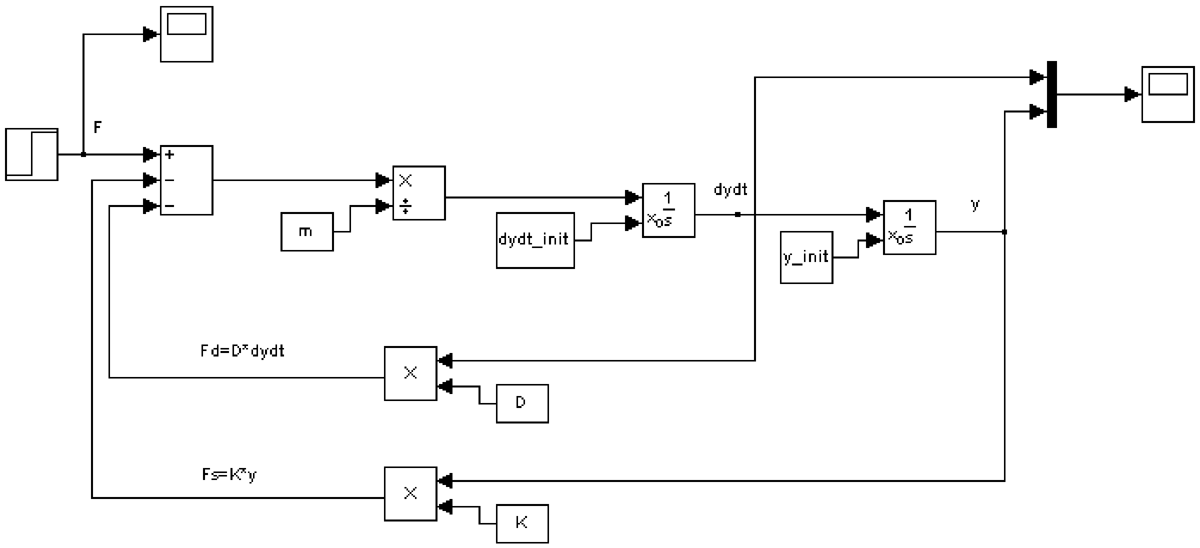
Telemark University College
Department of Electrical Engineering, Information Technology and Cybernetics

Tutorial

Introduction to Simulink

HANS-PETTER HALVORSEN, 2011.06.06



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Preface

Simulink, developed by The MathWorks, is a commercial tool for modeling, simulating and analyzing dynamic systems. Its primary interface is a graphical block diagramming tool and a customizable set of block libraries. It offers tight integration with the rest of the MATLAB environment and can either drive MATLAB or be scripted from it. Simulink is widely used in control theory and digital signal processing for simulation and design.

This training will give you the basic knowledge of Simulink and how you can use it together with MATLAB.

For more information about MATLAB and Simulink, see my Blog: **http://home.hit.no/~hansha**

Table of Contents

1Introduction to Simulink

Simulink is an environment for simulation and model-based design for dynamic and embedded systems. It provides an interactive graphical environment and a customizable set of block libraries that let you design, simulate, implement, and test a variety of time-varying systems, including communications, controls, signal processing, video processing, and image processing.

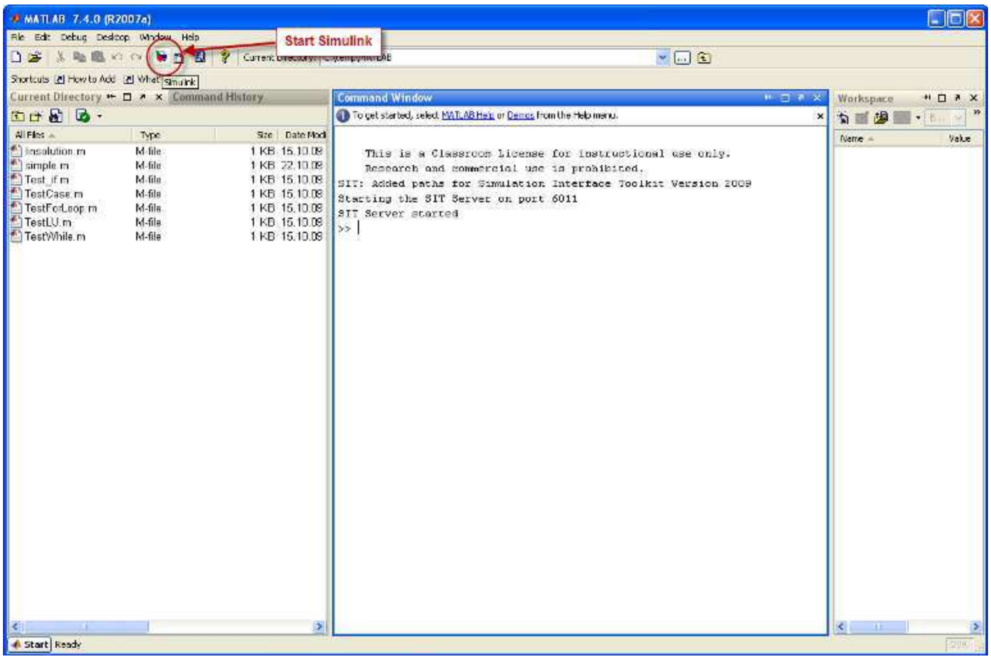
Simulink offers:

- A quick way of develop your model in contrast to text based-programming language such as e.g., C.
- Simulink has integrated **solvers**. In text based-programming language such as e.g., C you need to write your own solver.

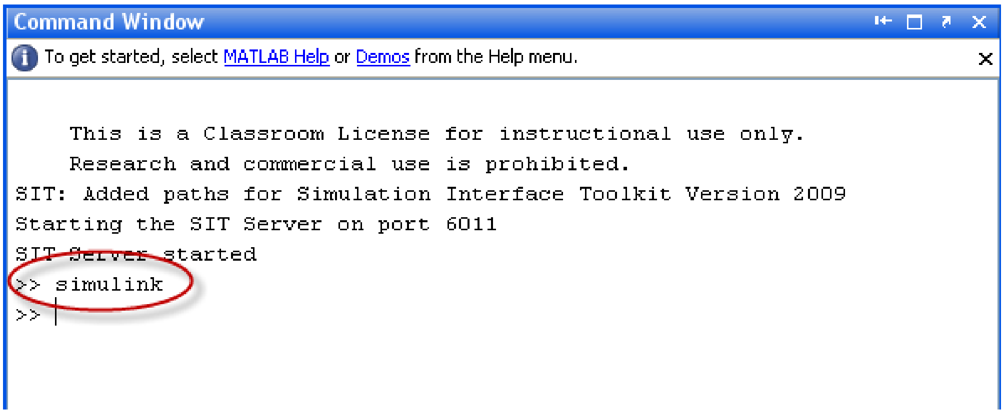
2 Start using Simulink

You start Simulink from the MATLAB IDE:

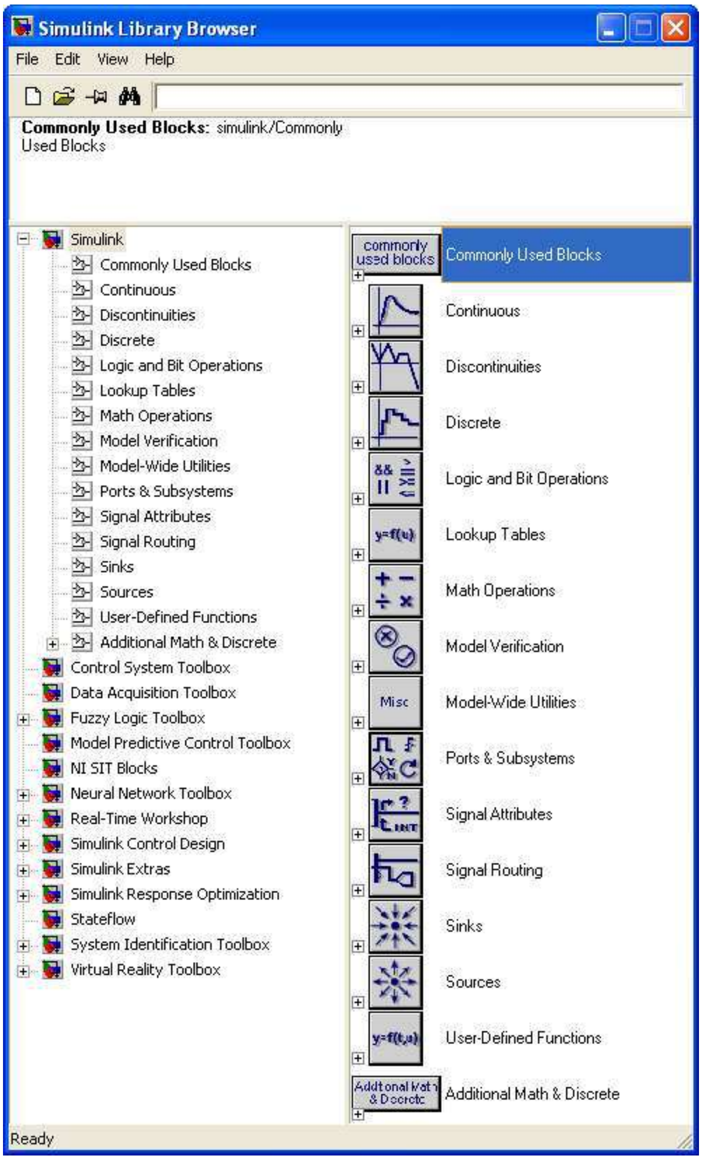
Open MATLAB and select the Simulink icon in the Toolbar:



Or type "**simulink**" in the Command window, like this:



Then the following window appears (**Simulink Library Browser**):

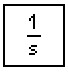


The **Simulink Library Browser** is the library where you find all the blocks you may use in Simulink. Simulink software includes an extensive library of functions commonly used in modeling a system. These include:

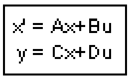
- Continuous and discrete dynamics blocks, such as Integration, Transfer functions, Transport Delay, etc.
- Math blocks, such as Sum, Product, Add, etc
- Sources, such as Ramp, Random Generator, Step, etc

2.1 Block Libraries

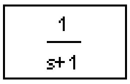
Here are some common used **Continuous** Blocks:



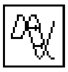
Integrator



State-Space

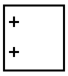


Transfer Fcn

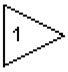


Transport Delay

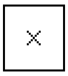
Here are some common used **Math Operations** Blocks:



Add



Gain



Product

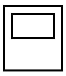
Sum

Here are some common used **Signal Routing** Blocks:

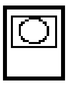
Mux

Demux

Here are some common used **Sinks** Blocks:

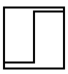


Scope

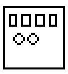


XY Graph

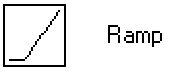
Here are some common used **Sources** Blocks:

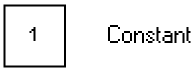


Step

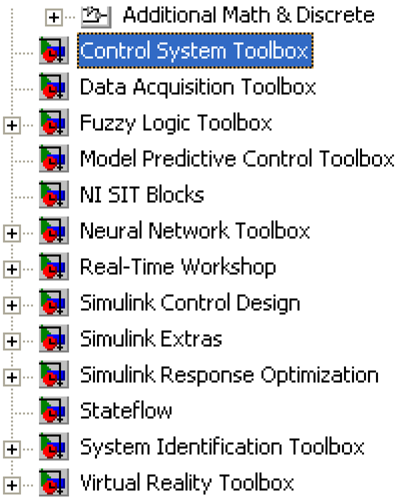


Signal Generator



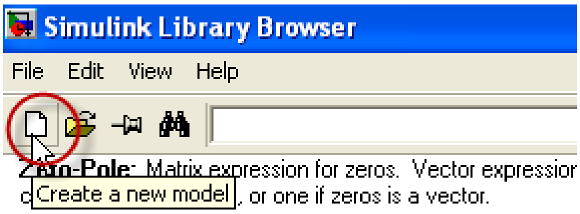


In addition there are lots of block in different Toolboxes:

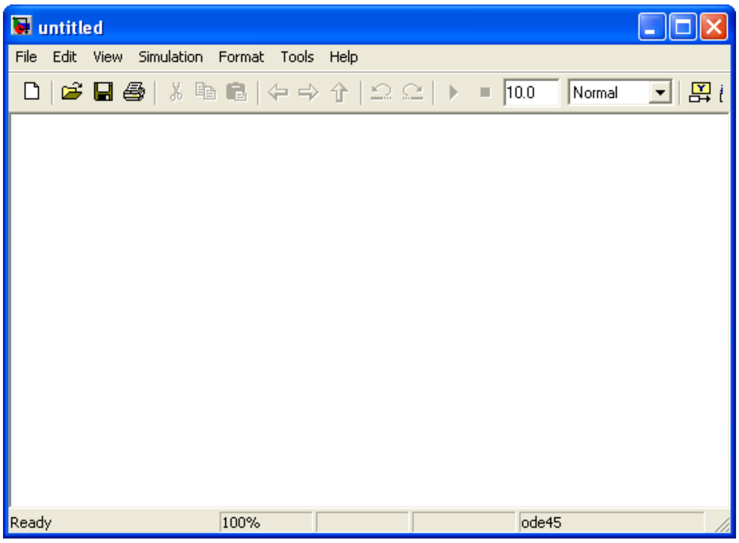


2.2 Create a new Model

Click the New icon on the Toolbar in order to create a new Simulink model:



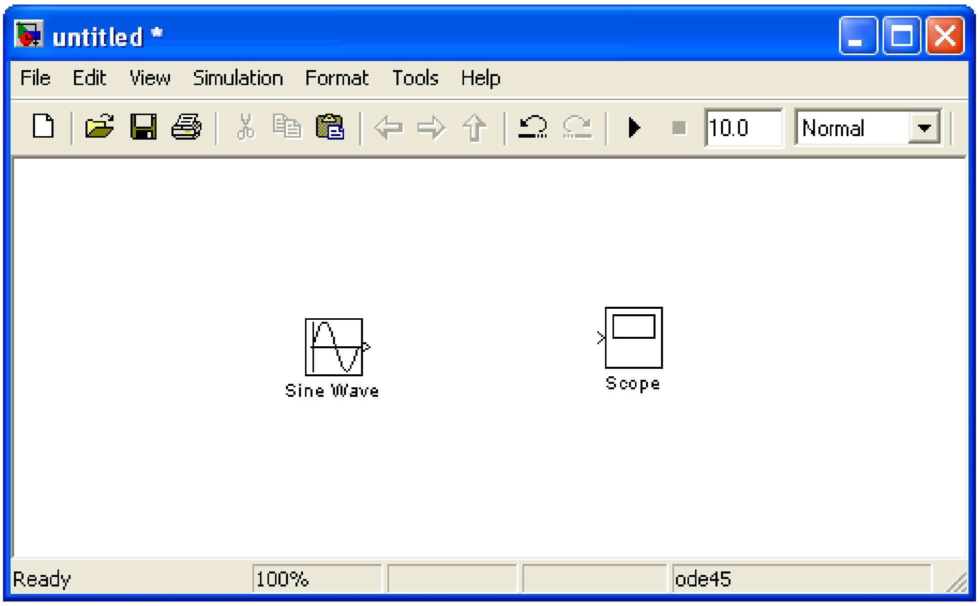
The following window appears:



You may now drag the blocks you want to use from the Simulink Library Browser to the model surface (or right-click on a block and select "Add to…").

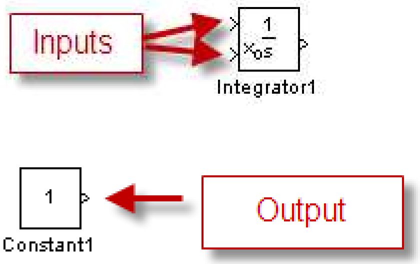
Example:

In this example we place (drag and drop) to blocks, a Sine Wave and a Scope, on the model surface:

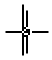


2.3 Wiring techniques

Use the mouse to wire the **inputs** and **outputs** of the different blocks. Inputs are located on the left side of the blocks, while outputs are located on the right side of the blocks.



When holding the mouse over an input or an output the mouse changes to the following symbol.



Use the mouse, while holding the left button down, to drag wires from the input to the output.

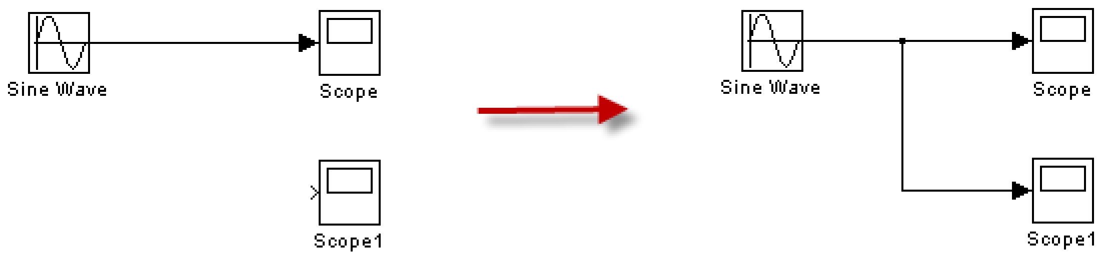
Automatic Block Connection:

Another wiring technique is to select the source block, then hold down the **Ctrl** key while left-clicking on the destination block.

Try the different techniques on the example above.

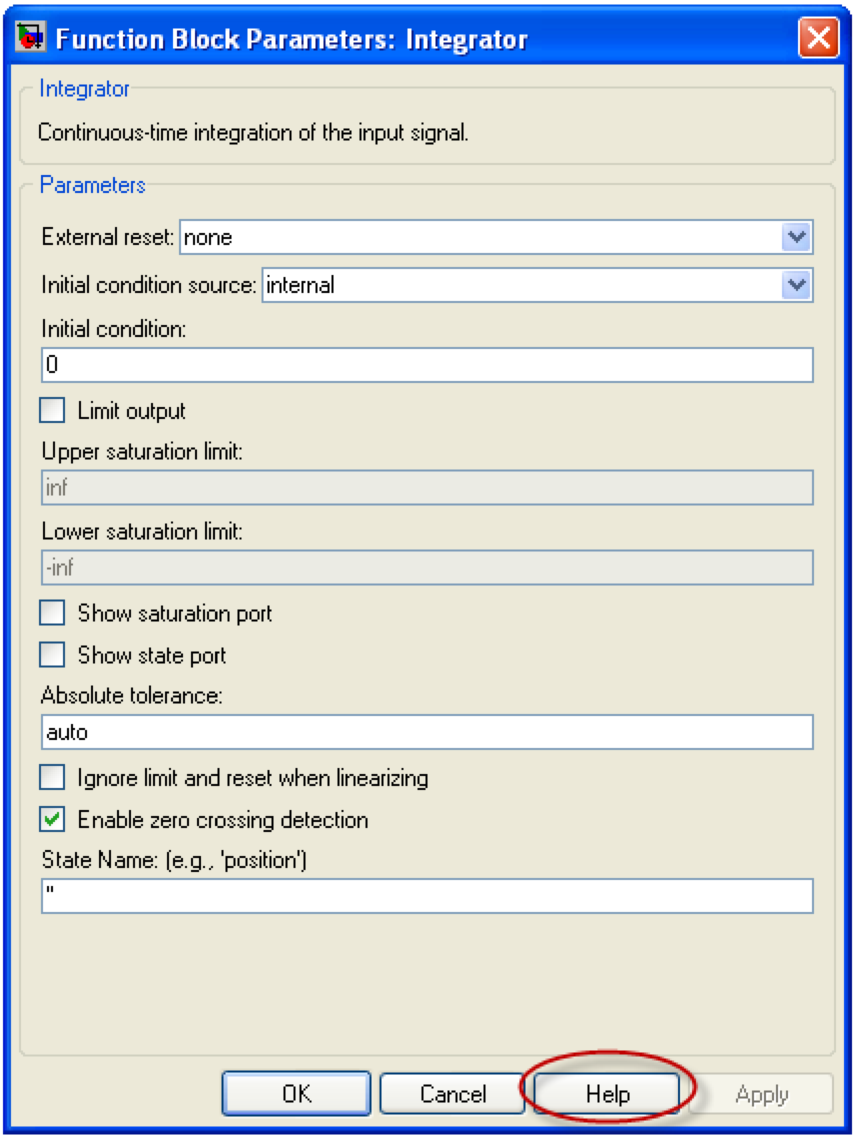
Connection from a wire to another block

If wire a connection from a wire to another block, like the example below, you need to hold down the **Ctrl** key while left-clicking on the wire and then to the input of the desired block.



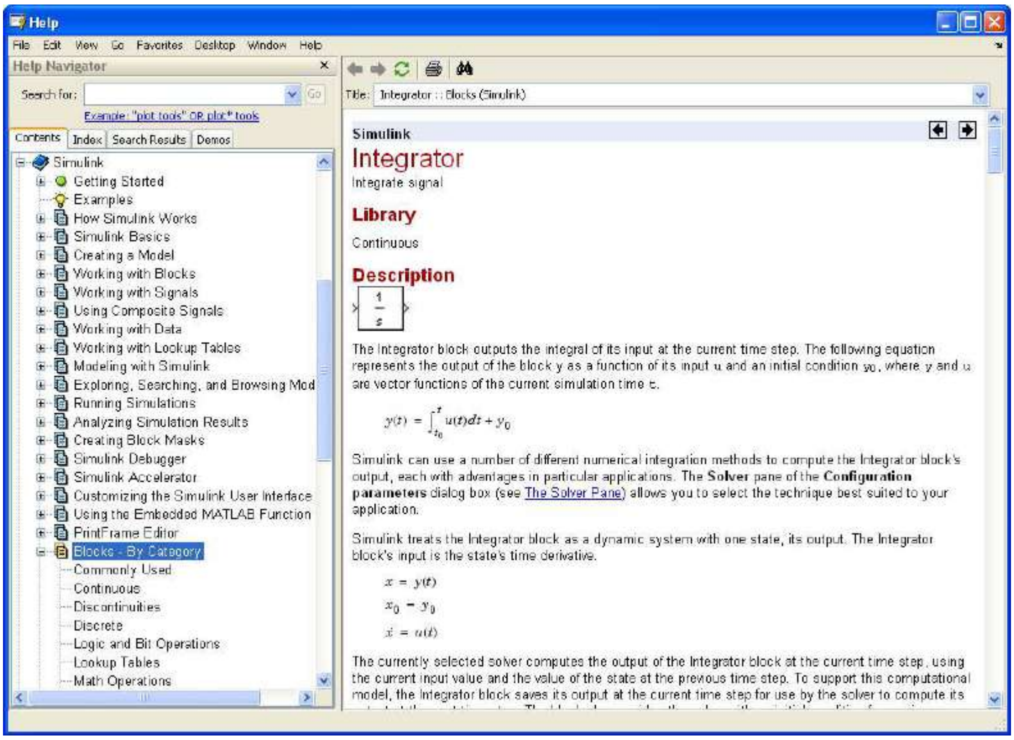
2.4 Help window

In order to see detailed information about the different blocks, use the built-in Help system.



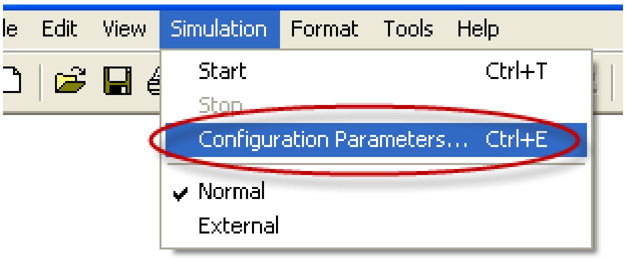
All standard blocks in Simulink have detailed Help. Click the Help button in the Block Parameter window for the specific block in order to get detailed help for that block.

The Help Window then appears with detailed information about the selected block:

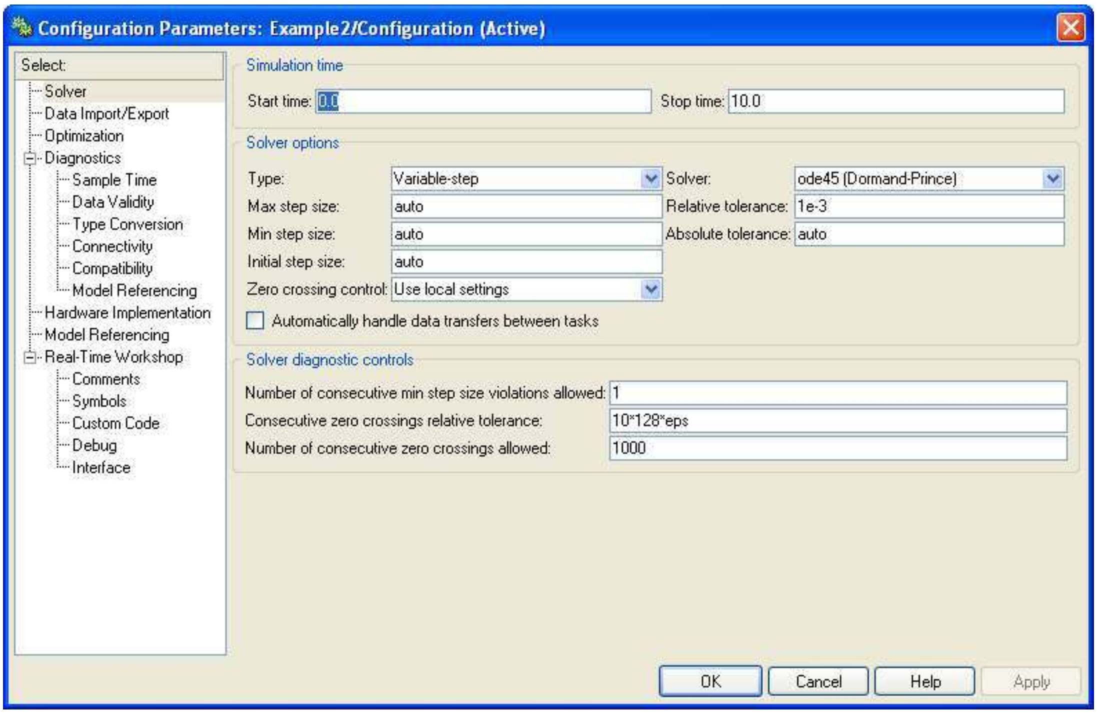


2.5 Configuration

There are lots of parameters you may want to configure regarding your simulation. Select "Configuration Parameters..." in the Simulation menu.



The following window appears:



Here you set important parameters such as:

- Start and Stop time for the simulation
- What kind of Solver to be used (ode45, ode23 etc.)
- Fixed-step/Variable-step

Note! Each of the controls on the Configuration Parameters dialog box corresponds to a configuration parameter that you can set via the "**sim**" and "**simset**" commands. You will learn more about these commands later.

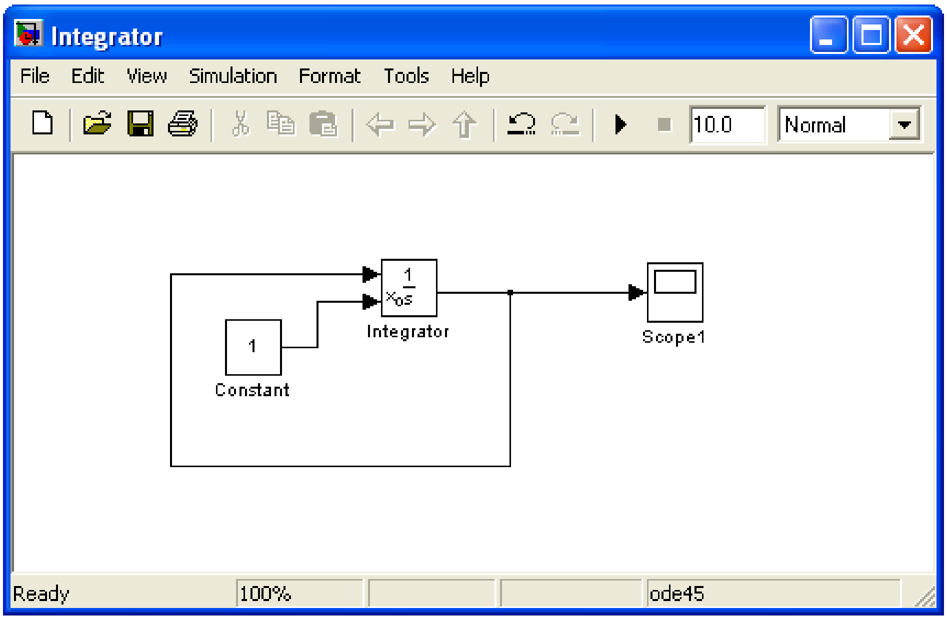
Solvers are numerical integration algorithms that compute the system dynamics over time using information contained in the model. Simulink provides solvers to support the simulation of a broad range of systems, including continuous-time (analog), discrete-time (digital), hybrid (mixed-signal), and multirate systems of any size.

2.6 Examples

Below we will go through some examples in order to illustrate how to create block diagrams and related functionality.

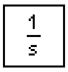
Example: Integrator with initial value

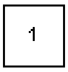
Create the following model (an integrator) and run the simulation:

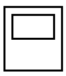


Step1: Place the blocks on the model surface

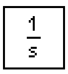
This example use the following blocks:


Integrator

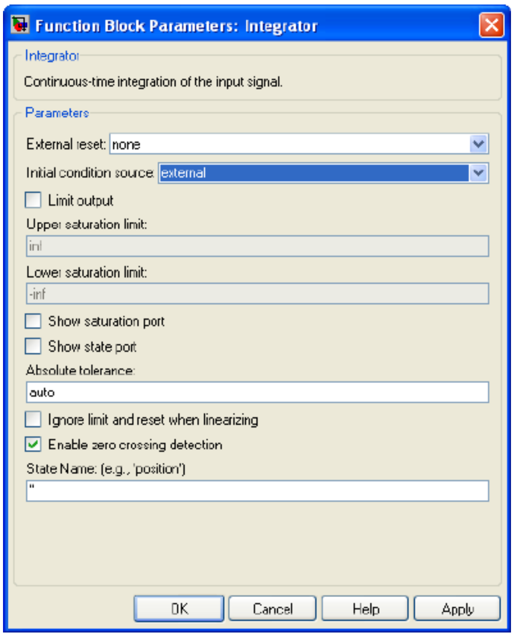

Constant


Scope

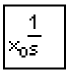
Step 2: Configuration

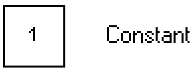

Integrator

Double-click on the Integrator block. The Parameter window for the Integrator block appears:

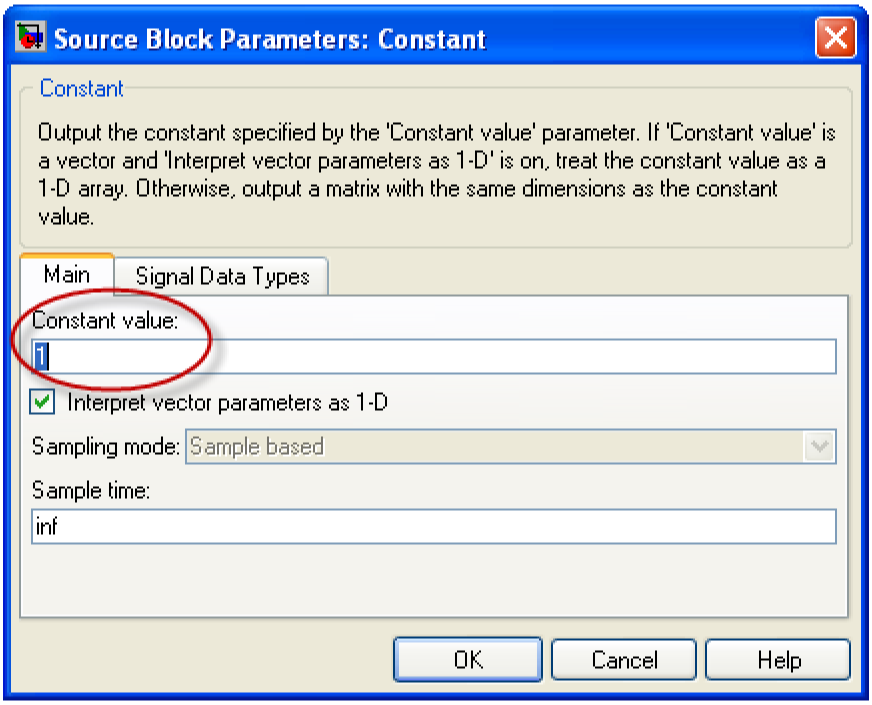


Select "**Initial condition source=external**". The Integrator block now looks like this:





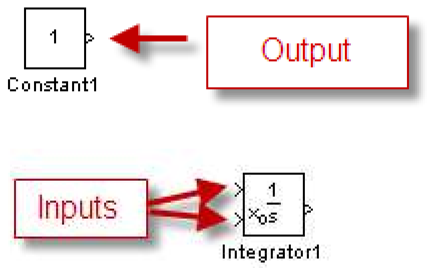
Double-click on the Constant block. The Parameter window for the Constant block appears:



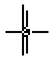
In the Constant value field we type in the initial value for the integrator, e.g., type the value 1.

Step 3: Wiring

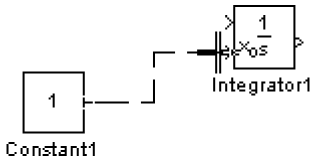
Use the mouse to wire the inputs and outputs of the different blocks.



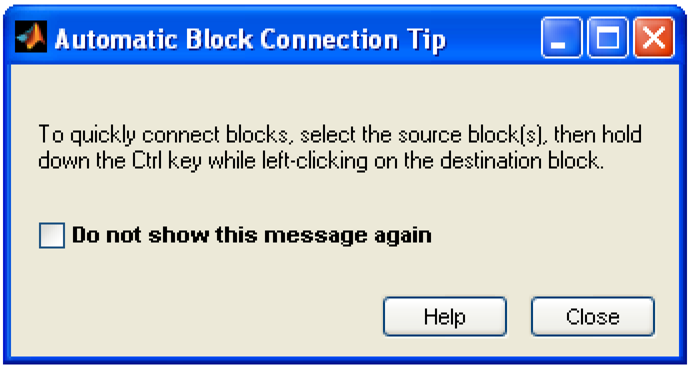
When holding the mouse over an input or an output the mouse change to the following symbol.



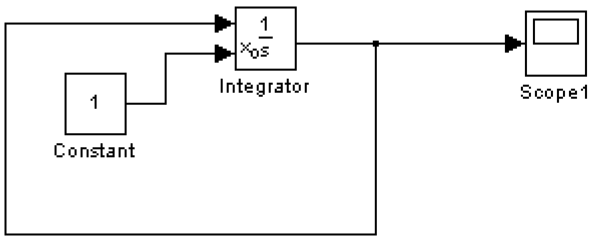
Draw a wire between the output on the Constant block to the lower input in the Integrator block, like this:



You could also do like this:

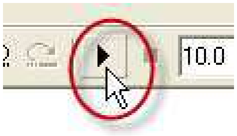


Wire the rest of the blocks together and you will get the following diagram:



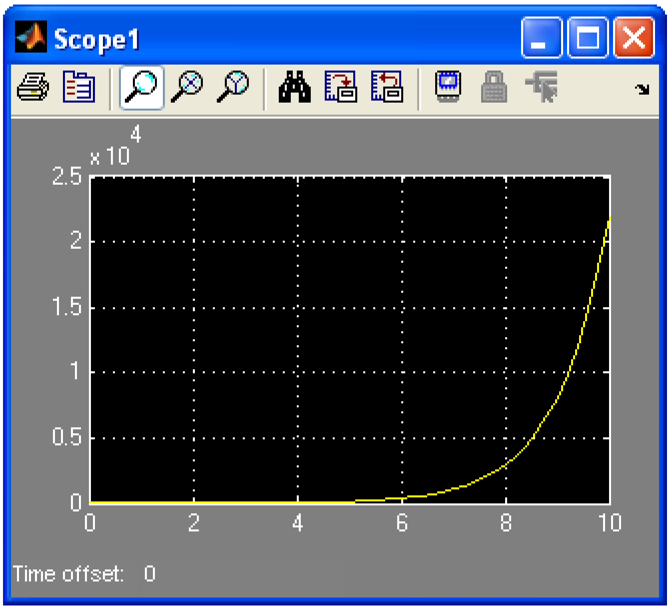
Step 4: Simulation

Start the simulation by clicking the “Start Simulation” icon in the Toolbar:



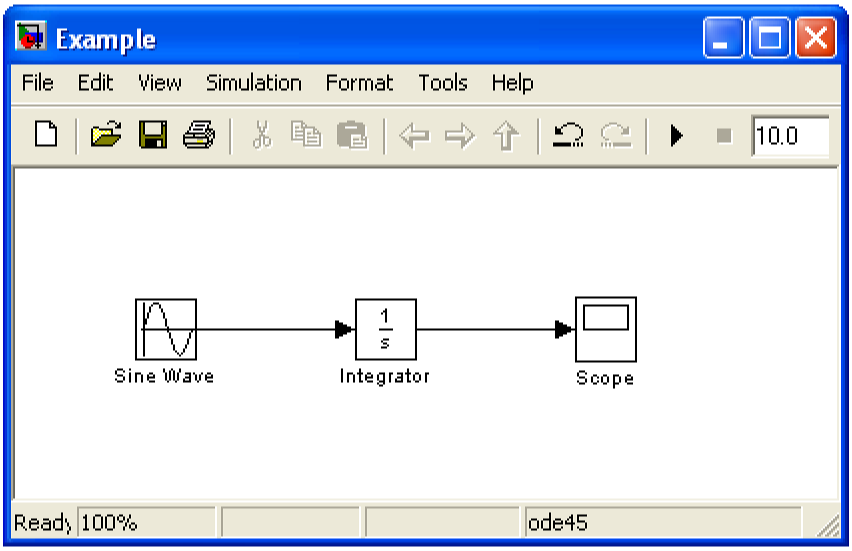
Step 5: The Results

Double-click in the Scope block in order to see the simulated result:

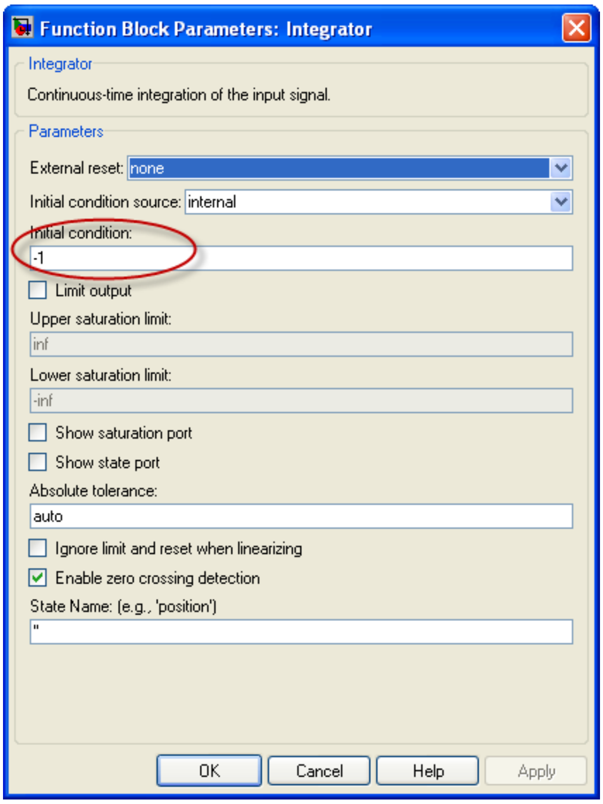


Example: Sine Wave

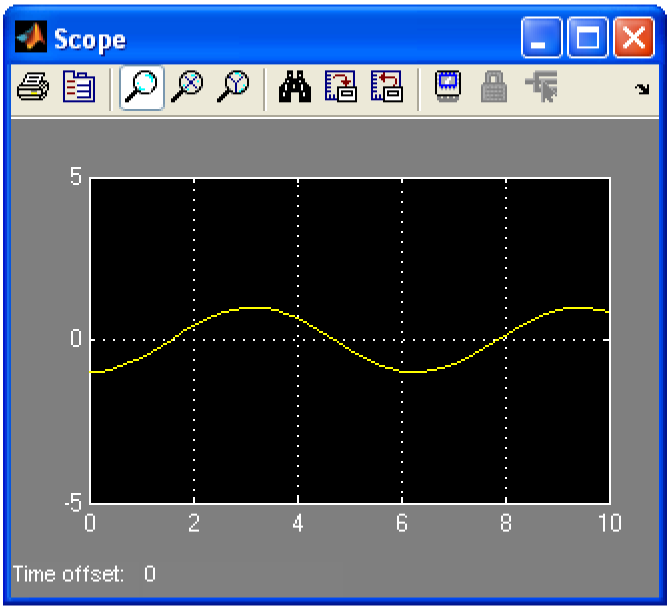
Create the block diagram as shown below:



Set the following parameter for the Integrator block:

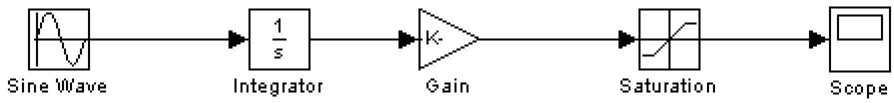


The result should be like this:

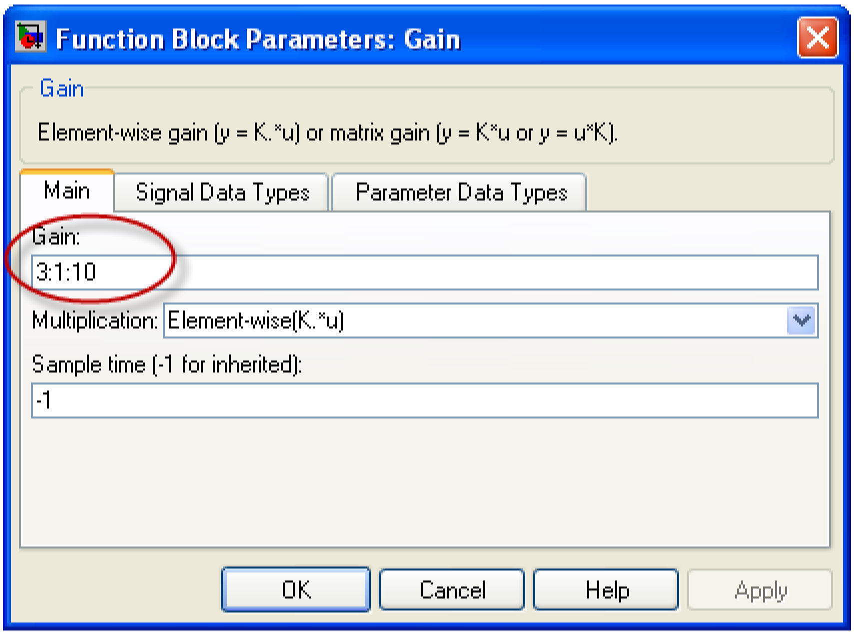


Example: Using vectors

Create the following block diagram:

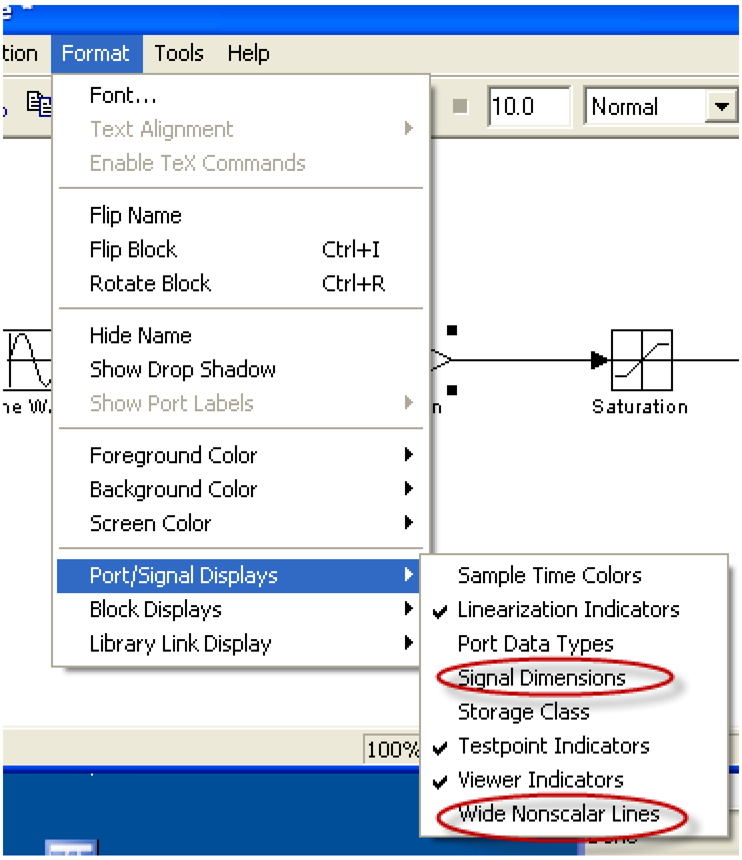


For the Gain block, type the following parameters:

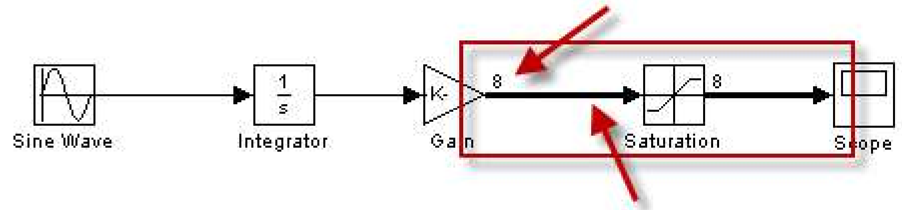


As you see, we can use standard MATLAB syntax to create a vector.

If you want to see the signal dimensions, select "Signal Dimensions" and "Wide Nonscalar Lines" as shown here:

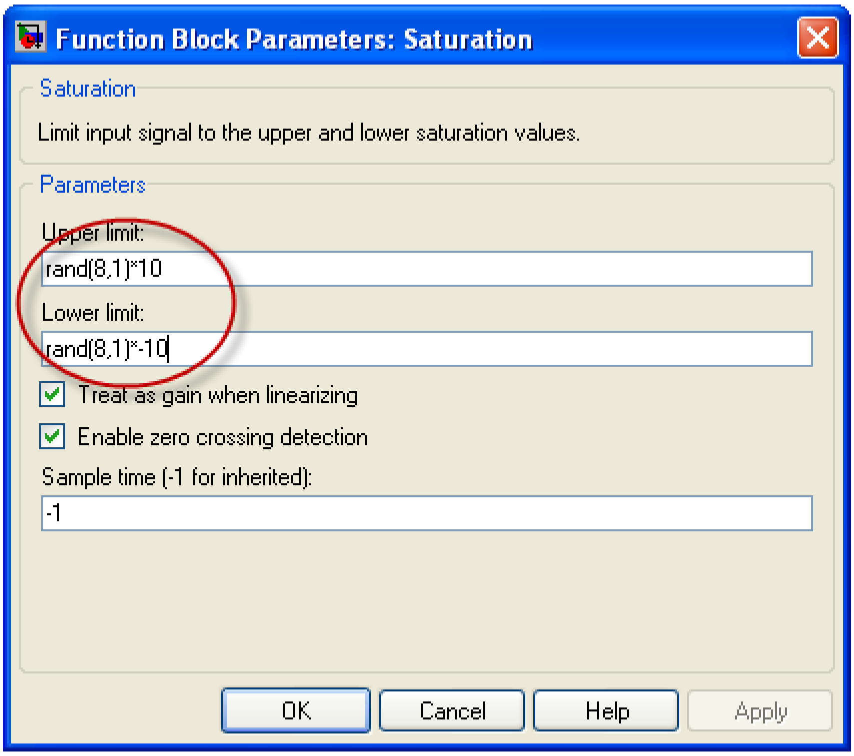


The block diagram should now look like this:



The thick lines indicate vectors, while the number (8) is the size of the vector.

Let's change the Saturation block:



As you see you may use standard MATLAB functions and syntax.

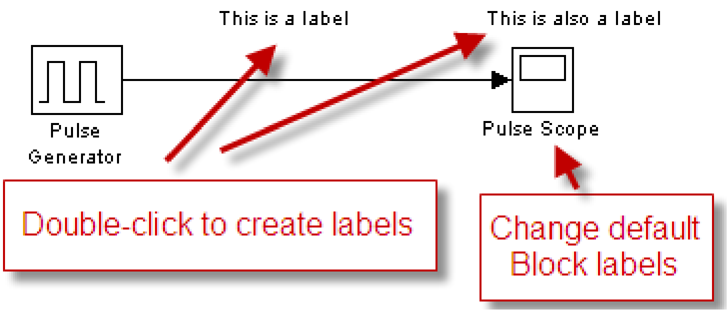
Run the simulation and see the results in the Scope block.

3 Useful Features

You should know about these features in Simulink in order to take full advantage of Simulink.

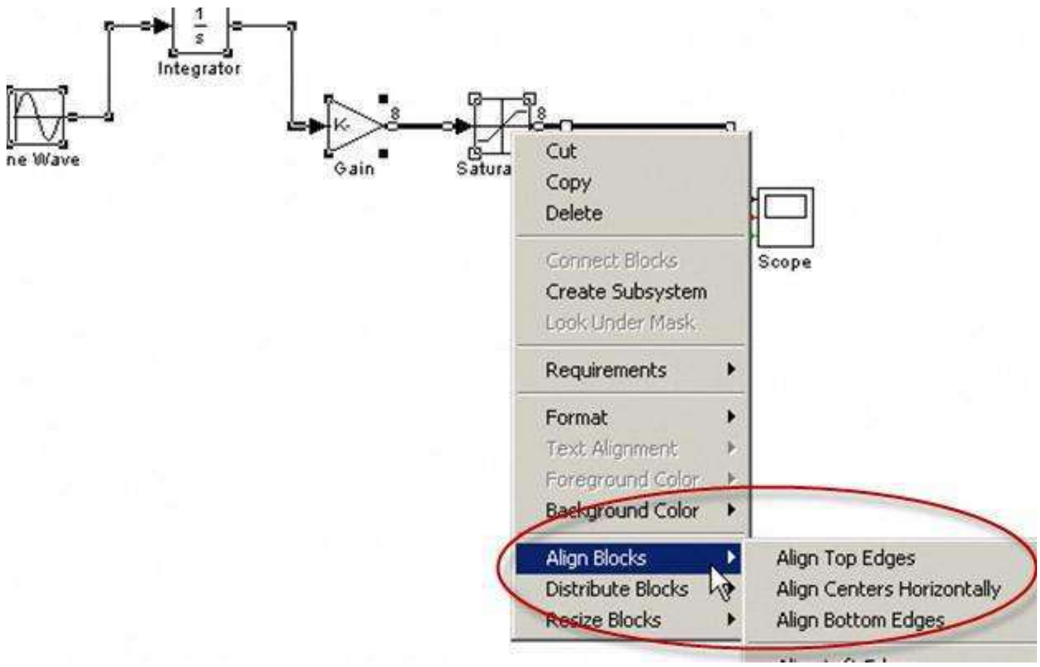
3.1 Comments/Labels

Double-click on your surface in order to write Labels or Comments in your model block diagram.



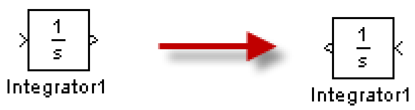
3.2 Align and Distribute Blocks

You may align your blocks:

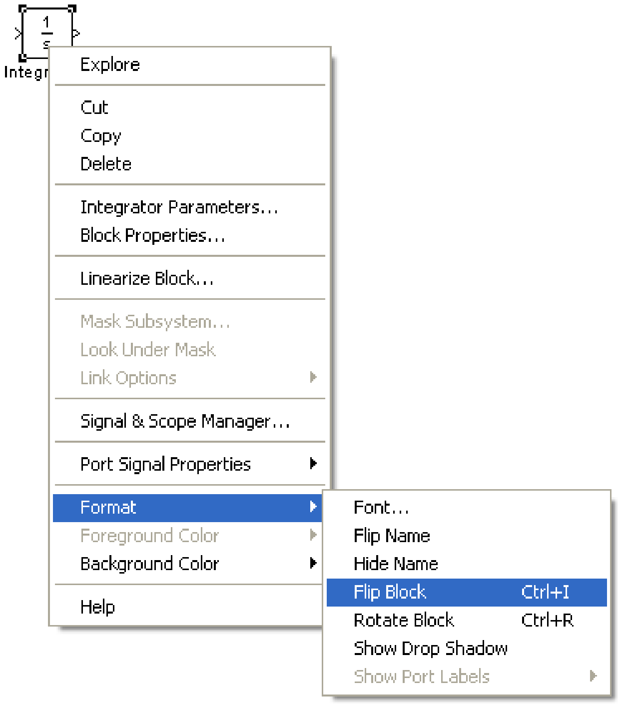


3.3 Flip Blocks

Normally the inputs are on the left and the outputs on the right, but in some cases it is convenient to have the inputs on the right and output on the left side.



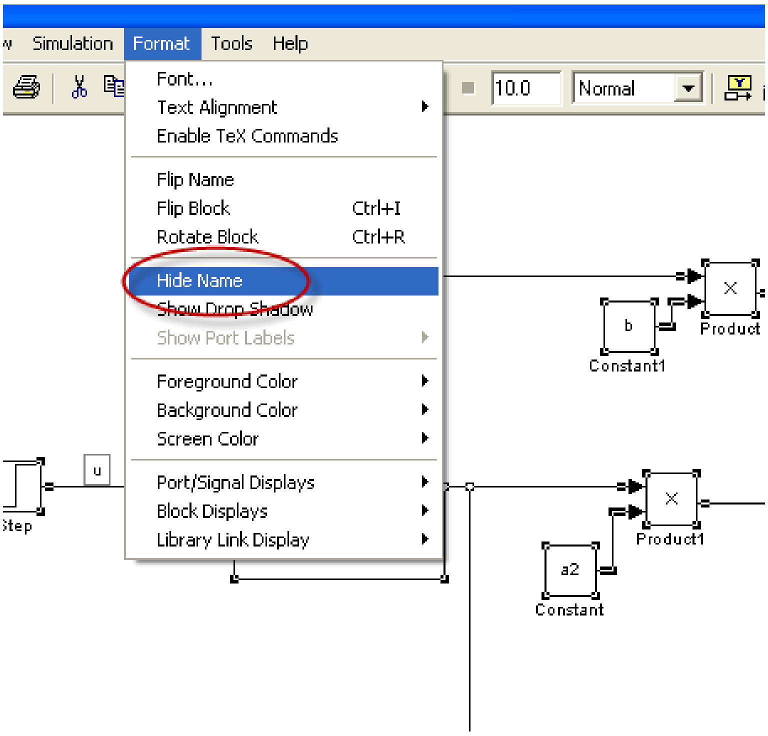
In order to "flip" the input and outputs right-click on the block and select "Flip Block".



3.4 Hide Names

Hide default labels that appear on the diagram, such as Constant1, Integrator1, etc.

Select “Hide Names” on the “Format” menu:

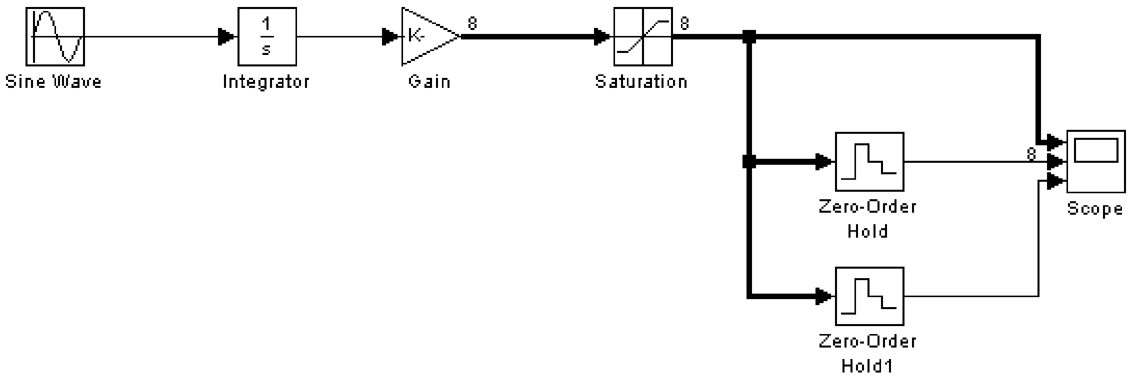

Simulation
Format
Tools
Help
10.0
Normal
Font...
Text Alignment
Enable TeX Commands
Flip Name
Flip Block Ctrl+I
Rotate Block Ctrl+R
Hide Name
Show Drop Shadow
Show Port Labels
Foreground Color
Background Color
Screen Color
Port/Signal Displays
Block Displays
Library Link Display
b
Constant1
Product
u
Product1
a2
Constant

4 Data-driven Modelling

You may use Simulink together with MATLAB in order to specify data and parameters to your Simulink model. You may specify commands in the MATLAB Command Window or as commands in an m-file. This is called data-driven modeling.

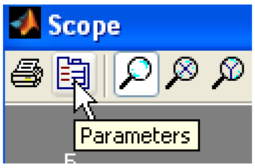
4.1 Command window

Example:

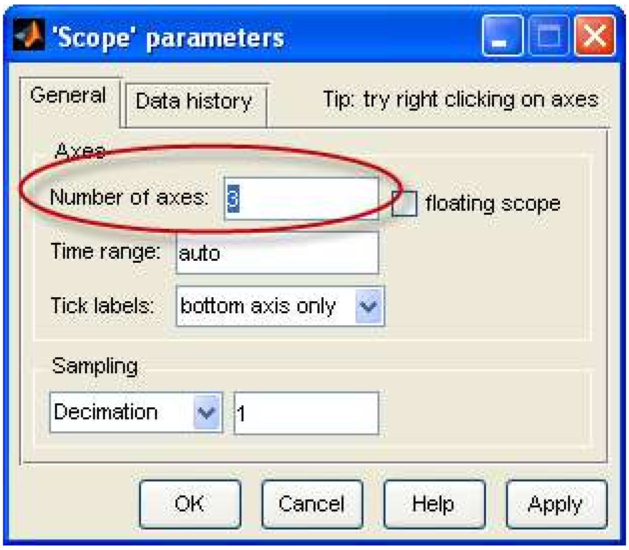


Note! In order to get 3 inputs on the Scope block:

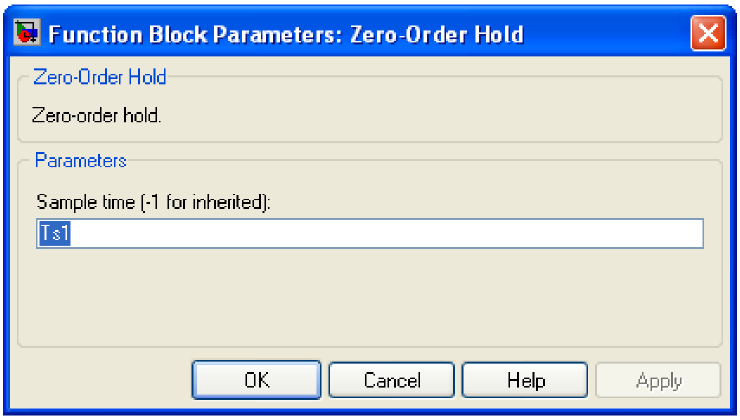
Double-click on the Scope and select the Parameters icon in the Toolbar:

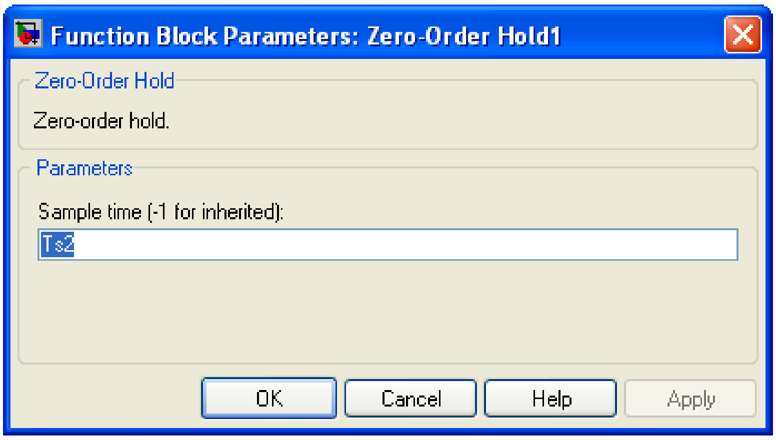


Then select Number of Axes=3:

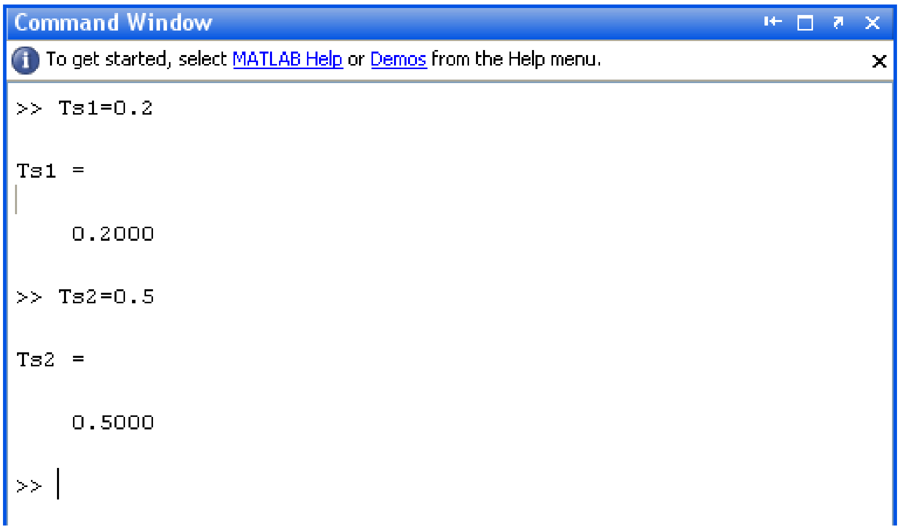


Configure the zero-order hold blocks like this:

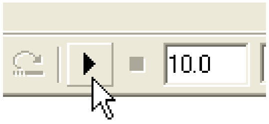




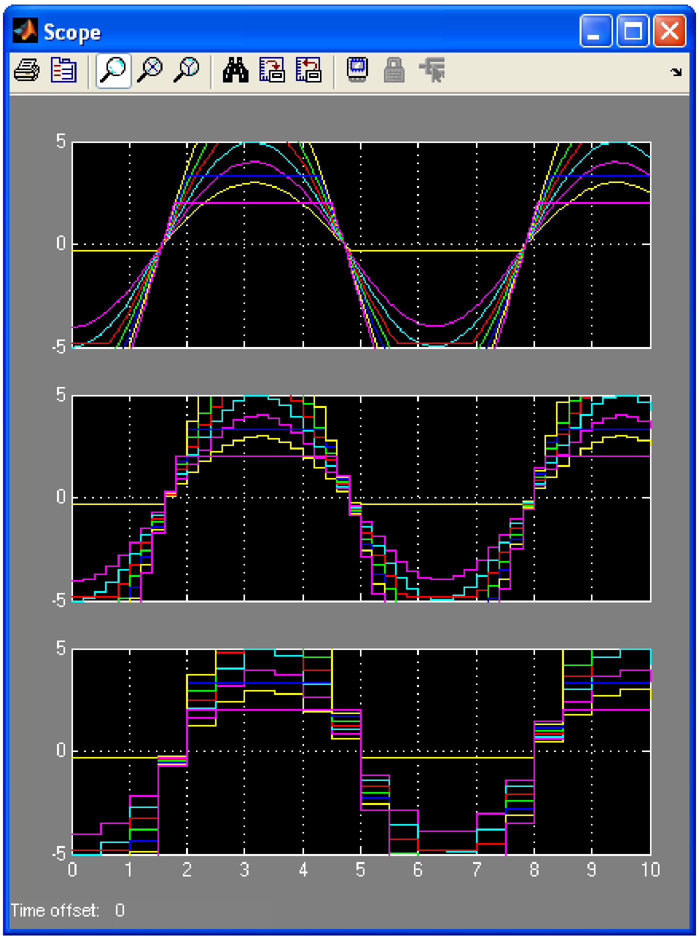
Write the following in the **Command window** in MATLAB:



Run the Simulink model from the Simulink:



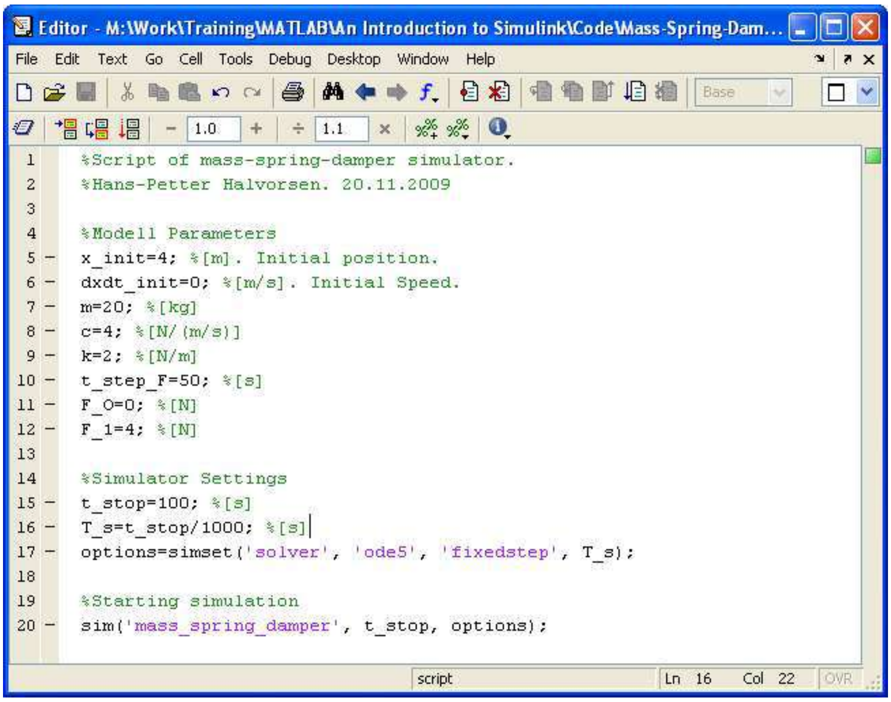
We then get the following results:



4.2 m-file

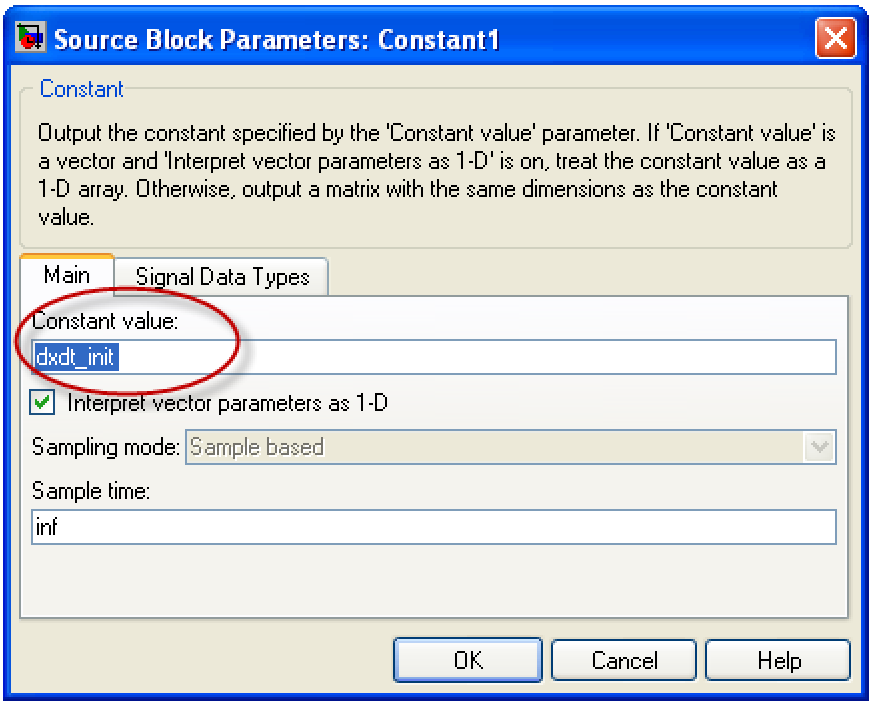
It is good practice to build your in Simulink and configure and run the simulation from a MATLAB m-file.

A Typical m-file could look like this:



You use the **simset** command to configure your simulation parameters and the **sim** command to run the simulation.

The variables you refer to in the m-file is set in the Constant value field in the Parameter window for each block.



4.3 Simulation Commands

The most used command is:

- simset
- sim

Use these commands if you configure and run your Simulink model from a m-file.

Example:

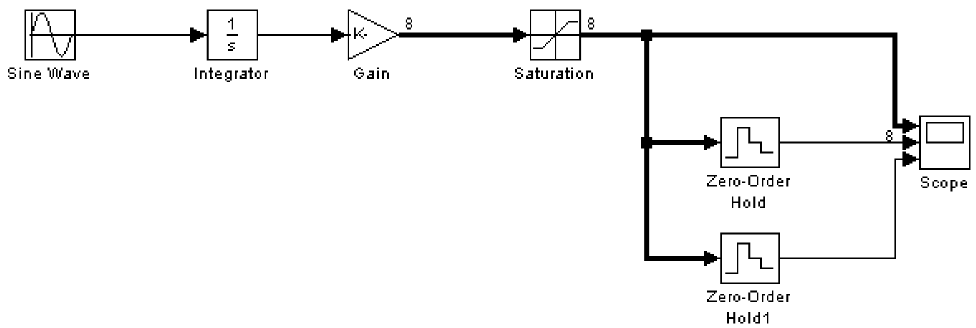
```
%Simulator Settings
t_stop=100; %[s]
T_s=t_stop/1000; %[s]
options=simset('solver', 'ode5', 'fixedstep', T_s);

%Starting simulation
sim('mass_spring_damper', t_stop, options);
```

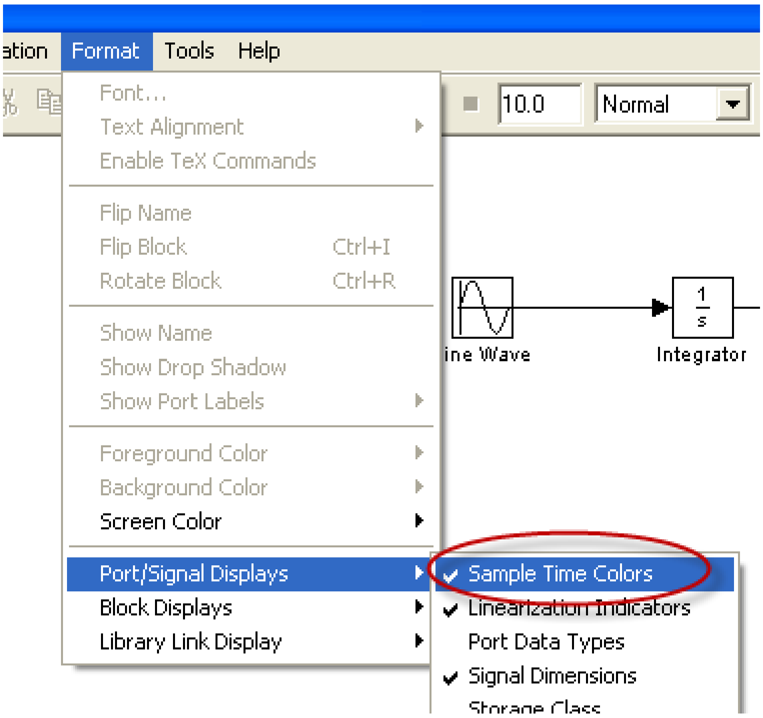
5 Hybrid Systems (continuous and discrete)

You may mix continuous blocks and discrete blocks in the same system, so-called Hybrid systems.

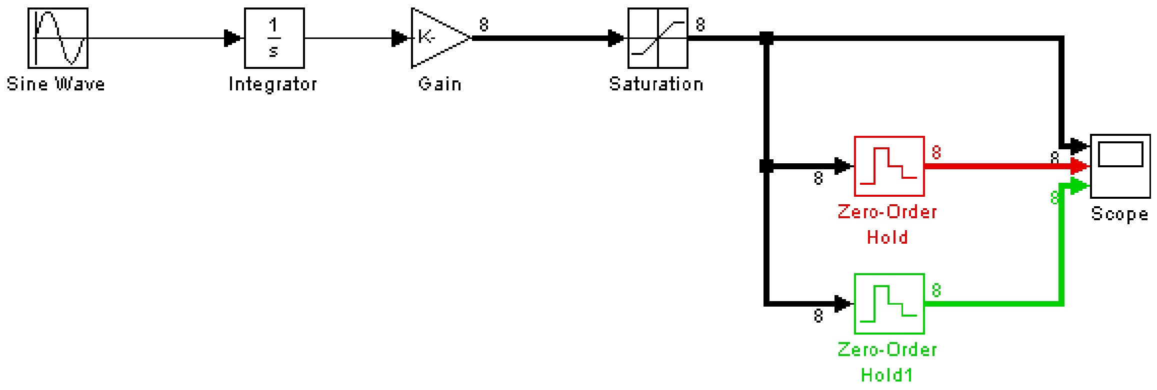
Example: Hybrid System

Create the following block diagram:





The Block diagram now looks like this:



The black color is the continuous system while the colored part (red and green) is the discrete part of the system.

6 Example: Mass-Spring-Damper System

6.1 Model

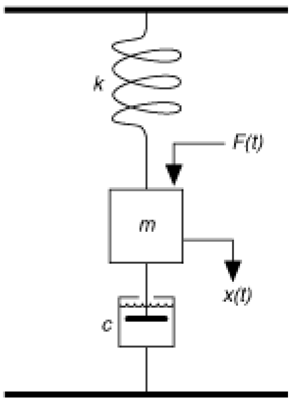
In this example we will create a mass-spring-damper model in Simulink and configure and run the simulation from a MATLAB m-file.

In this exercise you will construct a simulation diagram that represents the behavior of a dynamic system. You will simulate a spring-mass damper system.

$$F(t) - c\dot{x}(t) - kx(t) = m\ddot{x}(t)$$

where t is the simulation time, F(t) is an external force applied to the system, c is the damping constant of the spring, k is the stiffness of the spring, m is a mass, and x(t) is the position of the mass. $\dot{x}$ is the first derivative of the position, which equals the velocity of the mass. $\ddot{x}$ is the second derivative of the position, which equals the acceleration of the mass.

The following figure shows this dynamic system.



The goal is to view the position x(t) of the mass m with respect to time t. You can calculate the position by integrating the velocity of the mass. You can calculate the velocity by integrating the acceleration of the mass. If you know the force and mass, you can calculate this acceleration by using Newton's Second Law of Motion, given by the following equation:

Force = Mass × Acceleration

Therefore,

Acceleration = Force / Mass

Substituting terms from the differential equation above yields the following equation:

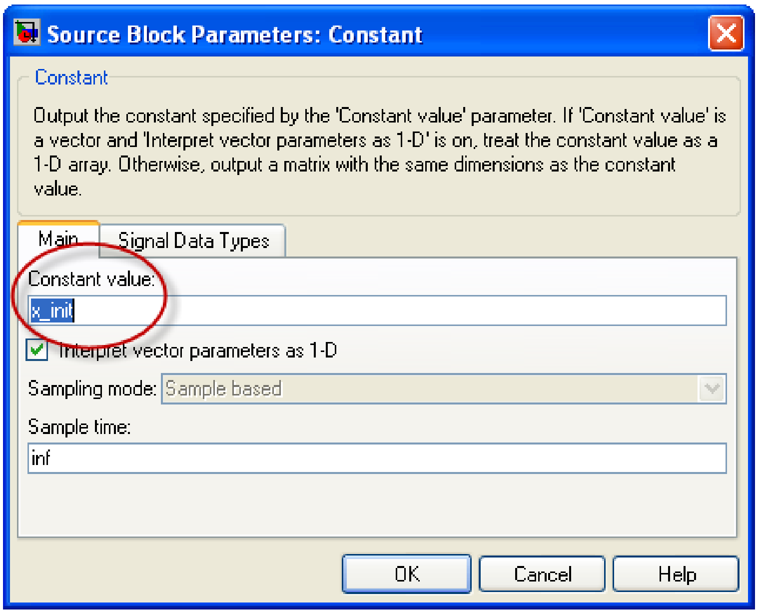
$$\ddot{x} = \frac{1}{m}(F - c\dot{x} - kx)$$

You will construct a simulation diagram that iterates the following steps over a period of time.

6.2 Simulink

Create the block diagram for the mass-spring-damper model above.

Instead of hard-coding the model parameters in the blocks you should refer to them as variables set in an m-file.



These variables should be configured:

- x_init

- dxdt_init
- m=
- c=
- k
- t_step_F
- F_O
- F_1

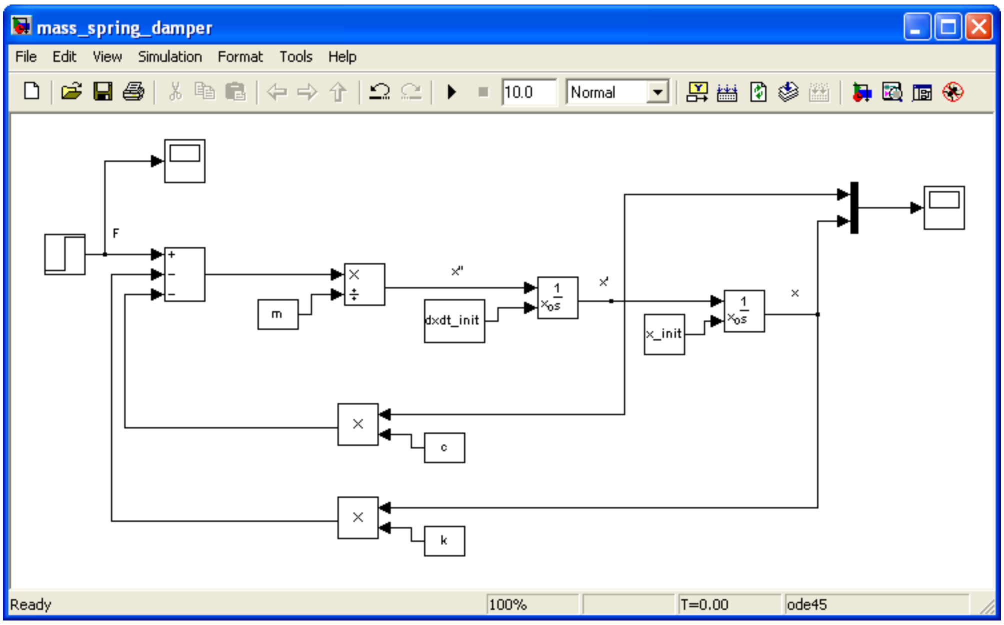
6.3 m-File

The following variables should then be set in the m-file:

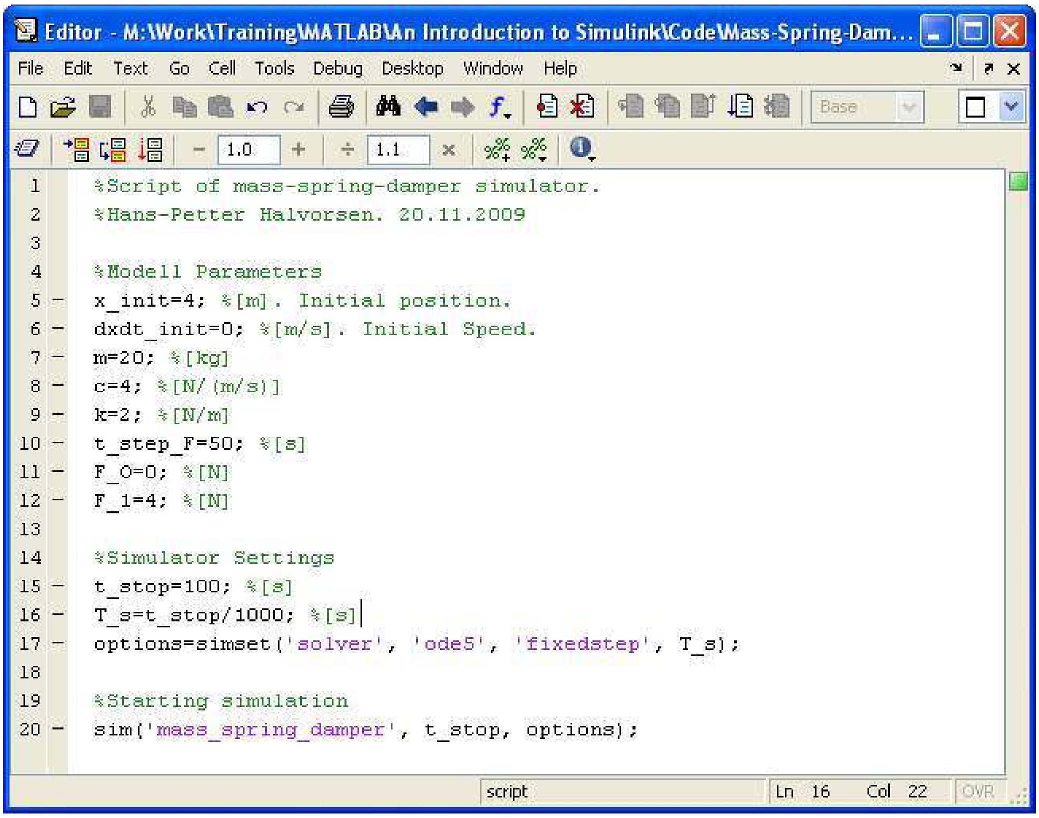
```
x_init=4; %[m]. Initial position.
dxdt_init=0; %[m/s]. Initial Speed.
m=20; %[kg]
c=4; %[N/(m/s)]
k=2; %[N/m]
t_step_F=50; %[s]
F_O=0; %[N]
F_1=4; %[N]
```

6.4 Results

The Block Diagram should look something like this:

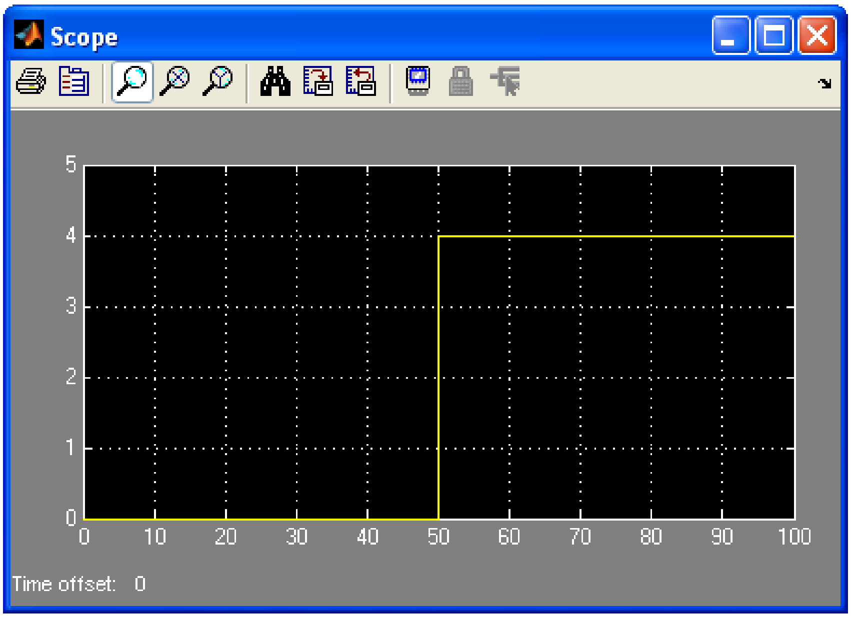


The m-File should look something like this:

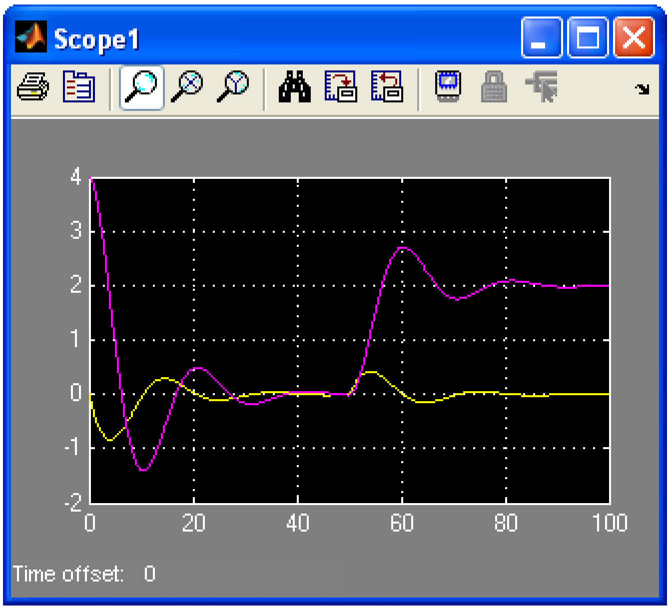


Graphs:

Force F



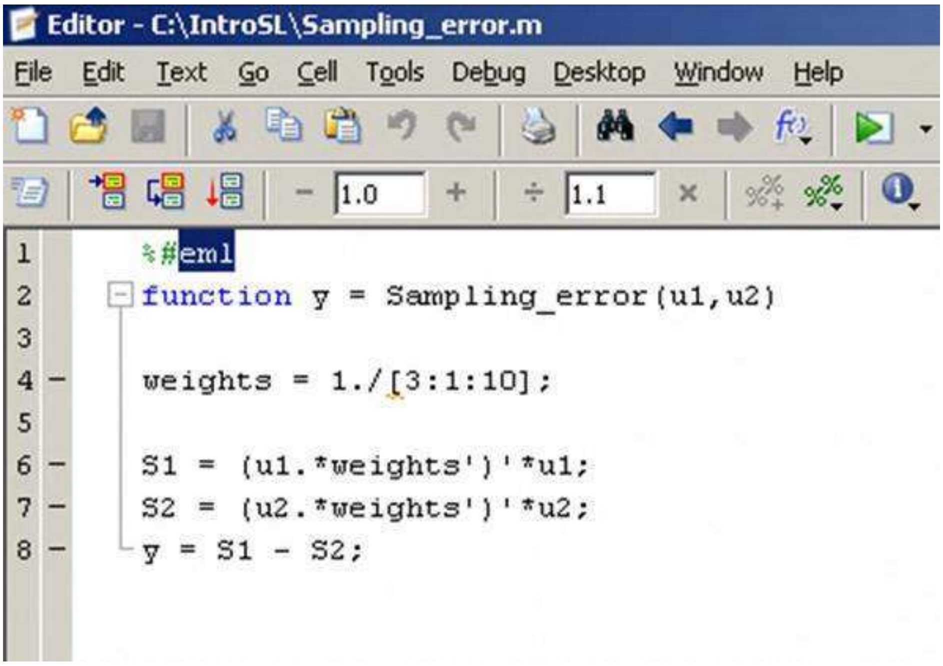
Position x and speed $\dot{x}$:

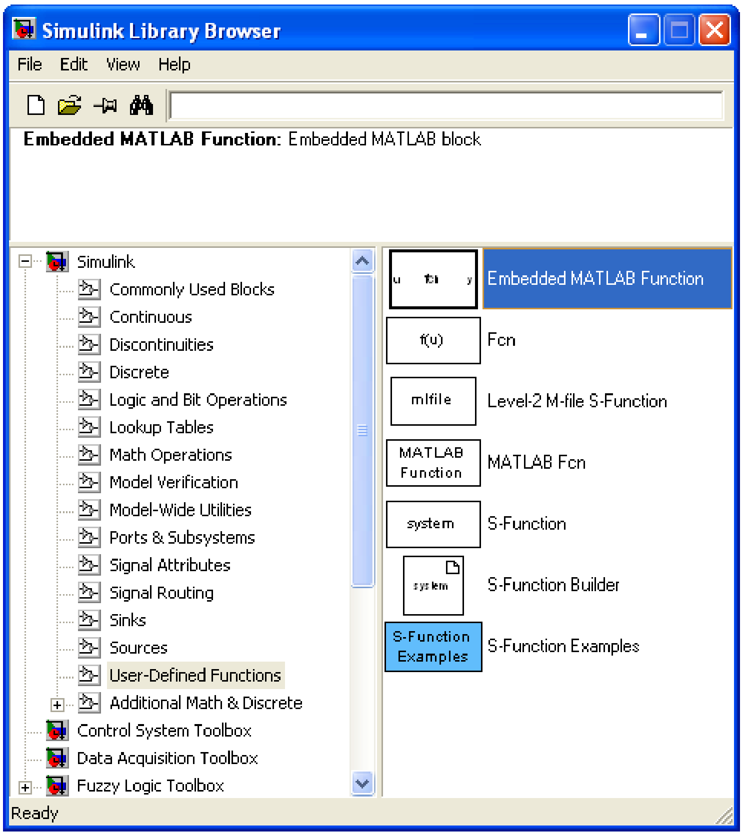

Scope1
4
3
2
1
0
-1
-2
0
20
40
60
80
100
Time offset: 0

7 Embedded Algorithms

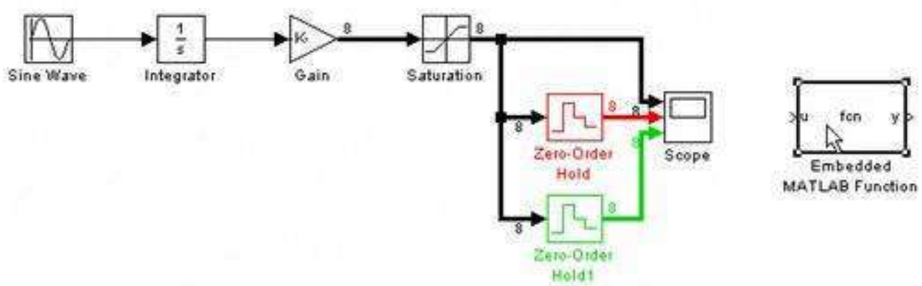
This chapter explains how you incorporate an existing MATLAB function into your Simulink model.

Make sure your MATLAB function is compiled as an embedded MATLAB function using the #eml directive, e.g.:

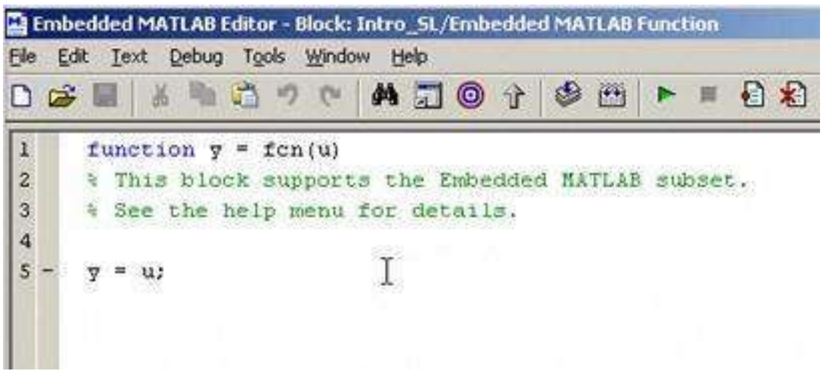




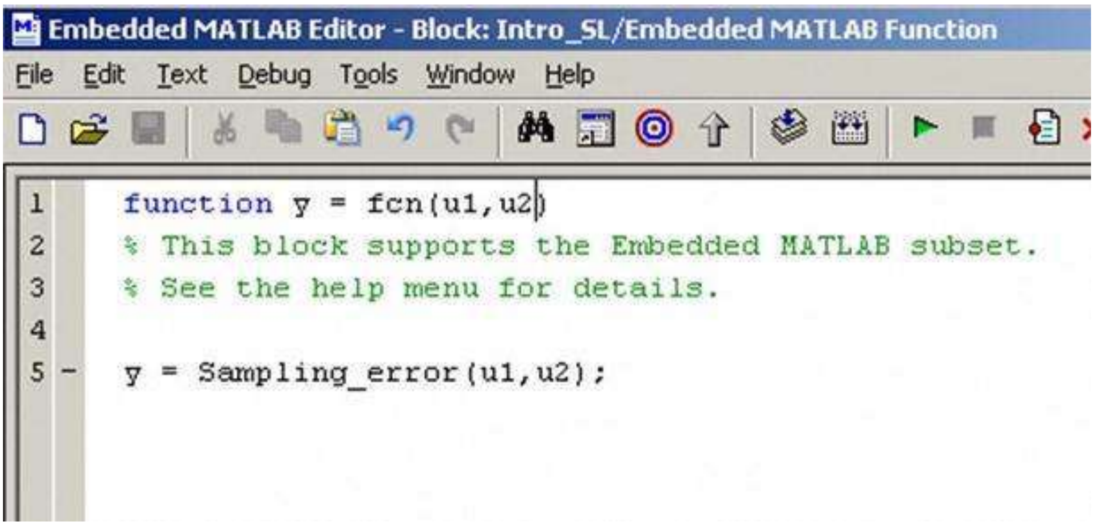
Drag in the Embedded MATLAB function:



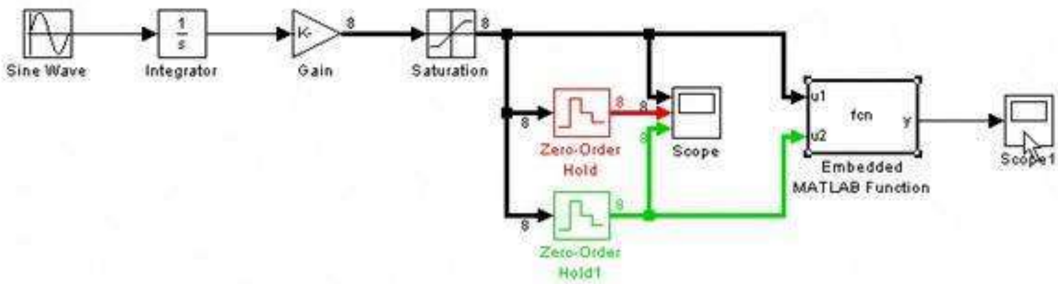
Double-click on the Embedded MATLAB function give us the standard template for an embedded function:



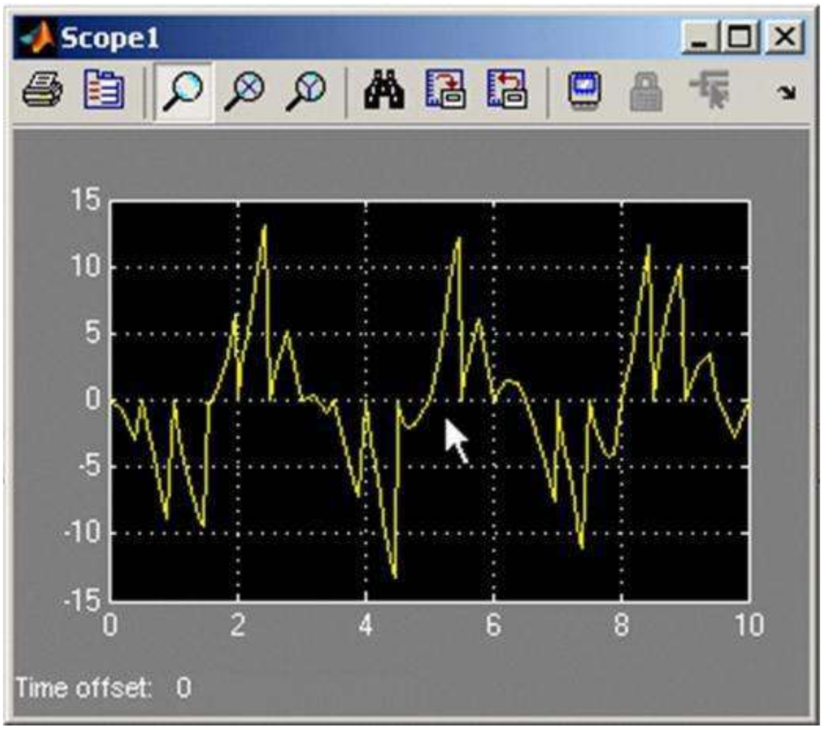
Modify the template so it calls your MATLAB function:



Wire the system like this:



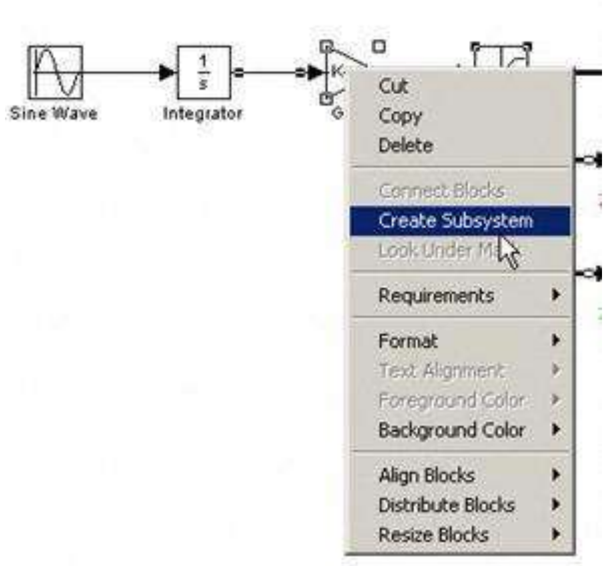
Run the Simulation:


Scope1
15
10
5
0
-5
-10
-15
0
2
4
6
8
10
Time offset: 0

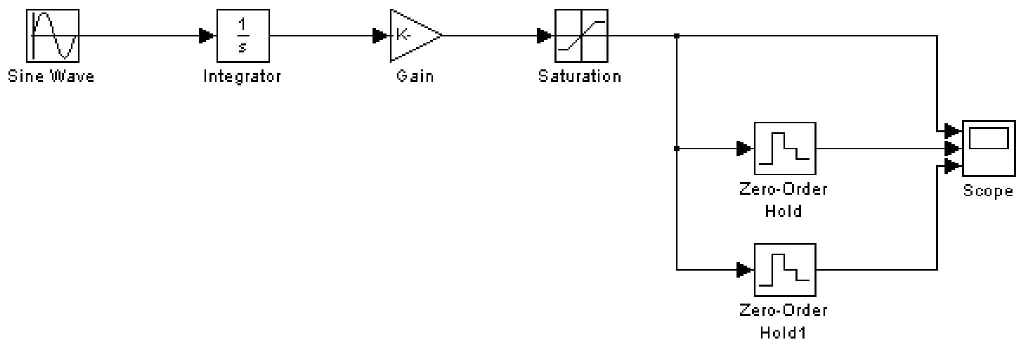
8 Subsystems

You create subsystems to create hierarchical systems and hide details in the model.

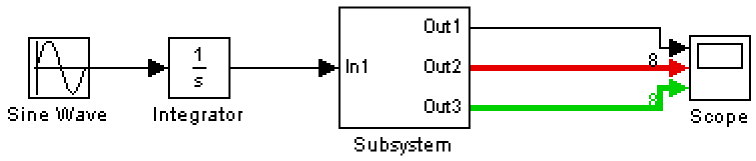
Select the part of your system from which you want to create a subsystem, right-click and select "Create Subsystem".



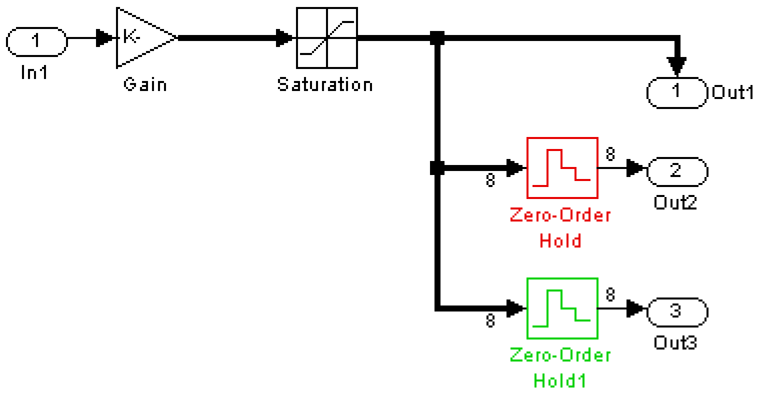
Example:



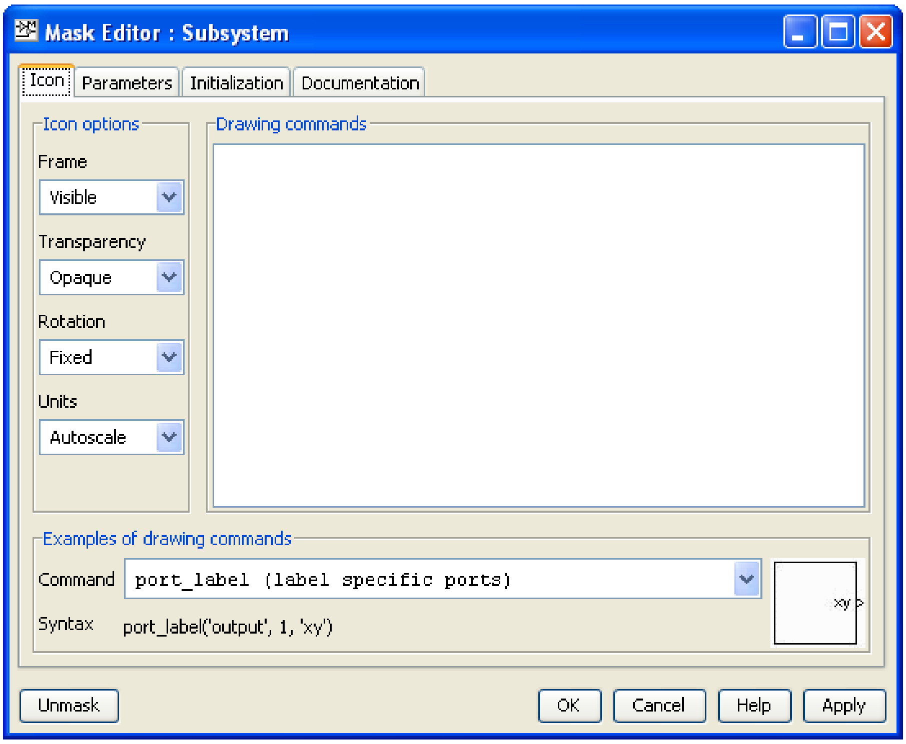
Right-click and select "Create Subsystem":



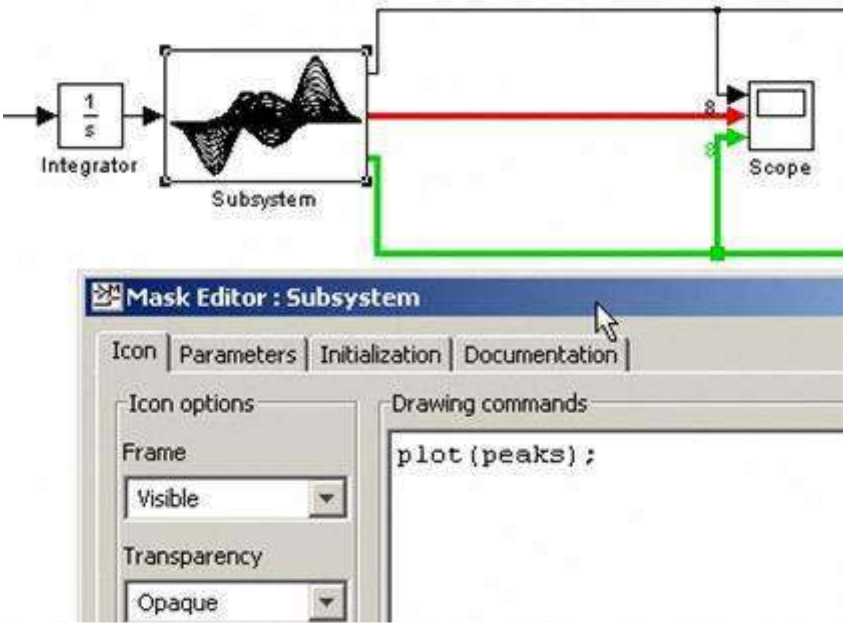
If we double-click on the subsystem we see the blocks in the subsystem:



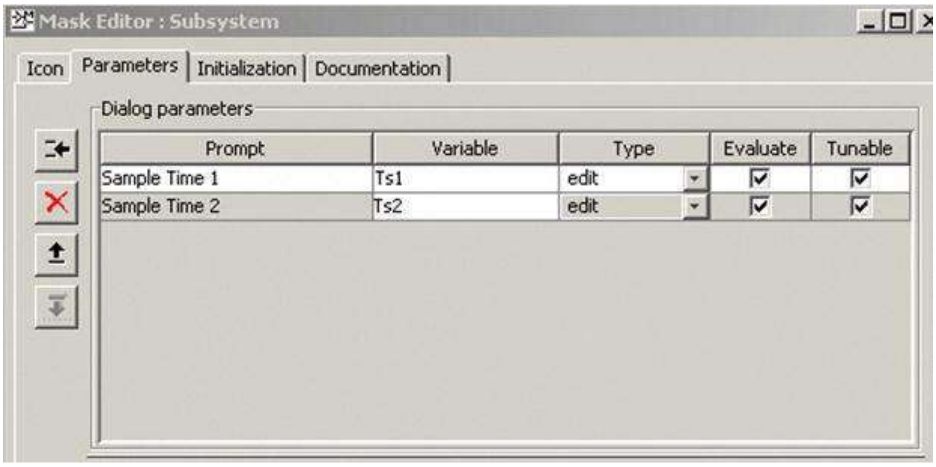
Right-click on the block and select "Edit Mask" in order to open the Mask Editor:



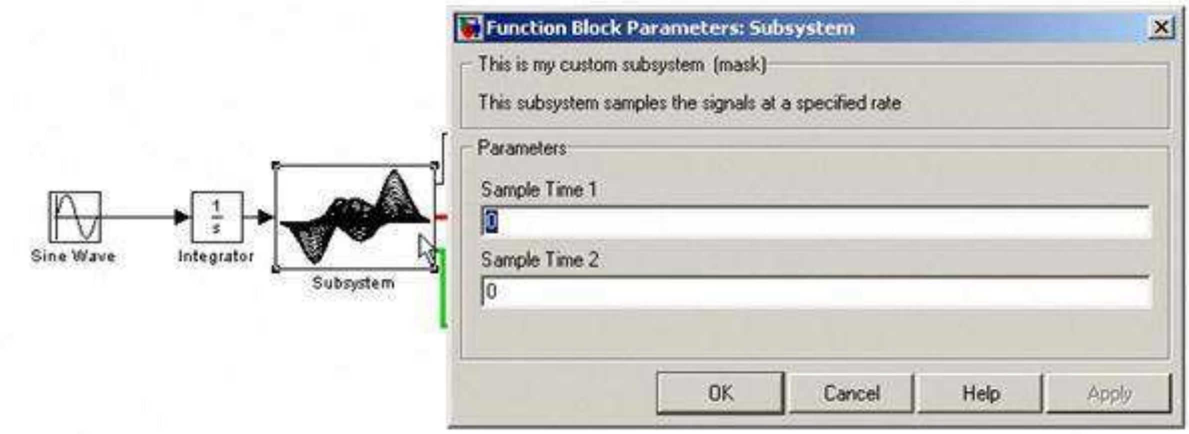
The Mask Editor allows you to change how the subsystem should look, e.g., the subsystem icon.



Set Parameters for the subsystem:



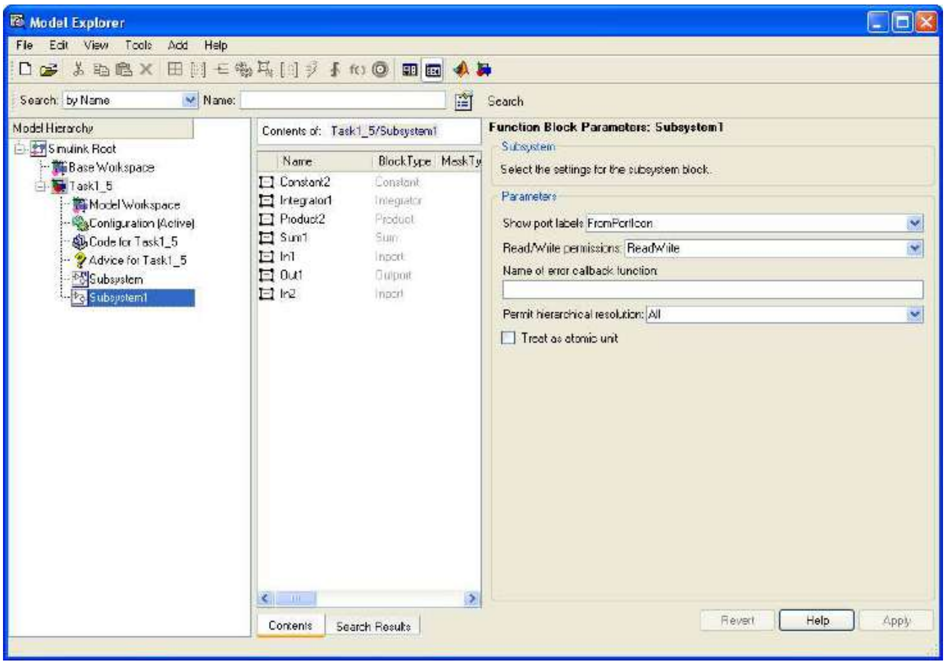
Double click on the sub system now gives the Parameter window for the subsystem:


Function Block Parameters: Subsystem
This is my custom subsystem (mask)
This subsystem samples the signals at a specified rate
Parameters
Sample Time 1
0
Sample Time 2
0
OK
Cancel
Help
Apply
Sine Wave
Integrator
1
s
Subsystem

9 Model Explorer

The Model Explorer allows you to quickly locate, view, and change elements of a Simulink model or Stateflow chart.

To display the Model Explorer, select Model Explorer from the Simulink View menu.

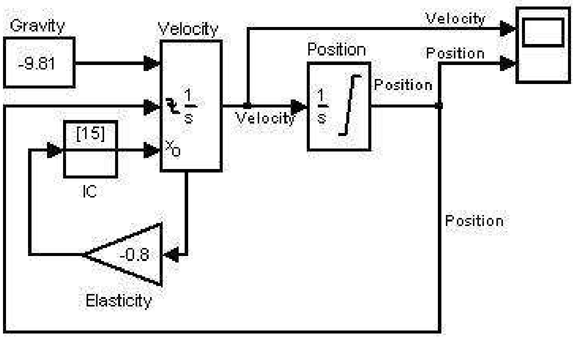


10 Exercises

In this chapter we provide more exercises.

Exercise:

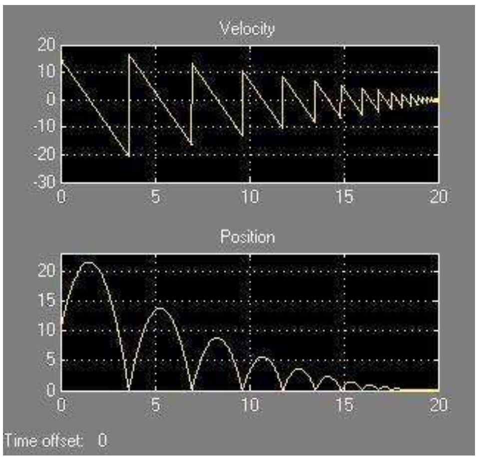
Build the following block diagram:



In this exercise we will model a rubber ball that is thrown in the air with an initial velocity of 15 m/s from a height of 10 m. We will model the dynamics of the ball as it bounces, under the influence of gravity. We will assume that 20% of the energy is lost on each bounce. (That is, after each impact, the ball will travel at 80% of its prior velocity, but in the opposite direction.)

We can model this example by integrating g (g = -9.81m/s^2) over time with the initial condition set to 15 m/s. We reset the integrator each time the position reaches zero meters and set the new initial condition to -80% of the impact velocity. Position is modeled by integrating the velocity over time with the initial condition set to 10m/s.

The result should be:



Watch this video to see the result:
http://www.mathworks.com/products/demos/simulink/Simulink_Key_Features/videos/building.html

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