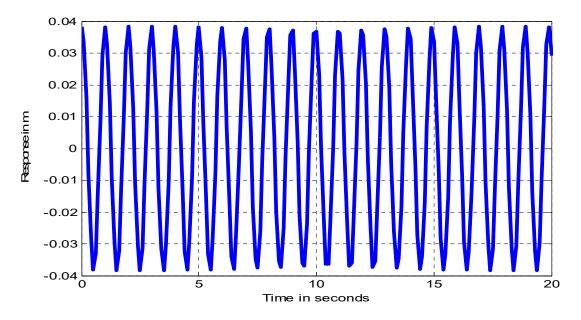


Figure 1.3 Response plot - Matlab

Solution using Simulink

Substituting the values in equation 1.1 gives.

$$10\ddot{x} + 200\dot{x} + 100x = 50\sin\omega t$$
(1.10)

Rewriting same as

5

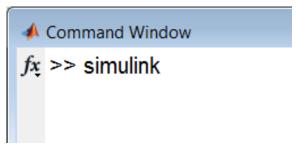
$$\sin \omega t - 20 \dot{x} - 10 x = \ddot{x}$$
(1.11)

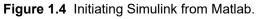
The logic for solving equation 1.11 using Simulink is given in Table 1.2.

Component of equation	Operation needs to be performed	Feature needed in Simulink	
Velocity, <i>x</i>	Integration of acceleration, \ddot{x}	Integration	
-20 <i>x</i>	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	
$5 \sin \omega t + (-20 \dot{x}) + (-10 x)$	Summation	Sum	
$5 \sin \omega t + (-20 \dot{x}) + (-10 x) = \ddot{x}$	Equating evaluated LHS expression to acceleratio integrating which of same gives velocity and furth integrating gives displacement response		

Table 1.2 Logic for solving equation 1.11 using Simulink

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.





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

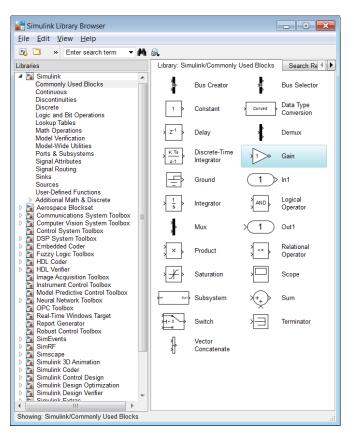


Figure 1.5 Simulink library browser window

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

HOME	PLOTS	APPS	
Script 💌	Pipen Compare	New Variable	@ Preferences ? ?

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.

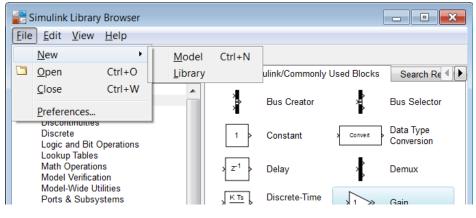


Figure 1.7 Creating new Simulink model

Then a window shown in Figure 1.8 will appear.

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<u>F</u> ile	<u>E</u> dit	<u>V</u> iew	<u>D</u> isplay	/ Dia <u>gr</u> an	n <u>S</u> imulation	n <u>A</u> nalysis	<u>C</u> ode	<u>T</u> ools <u>H</u> elp	
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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.

Simulink Library Browser		_ • •	
<u>Eile E</u> dit <u>V</u> iew <u>H</u> elp			📲 untitled *
📧 🗀 🔹 Enter search term 💌 🛤	A		
Libraries	Library: Simulink/Sources	Search Results: (none)	<u>File Edit View Display Diagram Simulation Analysis Code</u>
Simulink Commonly Used Blocks Continuous Discontinuities	Band-Limited White Noise	Chirp Signal	
Discrete Logic and Bit Operations Lookup Tables	Clock	1 Constant	
Math Operations Model Verification Model-Wife Utilities	Counter Free- Running	Counter Limited	untitled
Ports & Subsystems Signal Attributes Signal Routing	12:34 Digital Clock	somesen Parties Constant	Image: A state of the stat
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Additional Math & Discrete Acrospace Blockset Communications System Toolbox ==	Ground	1 In1	(Q)
Computer Vision System Toolbox Control System Toolbox DSP System Toolbox	Generator	Ramp	
Embedded Coder Fuzzy Logic Toolbox HDL Coder	Random Repeating Sequence	Repeating Sequence	
HDL Verifier Image Acquisition Toolbox Instrument Control Toolbox	Repeating Se- quence Interp.	Repeating Sequence Stair	
Model Predictive Control Toolbox Image: Second Se	Signal Builder	Generator	EA
 Real-Time Windows Target Report Generator Robust Control Toolbox 	Sine Wave	Step	
 SimEvents SimRF Simscape 	Uniform Ran- dom Number		
Simulink 3D Animation Simulink Coder Simulink Coder Simulink Control Design			Sine Wave
Simulink Design Optimization Simulink Design Verifier Simulink Extract			
Showing: Simulink/Sources		ła.	



Cal Source Block Parameters: Sine Wave						
Sine Wave						
Output a sine wave:						
O(t) = Amp*Sin(Freq*t+Phase) + Bias						
Sine type determines the computational technique used. The parameters in the two types are related through:						
Samples per period = 2*pi / (Frequency * Sample time)						
Number of offset samples = Phase * Samples per period / (2*pi)						
Use the sample-based sine type if numerical problems due to running for large times (e.g. overflow in absolute time) occur.						
Parameters						
Sine type: Time based						
Time (t): Use simulation time						
Amplitude:						
1						
Bias:						
0						
Frequency (rad/sec):						
6.3246						
Phase (rad):						
1.4528						
Sample time:						
0						
•						
OK Cancel Help Apply						

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, $\omega = 6.3246$ rad/sec

Phase difference, $\phi = -1.4528$ 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 (ω t+ ϕ) whereas formulation is in the form of sin (ω t- 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.

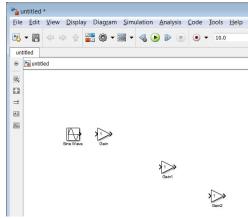


Figure 1.11 Gain blocks

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.

🚹 Functi	Ta Function Block Parameters: Gain						
Gain							
Element-wise gain (y = K.*u) or matrix gain (y = K*u or y = u*K).							
Main Signal Attributes Parameter Attributes							
Gain:							
5							
Multiplic	Multiplication: Element-wise(K.*u)						
Sample	time (-1 for inherited):						
-1							
0	<u>Q</u> K <u>C</u> ancel <u>H</u> elp <u>A</u> p	ply					

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.

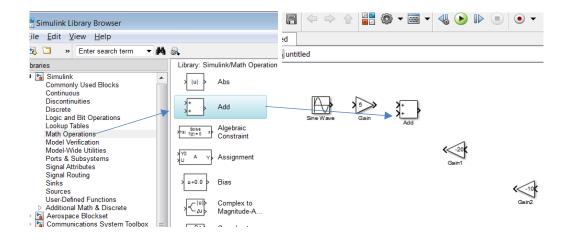


Figure 1.14 Add block

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

🚹 Function	Tunction Block Parameters: Add						
Sum							
Add or subtract inputs. Specify one of the following: a) string containing + or - for each input port, for spacer between ports (e.g. ++ - ++) b) scalar, >= 1, specifies the number of input ports to be summed. When there is only one input port, add or subtract elements over all dimensions or one specified dimension							
Main	Signal Attributes						
Icon shap	e: rectangular	•					
List of sig	ns:						
+++							
Sample ti	me (-1 for inherited):						
-1	-1						
0	OK Cancel Help Ap	ply					

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.

File	intitled Edit	* <u>V</u> iew <u>C</u>	isplay Dia	agram Simu	ulation <u>A</u> nalysis	Code Tool
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	untit	led				
of to the late		Sine Wave	5 Gain	X++ Add	1 s Integrator	▶ 1/s Integrator 1
					Gain1	Gain2

Figure 1.16 Integrator blocks

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

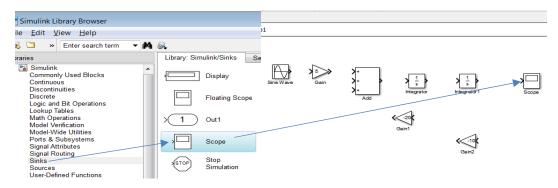


Figure 1.17 Scope block

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.

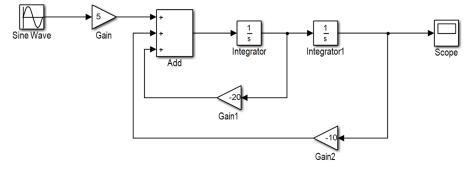


Figure 1.18 Simulink model file

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.

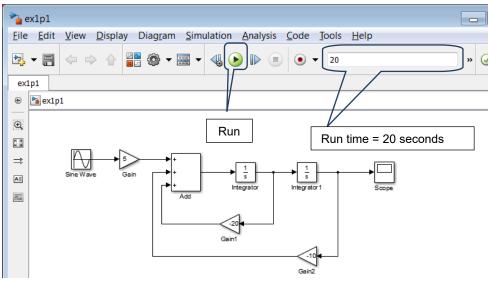


Figure 1.19 Run and Run time features

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.

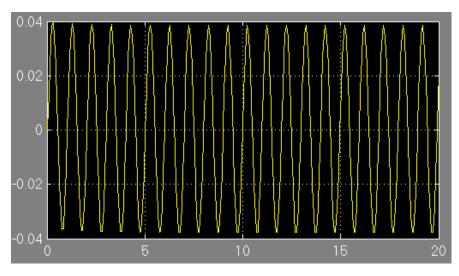


Figure 1.20 Response plot - Simulink

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.

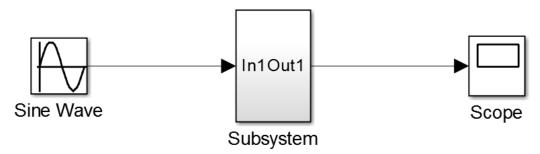


Figure 1.21 Simplified Simulink model using subsystem block

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.

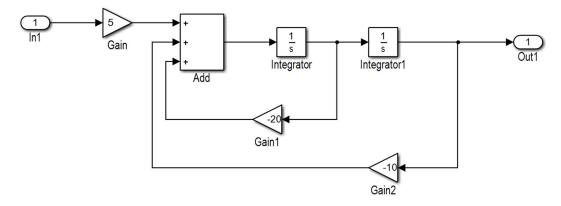


Figure 1.22 Expanded Simulink model - Subsystem block

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.

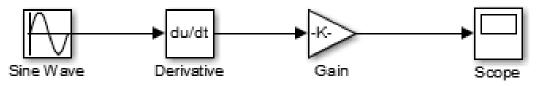


Figure 1.23 Typical Simulink model

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.

Function Block Parameters: Gain Gain Element-wise gain (y = K.*u) or matrix gain (y = K*u or y = u*K).				
Main Signal Attributes Parameter Attributes Gain: a^b	📣 Workspace			
	Name 🔶	Value	Min	Max
Multiplication: Element-wise(K.*u)	⊞a	10	10	10 🐨
Sample time (-1 for inherited):	⊟b	2	2	2
	🖽 tout	51x1 double	0	10
	•	111		1
OK Cancel Help Apply				

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.

Simulink model for displaying velocity

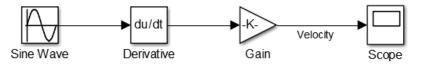


Figure 1.25 Simulink model with labels

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.

Simulink model for displaying velocity

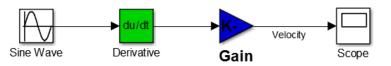


Figure 1.26 Simulink model with formatted blocks

1.6 QUICK OPTIONS

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

SI. 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

Table 1.3 Options available in Simulink for performing quick operations

SI. 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.