

Simulink® Tutorial 1

Simulation of a temperature measuring system

1. Aims

- To use Simulink as a simulation and diagnostic tool for dynamic systems
- To simulate instrumentation systems with Simulink
- To do scientific computation with Simulink

2. Learning Outcomes

Upon completion of this Tutorial you will be able to:

- Create and run a Simulink model
- Compute value of a function and display computed results with Simulink
- Use blocks in Simulink Library Browser
- Configure system parameters
- Configure simulation parameters
- Store simulated data to Workspace and save Workspace to files

3. Hands-on Exercises

Hands-on Exercise 1: Create and Run a simple Simulink model

Statement of Problem

Create a Simulink model to simulate a signal that have the following form:

$$y = 2 + 3 \sin(\omega t + \pi/2) \quad (t = 0 \text{ to } 10, \omega = 2 \text{ rad/s}) \quad (1)$$

In the Simulink simulation program, do the following:

- Compute value of y vs t (from 0 to 10 seconds)
- Display value of y (with digital display and graph)
- Save data to Workspace

SOLUTION

Block diagram algorithm:

Block diagram algorithm for function (1) is given in **Fig. 1**.

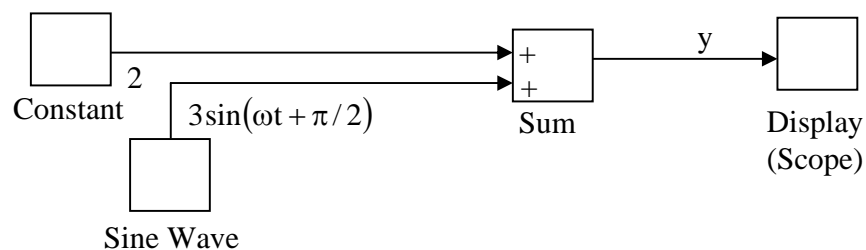


Figure 1 Block diagram algorithm for equation (1)

Create a Simulink model:

Do the following steps:

- Start Simulink
- Open a new model – Save the Simulink model as MyFirstSimTute01Ex01.mdl
- Select a Constant block (Sources)
- Select a Sine Wave block (Sources)
- Select a Sum block (Math Operations)
- Select a Clock block (Sources)
- Select a Display (Sinks)
- Copy Display to Display 1
- Select a Scope (Sinks). The Simulink model should look like the one in **Fig. 2**.
- Save the Simulink model.
- Connect/wire blocks as shown in **Fig. 3**.

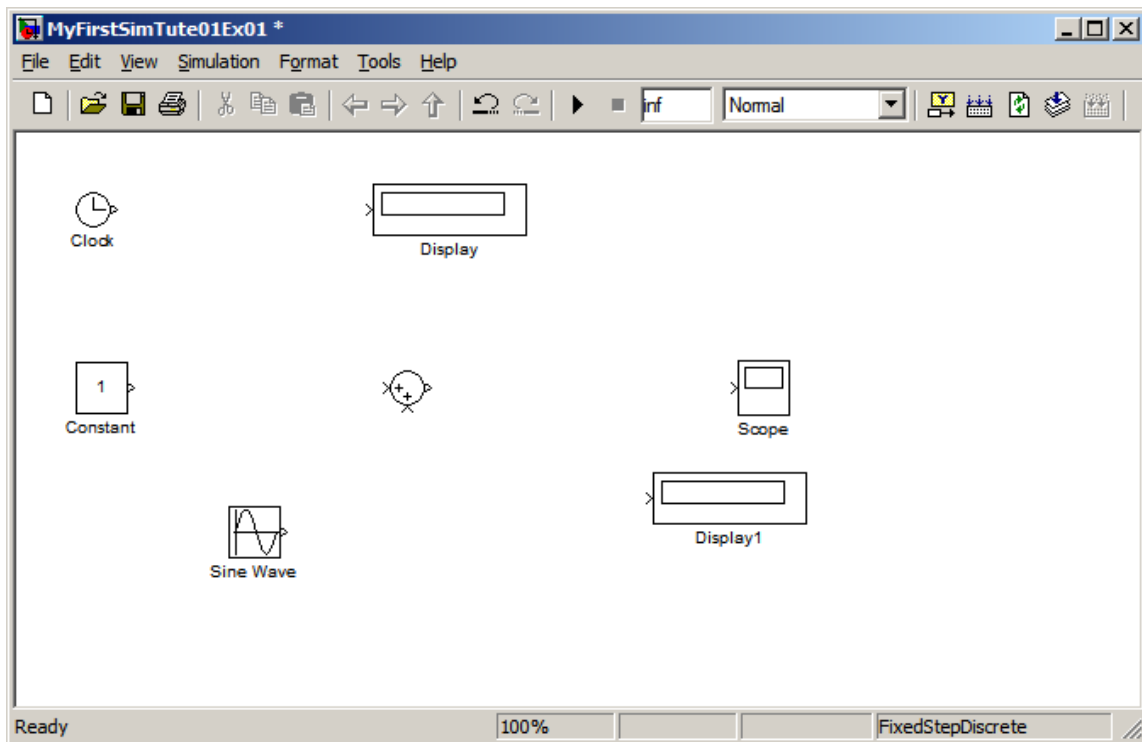


Figure 2 Start a simple Simulink model

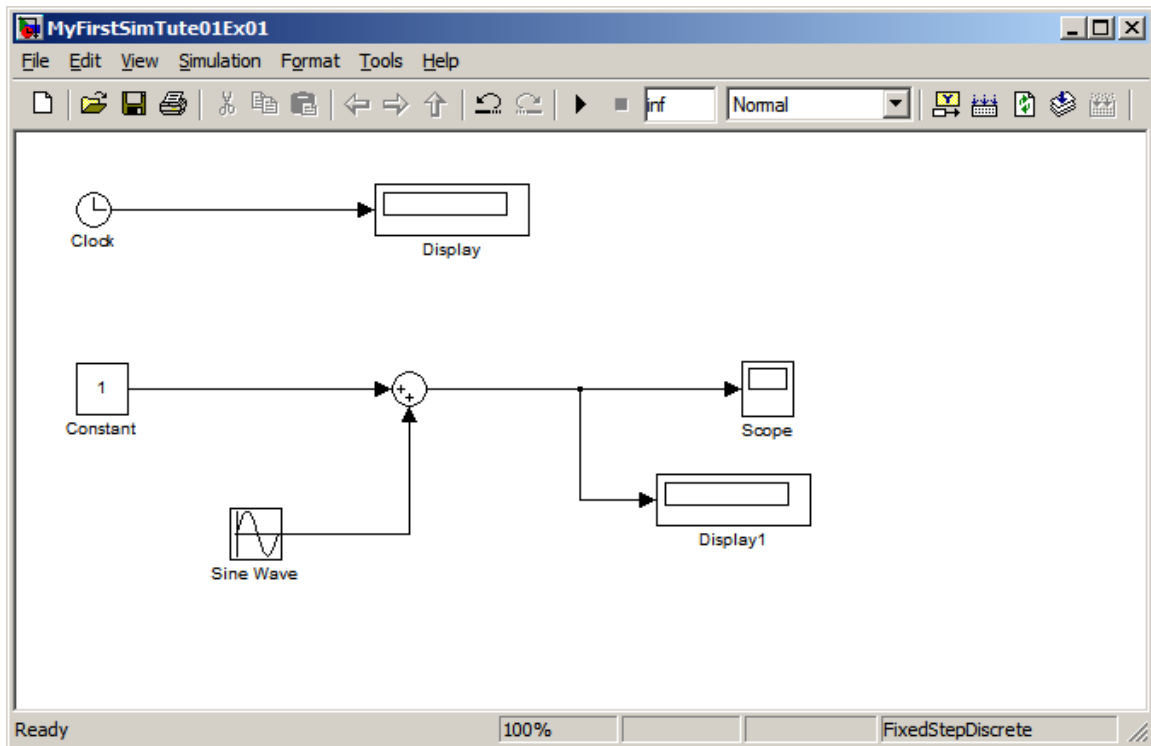


Figure 3 The Simulink model 'MyFirstSimTute01Ex01.mdl'

System Parameters:

- Double-click the Constant, change the Constant value to 2 as shown in **Fig. 4**.
- Click the OK button.

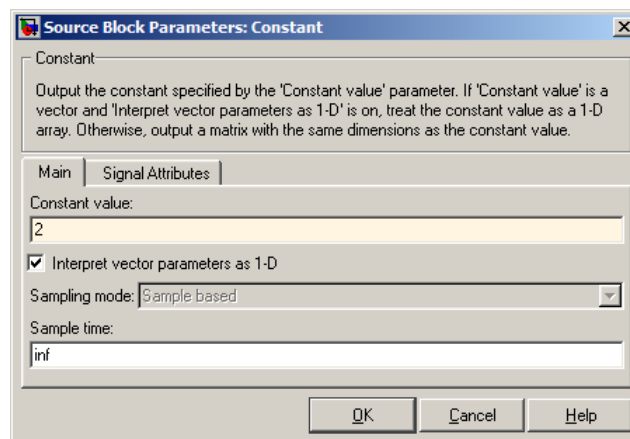


Figure 4 Change parameter of the Constant block

- Double-click the SineWave block, do some changes as shown in **Fig. 5**.
- Click OK button.

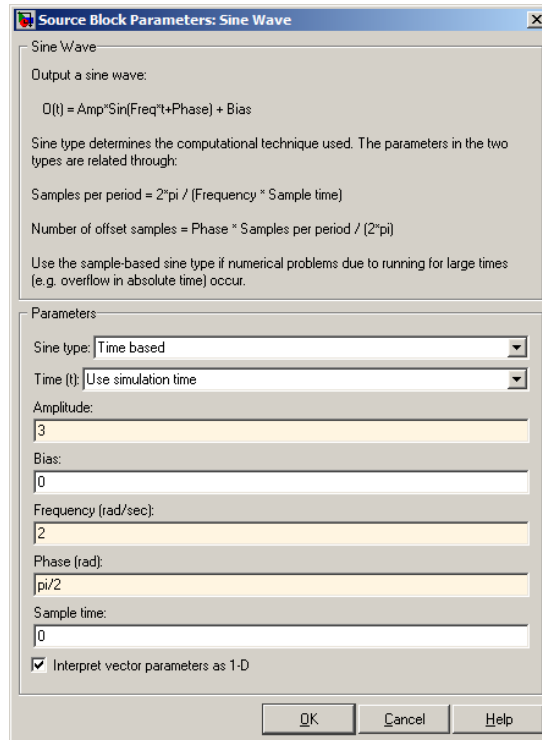


Figure 5 Settings of sine wave signal

Configuration of Simulation Parameters:

- Before running the Simulink model, we need to set simulation parameters by selecting the Simulation menu → Configuration Parameters:

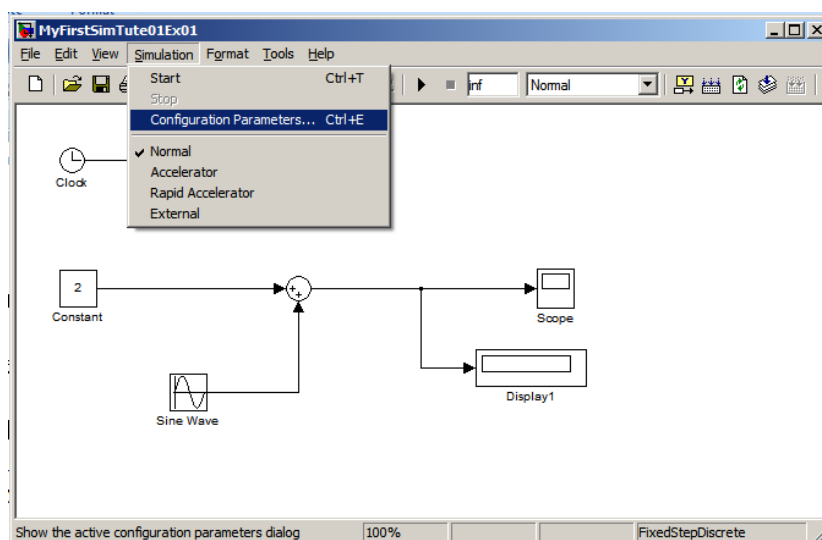


Figure 6 Simulation menu > Configuration Parameters...

The Configurations dialog box will appear as shown in **Fig. 7**. In this dialog box we can set some parameters such as Start time 0.0, Stop time: 10.0 (seconds), and Solver: ode45. Click OK button. The Simulink model is ready to run.

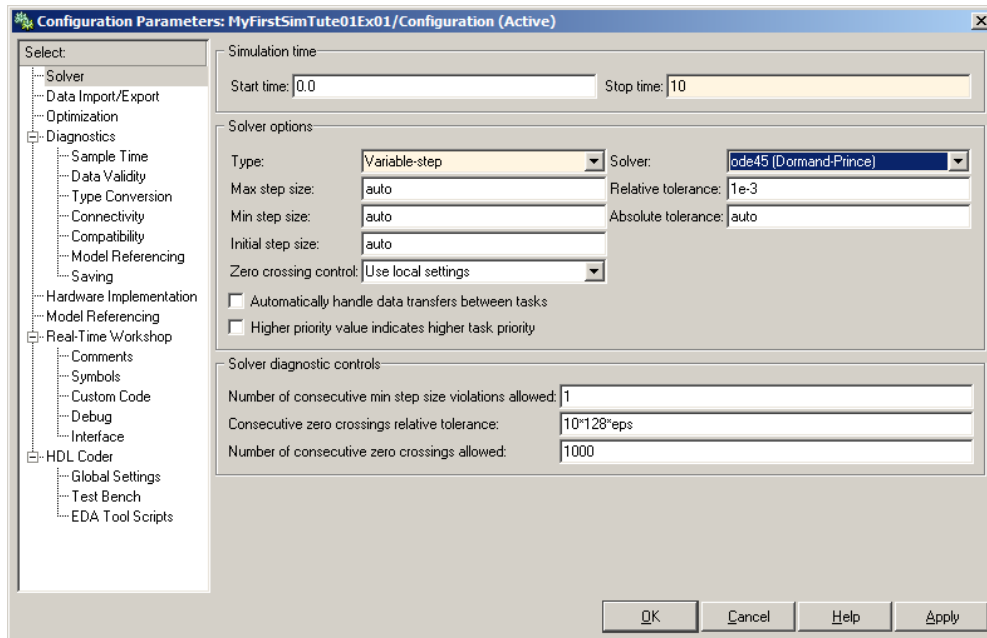



Figure 7 Configuration Parameter dialog box

Run Simulink model:

- Double the Scope block and move it to a desired position on the screen.
- Run the Simulink model by selecting Simulation → Start or click the  button.

The resulting Simulink model should look like...

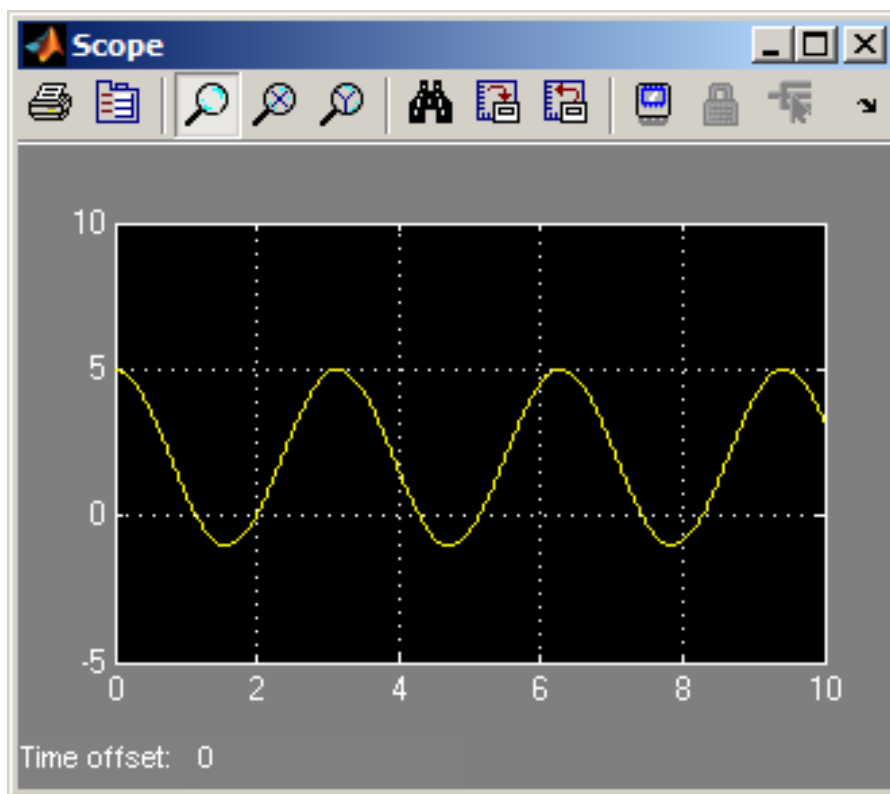
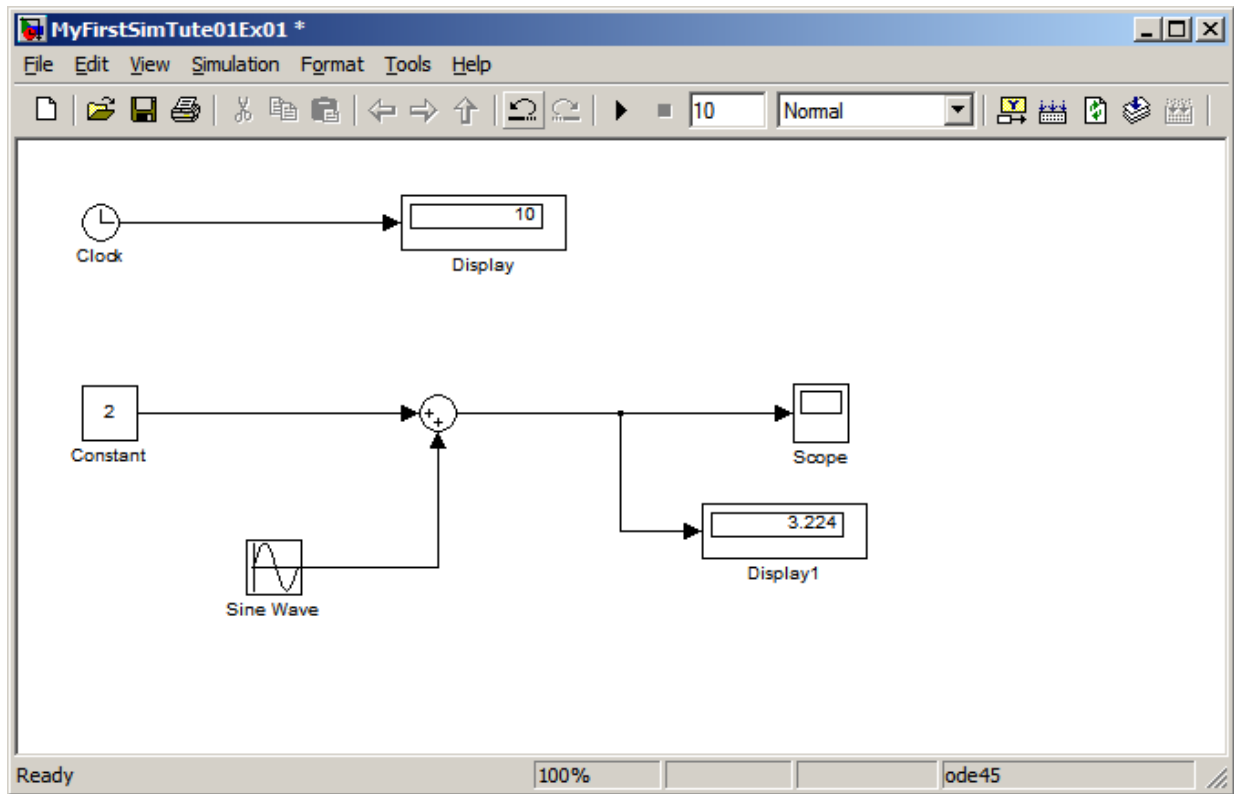


Figure 8 Resulting Simulink model

Store Data to Workspace

1. Use of To Workspace and a Mux

Simulated data (including time, t, and value of the function (1), y in a matrix)

- Launch a To Workspace block from the Simulink Library Browser > Sinks
- Launch a Mux block (from Commonly-Used Blocks)
- Wire them as shown in the following figure:

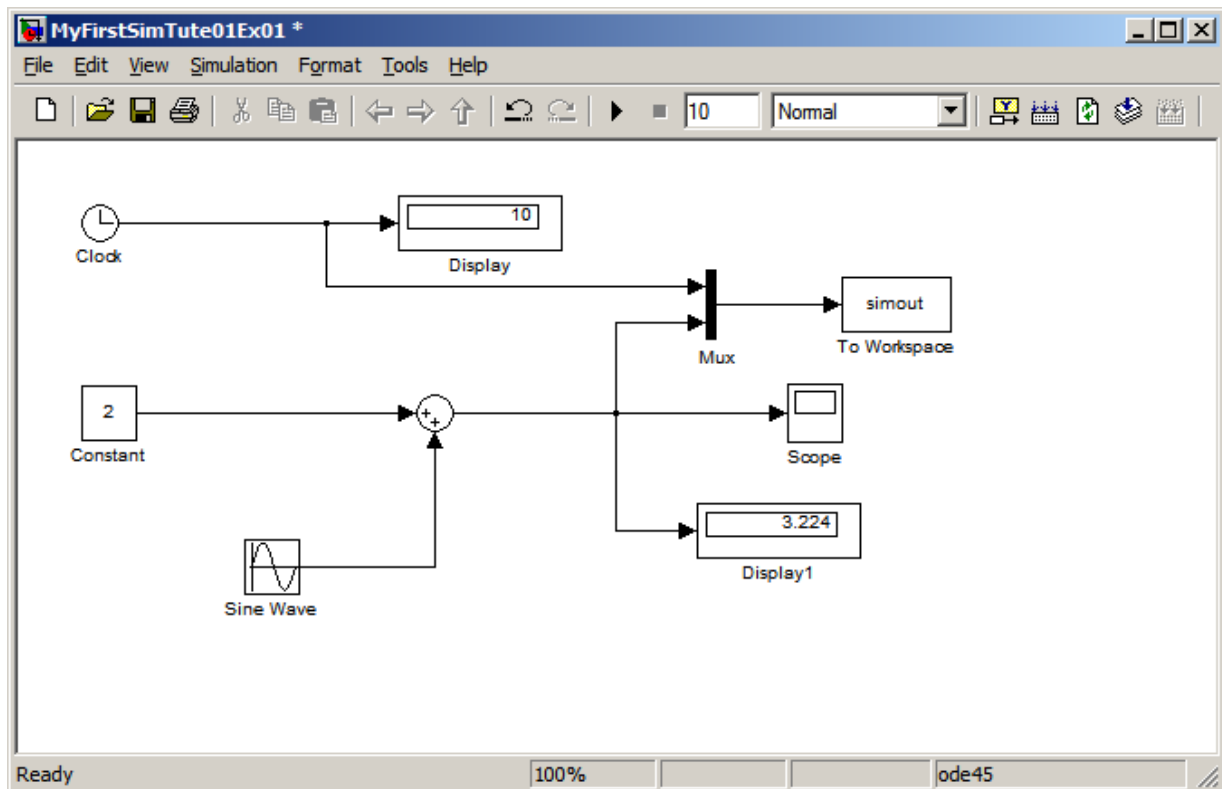


Figure 10 Launching To Workspace and Mux blocks

- Double click the To Workspace, and set:
 - Variable name: data
 - Save format: Array
- Click the Apply button then the OK button.

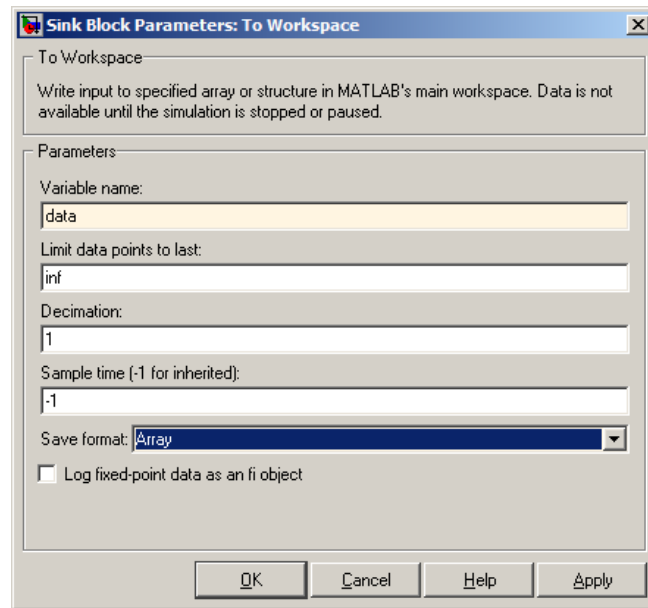


Figure 11 Sink Block Parameters: To Workplace Window

- Save the Simulink model
- Run the Simulink model. The simulated data are in Workspace (matrix “data”).
- In the Command Window, type the following commands:

```
>>t=data(:,1)
>>y=data(:,2)
>>plot(t,y);grid
```

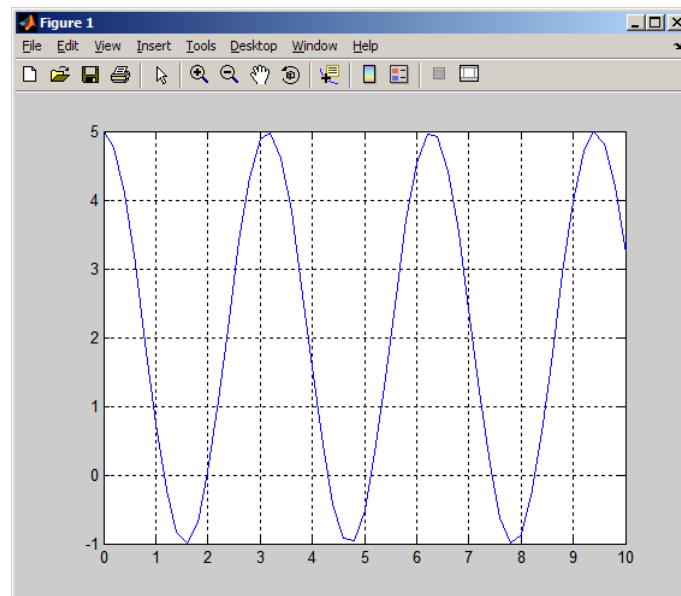


Figure 12 Graph of $y = 2 + 3 \sin(\omega t + \pi/2)$

2. Use of Scope

- Save the Simulink model as “MyFirstSimTute01Ex0102.mdl”.
- Double click the Scope block
- Click the Parameter button:

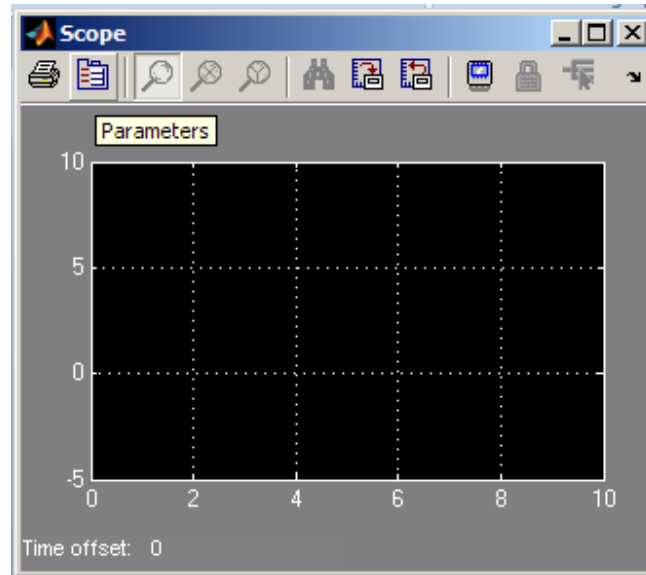


Figure 13 Scope > Parameters button

- Select the History tab
- Set the ‘Scope’ parameters as in the following figure:

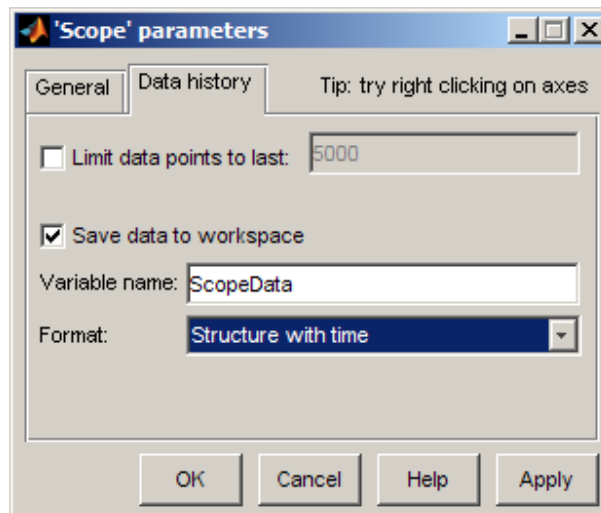


Figure 14 Data history tab

- Click Apply button
- Click OK button
- Save the Simulink model
- Run the model
- View Workspace... there must be a variable named “ScopeData”

In the Command Window, type the following command:

```
>> ScopeData
```

that is resulting...

```
ScopeData =
```

```
    time: [10001x1 double]  
  signals: [1x1 struct]  
  blockName: 'MyFirstSimTute01Ex0102/Scope'
```

Let's extract signals from the ScopeData variable by typing the following commands in Command Windows:

```
>>t = data.time
```

(to retrieve time)

```
>> y=ScopeData.signals.values
```

(to retried signal y)

```
>>plot(t,y);grid
```

The resulting plot looks like...

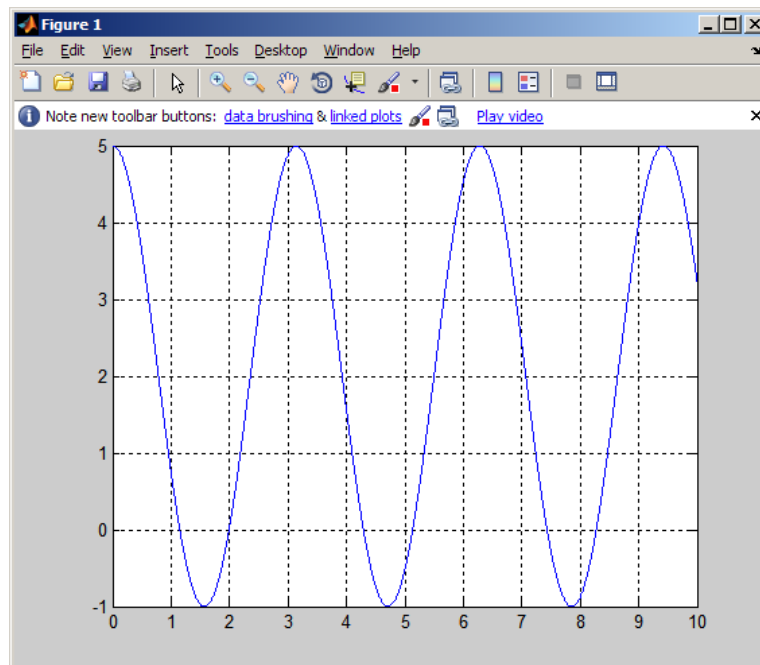


Figure 15 Plotting data (y vs t) from ScopeData

Selection of Solver and Step Size:

- Simulation menu > Simulation parameters > see the following figure:

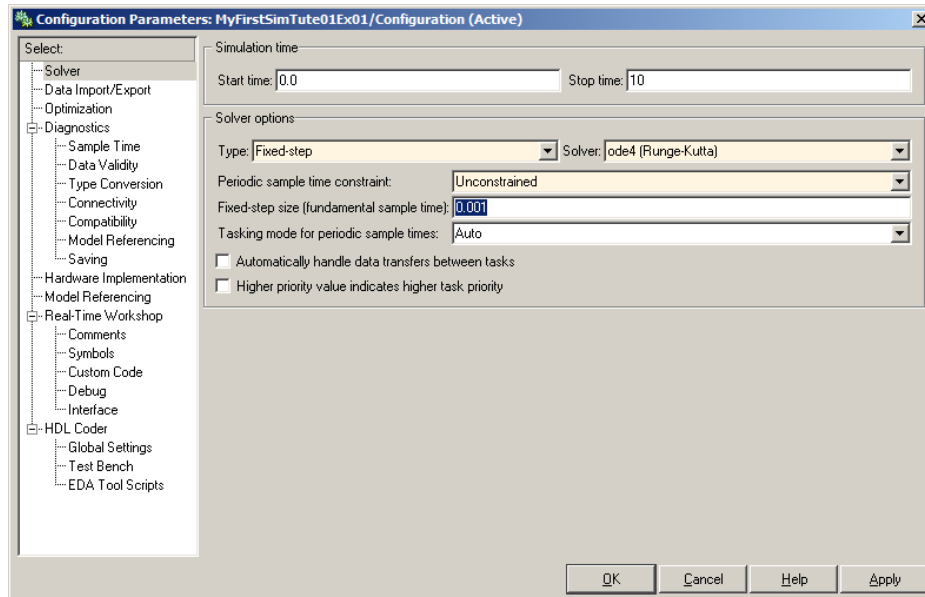


Figure 16 Change Variable step to Fixed-step and Solver to Ode4 (Runge-Kutta)

- Click Apply button, then OK button. Run the Simulink model and plot y vs t:

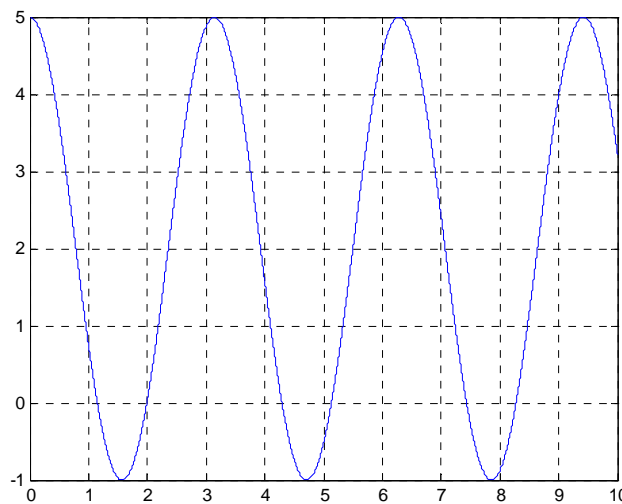


Figure 17 Smoother graph of $y = 2 + 3\sin(\omega t + \pi/2)$

Save Workspace to a MAT-formatted files:

In some cases it is necessary to save all data in Workspace to files. In order to view the contents of Workspace, select the Workspace tab as follows:

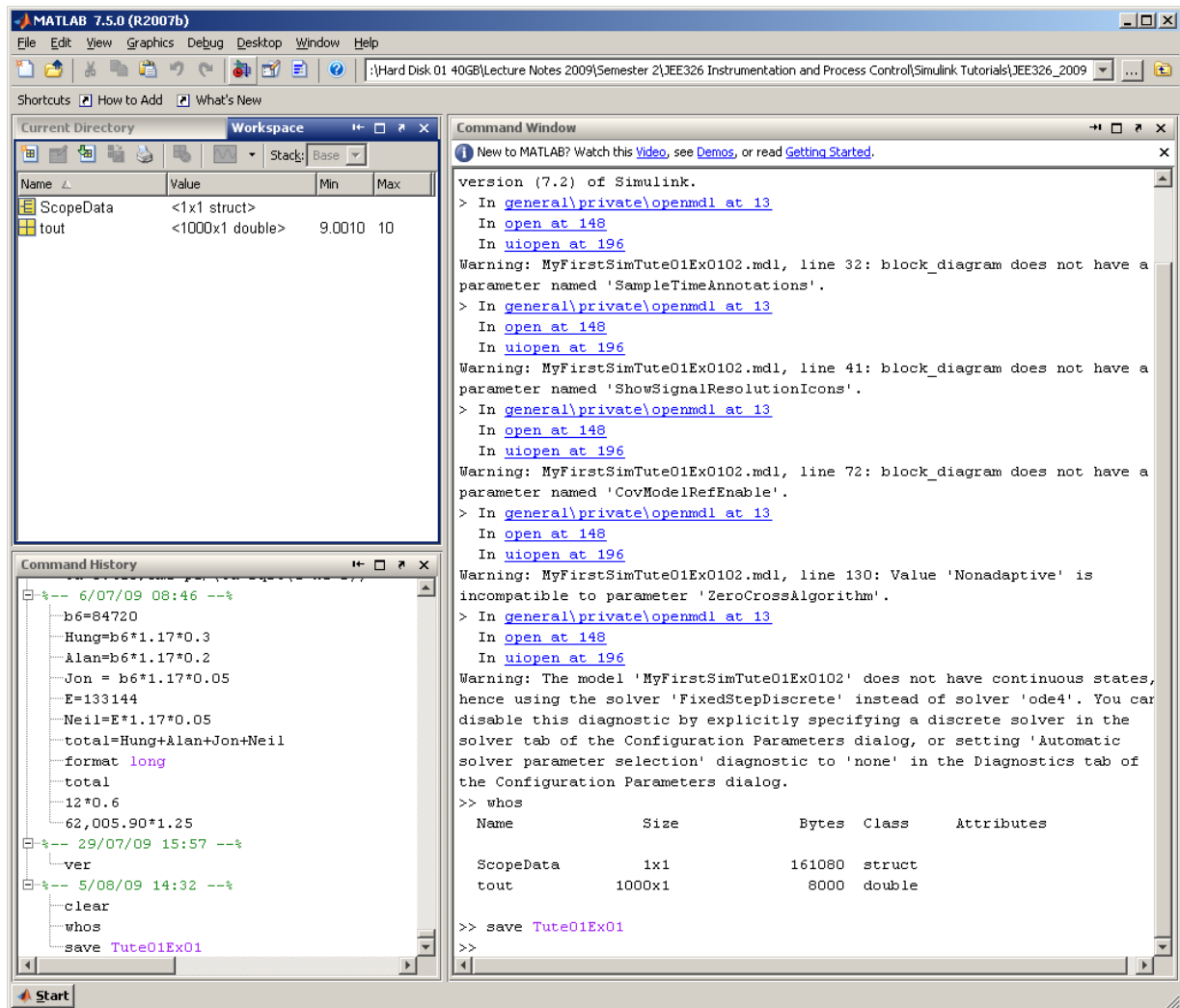


Figure 18 Workspace tab

Or type the following command in Command Window:

```
>> whos
```

That results in

Name	Size	Bytes	Class	Attributes
ScopeData	1x1	161080	struct	
tout	1000x1	8000	double	

Type the following command to save all data in Workspace to “Tute01Ex01.MAT” file

```
>> save Tute01Ex01
```

The file will be in the Current Directory as follows:

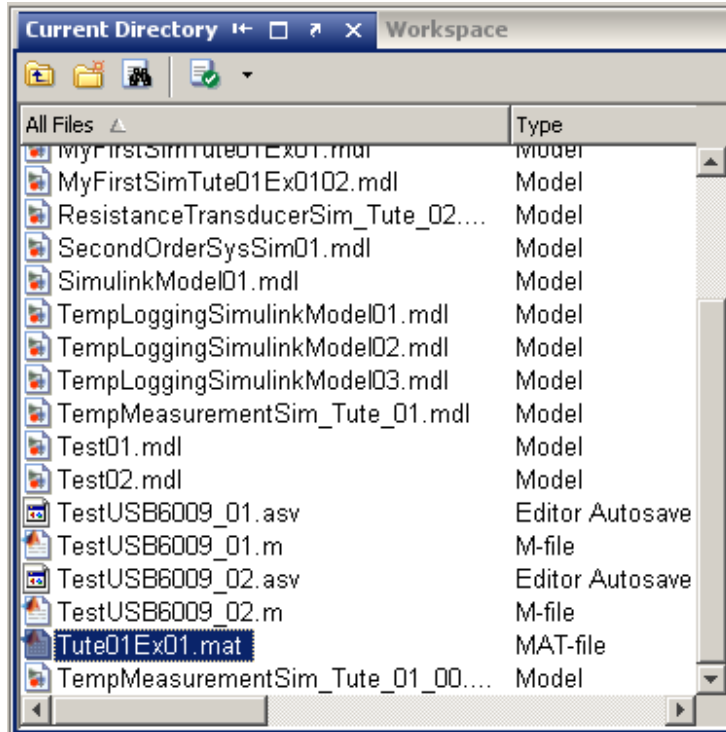


Figure 19 A new MAT file has been created

To load the MAT file, type the following commands:

```
>>clear
>>whos
>>load Tute01Ex01
>>whos
```

That results...

Name	Size	Bytes	Class	Attributes
ScopeData	1x1	161080	struct	
tout	1000x1	8000	double	

2. Hands-on Exercise 2: Simulation of a temperature control system

Statement of Problem: Temperature measurement

A PC-based temperature measuring system is shown in **Fig. 14** in which the signal is processed as: $0-100^{\circ}\text{C} > \text{mV} > \text{mA} (4-20 \text{ mA}) > \text{SC-2345: } 1-5 \text{ [V]} - \text{DAQ} : 1-5\text{V (software)}$.

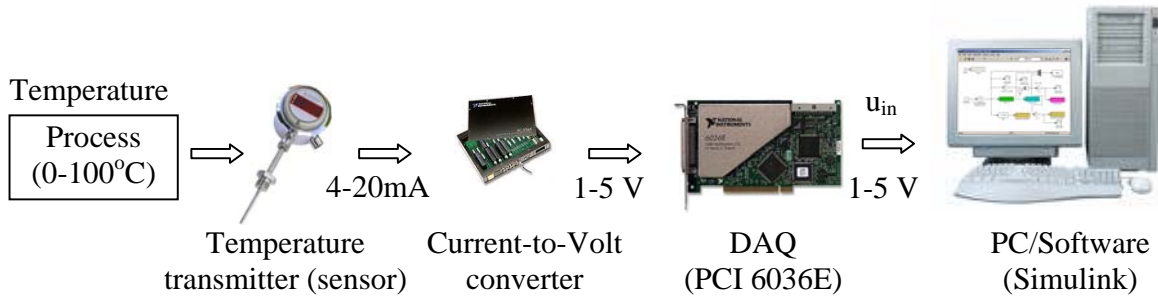


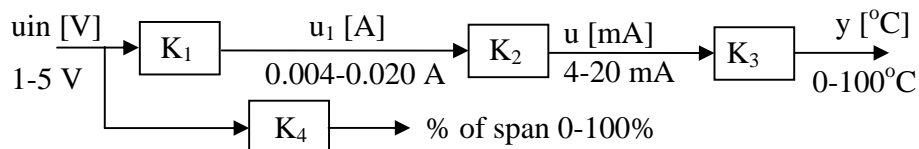
Figure 14 PC-based temperature measuring system

In the Simulink model, perform signal processing (conditioning) and display:

- Temperature in V (u_{in} : 1-5 V) – simulated by a signal generator block
- Temperature in mA (u : 4-20 mA)
- Temperature in $^{\circ}\text{C}$ (y : 0-100 $^{\circ}\text{C}$)

SOLUTION

The signal processing in PC/software will be:



Therefore we have the following algorithm

Ohm's law:

$$u_1 [\text{A}] = \frac{u_{in}}{R} = u_{in} \times K_1 \quad (R = 250 \, \Omega, \text{ thus } K_1 = 1/R = 1/250)$$

Convert A to mA:

$$u = u_1 \times K_2 \quad (K_2 = 1000)$$

Convert mA to $^{\circ}\text{C}$:

$$K_3 = \frac{\Delta y}{\Delta u} = \frac{y_{\max} - y_{\min}}{u_{\max} - u_{\min}} = \frac{100^{\circ}\text{C} - 0^{\circ}\text{C}}{20\text{mA} - 4\text{mA}} = \frac{100^{\circ}\text{C}}{16\text{mA}} = 6.25 \frac{^{\circ}\text{C}}{\text{mA}}$$

$$K_3 = \frac{\Delta y}{\Delta u} = \frac{y - y_{\min}}{u - u_{\min}} \Rightarrow y = K_3(u - u_{\min}), \quad u_0 = u_{\min} = 4 \text{ mA}, \text{ thus: } y = K_3(u - u_0)$$

Convert V to % of span:

$$\% \text{ of span} = u_{in_{max}} - u_{in_{min}} = 5V - 1V = 4V$$

$$K_4 = \frac{100\%}{4} = 25[\%]$$

or

$$\% \text{ of span} = K_4 (u_{in_{max}} - u_{in_{min}}) = 25\% (5V - 1V)$$

Block diagram algorithm:

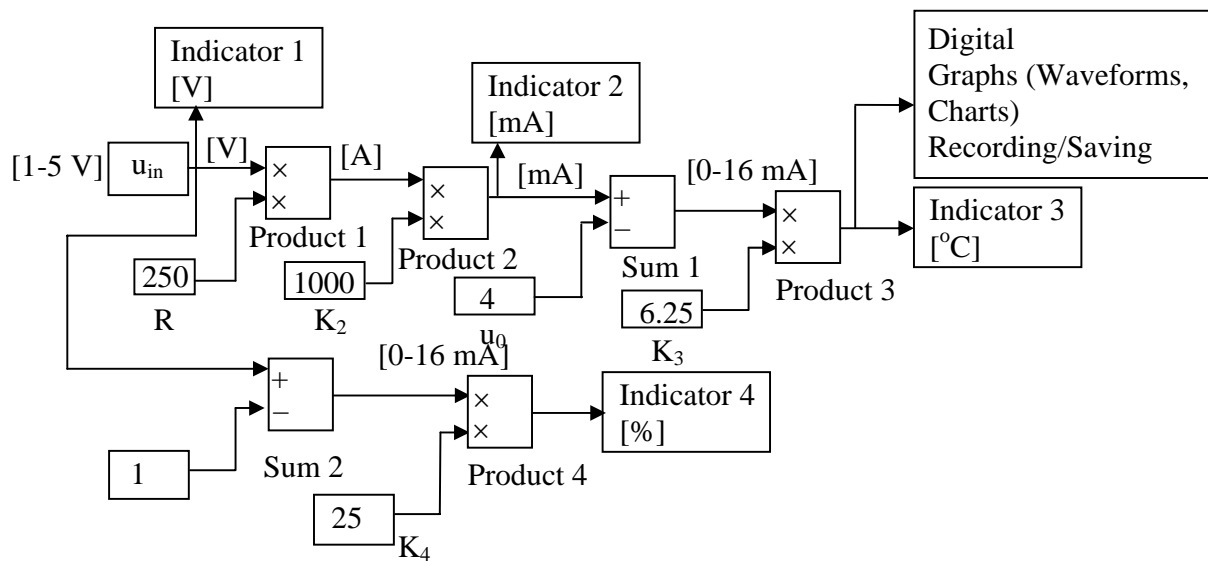


Figure 15 Block diagram for temperature measurement

Programming with Simulink

- Open a new Simulink model
- Save as “TempMeasurementSim_Tute01_Ex02.mdl”
- Refer to the block diagram algorithm in **Fig. 15** select all necessary blocks from the Simulink Library Browser as in **Fig. 16**.
- Wire the blocks and set system parameters as in **Fig. 17** (demonstrate each step).

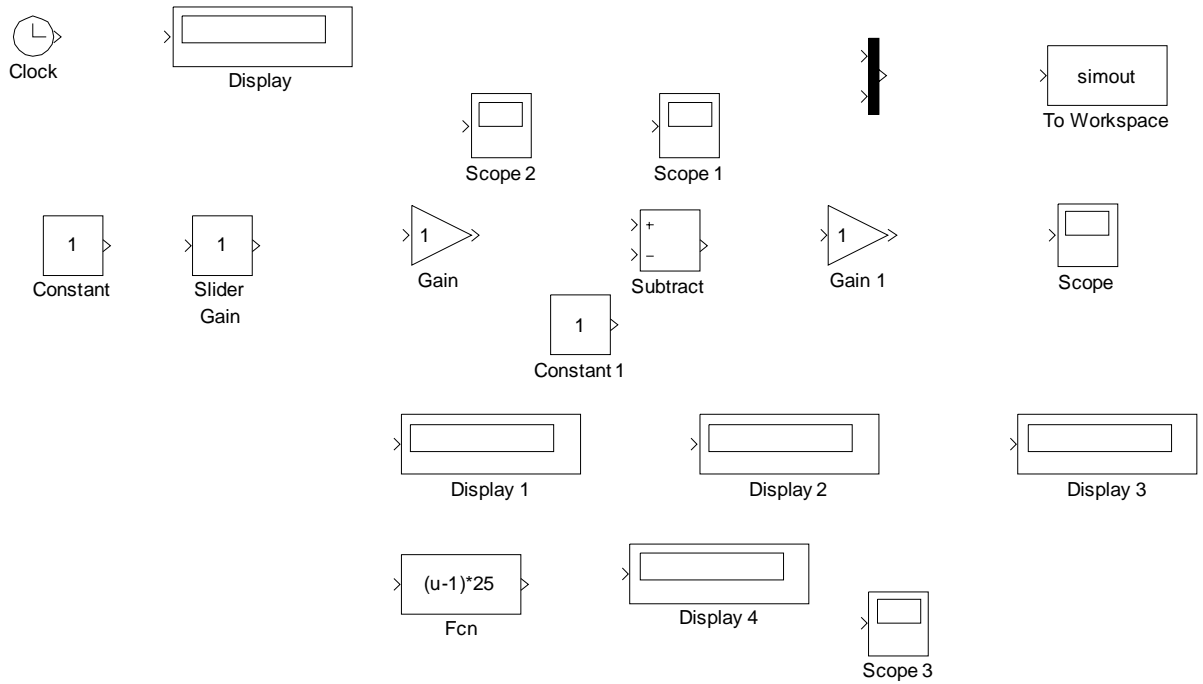


Figure 16 Necessary blocks for block diagram algorithm in Fig. 15

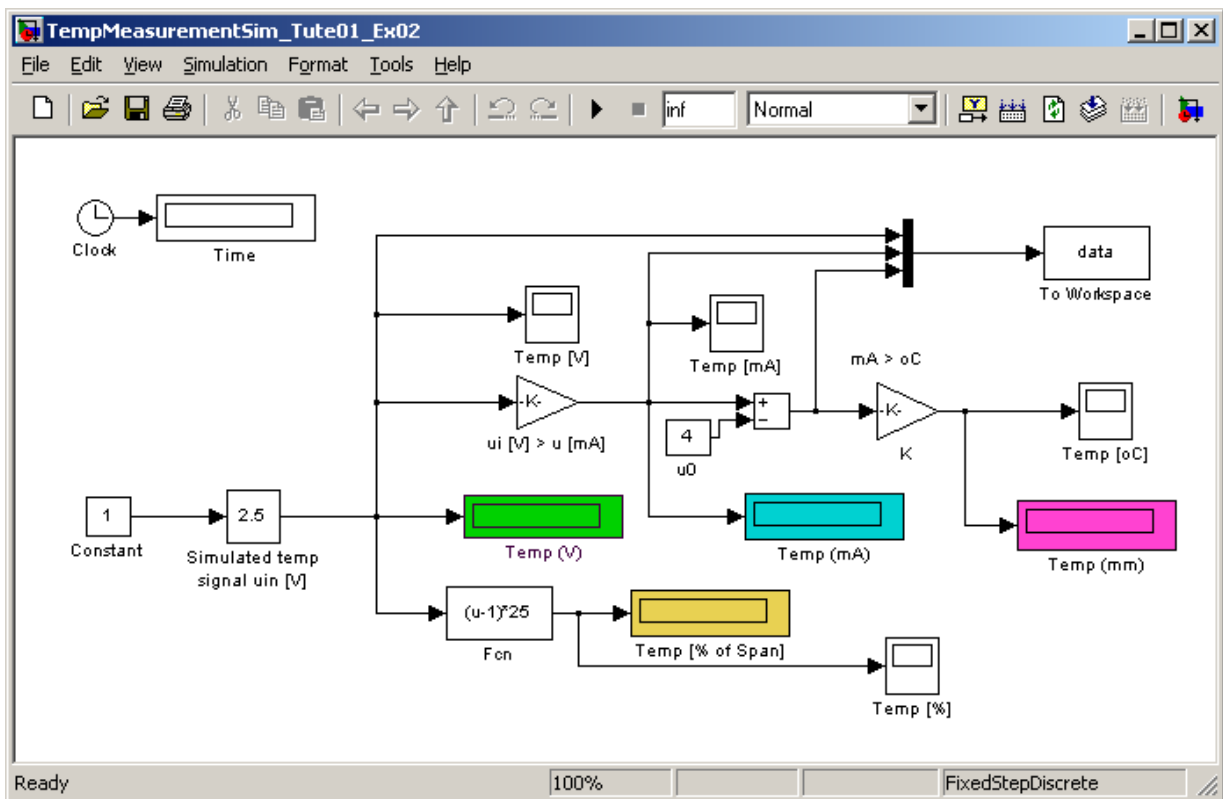


Figure 17 System parameters

- Configure simulation parameters as in the following figure:

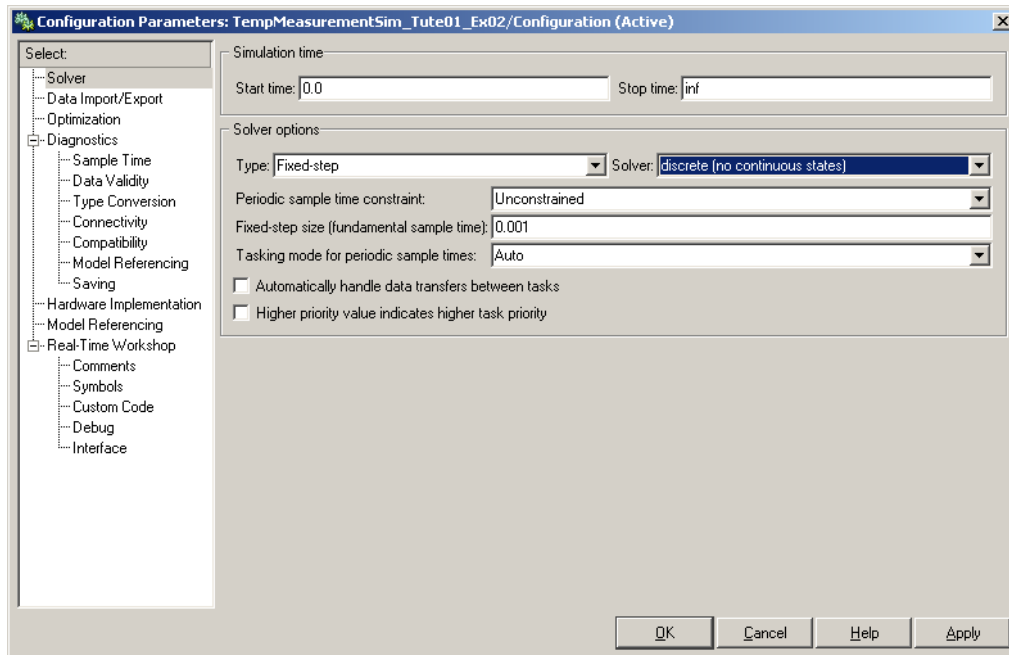


Figure 18 Simulation parameters

- Save the program.
- Run the Simulink program... The resulting program looks like...

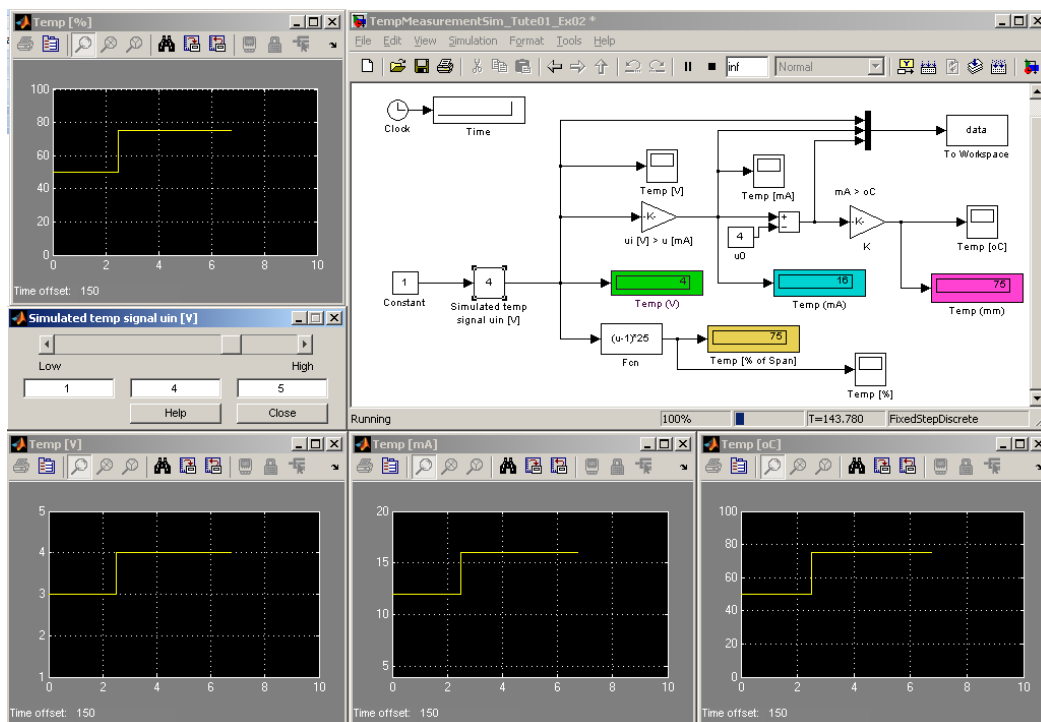


Figure 19 Simulation program for temperature measurement

- Luckily so far there is no error!

You can test the functionality of the program by changing some values of u_{in} below:

$u_{in} = 1 \text{ V} \rightarrow 4 \text{ mA} \rightarrow 0^\circ\text{C} \rightarrow 0\%$
 $u_{in} = 2 \text{ V} \rightarrow 8 \text{ mA} \rightarrow 25\% \rightarrow 25\%$
 $u_{in} = 3 \text{ V} \rightarrow 12 \text{ mA} \rightarrow 50^\circ\text{C} \rightarrow 50\%$
 $u_{in} = 4 \text{ V} \rightarrow 16 \text{ mA} \rightarrow 75^\circ\text{C} \rightarrow 75\%$
 $u_{in} = 5 \text{ V} \rightarrow 20 \text{ mA} \rightarrow 100^\circ\text{C} \rightarrow 100\%$

WELL-DONE!

Conclusions

At this point the following learning objectives have been met:

- Create and run a Simulink model
- Compute value of a function and display computed results with Simulink
- Use blocks in Simulink Library Browser
- Configure system parameters
- Configure simulation parameters
- Store simulated data to Workspace and save Workspace to files

Follow-up Exercise Simulation of a level measurement system

A PC-based level measuring system is shown in **Fig. 20** in which the signal is processed as: 0-400mm > mA (4-20 mA) > SC-2345: 1-5 [V] – DAQ : 1-5V (software). Make a Simulink model to simulate the level measuring system (you can modify the above simulation program).

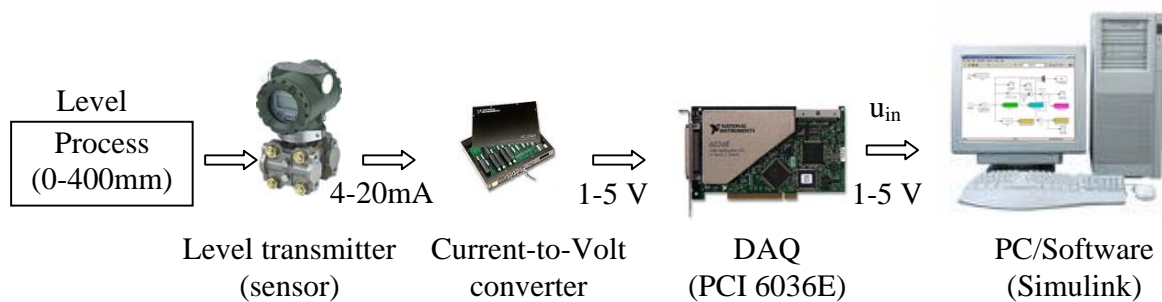


Figure 20 PC-based level measuring system