ТОМСКИЙ ПОЛИТЕХНИЧЕСКИЙ УНИВЕРСИТЕТ

МАТЕМАТИЧЕСКОЕ МОДЕЛИРОВАНИЕ ФИЗИЧЕСКИХ ПРОЦЕССОВ

ЛЕКЦИЯ №16

«Математическое описание физико-химических процессов в физических установках: применение пакета Matlab и его расширения Simulink»

Отделение ядерно-топливного цикла

Лектор:
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2020

План лекции

16.1. Вычислительная статистика в Matlab
(https://www.youtube.com/watch?v=Qshi5W-p1Jw)

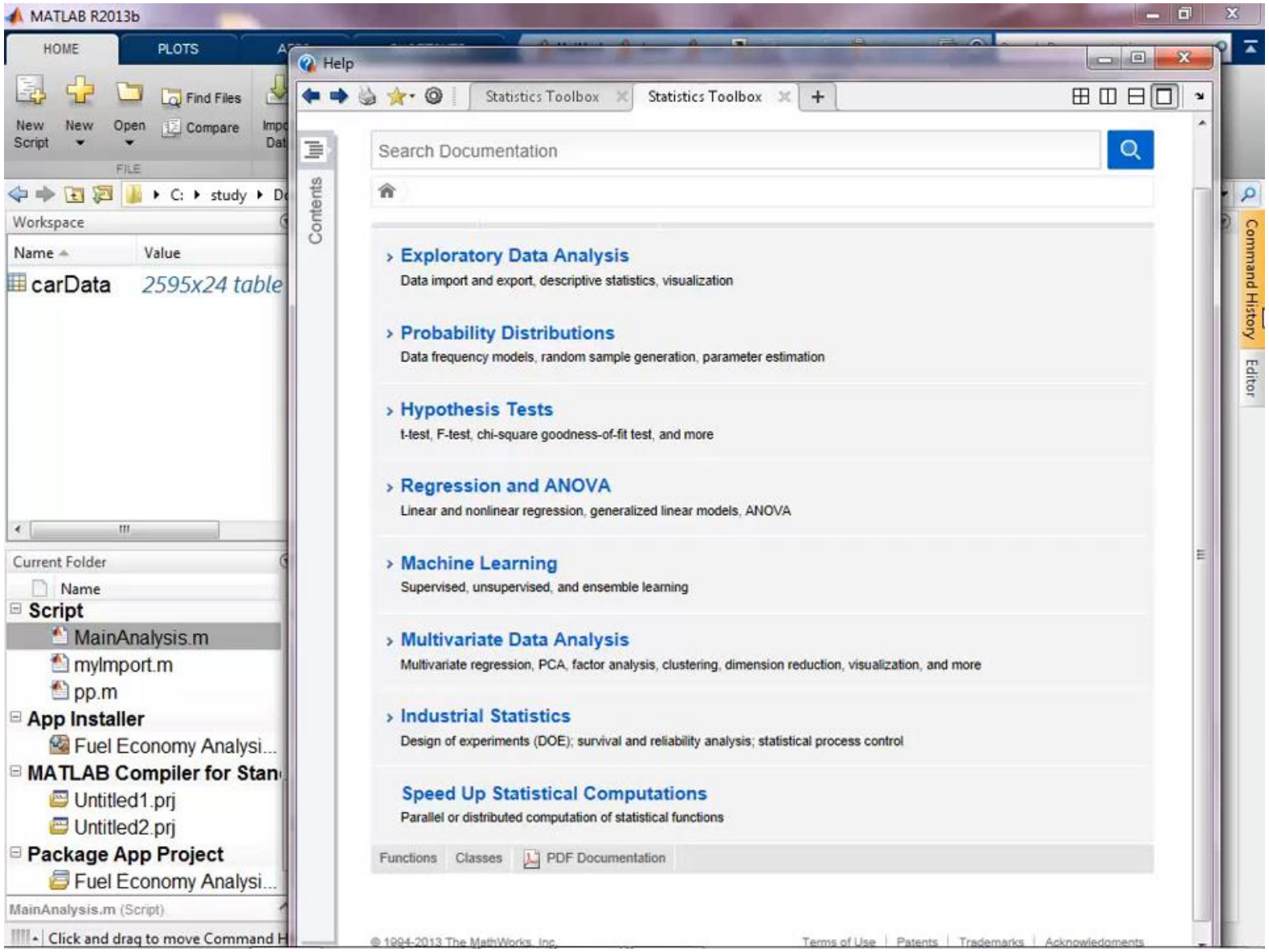
16.2. Начало работы в Simulink
(https://www.youtube.com/watch?v=_gDsghQ-Y1s)
(https://www.youtube.com/watch?v=K61lx2WklyI)

16.3. Пример моделирования физического процесса в Simulink

Информация по курсу:
https://portal.tpu.ru/SHARED/a/ALEX1479/study/Matmod/Tab

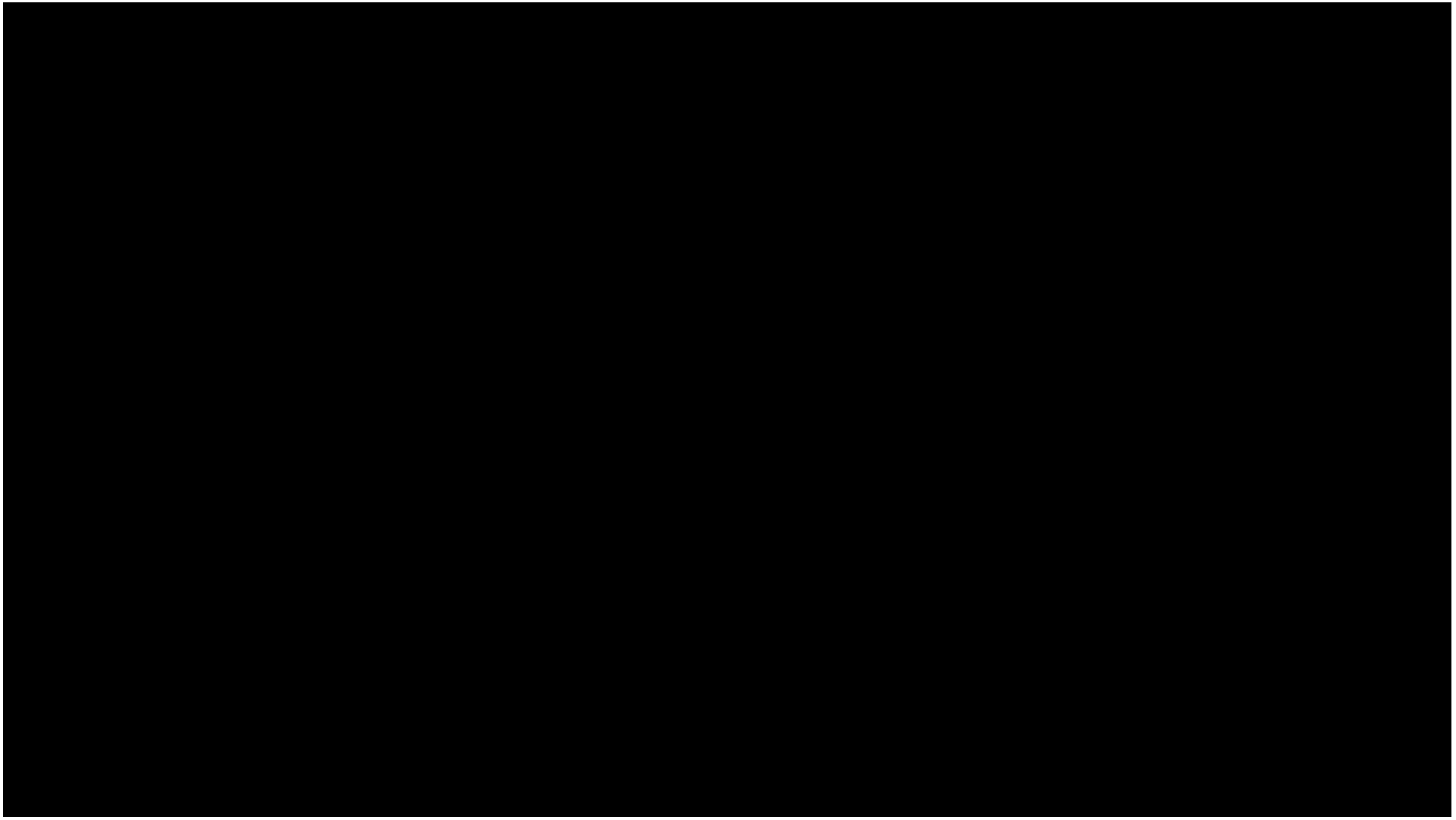
16.1 Вычислительная статистика

(https://www.youtube.com/watch?v=Qshi5W-p1Jw)



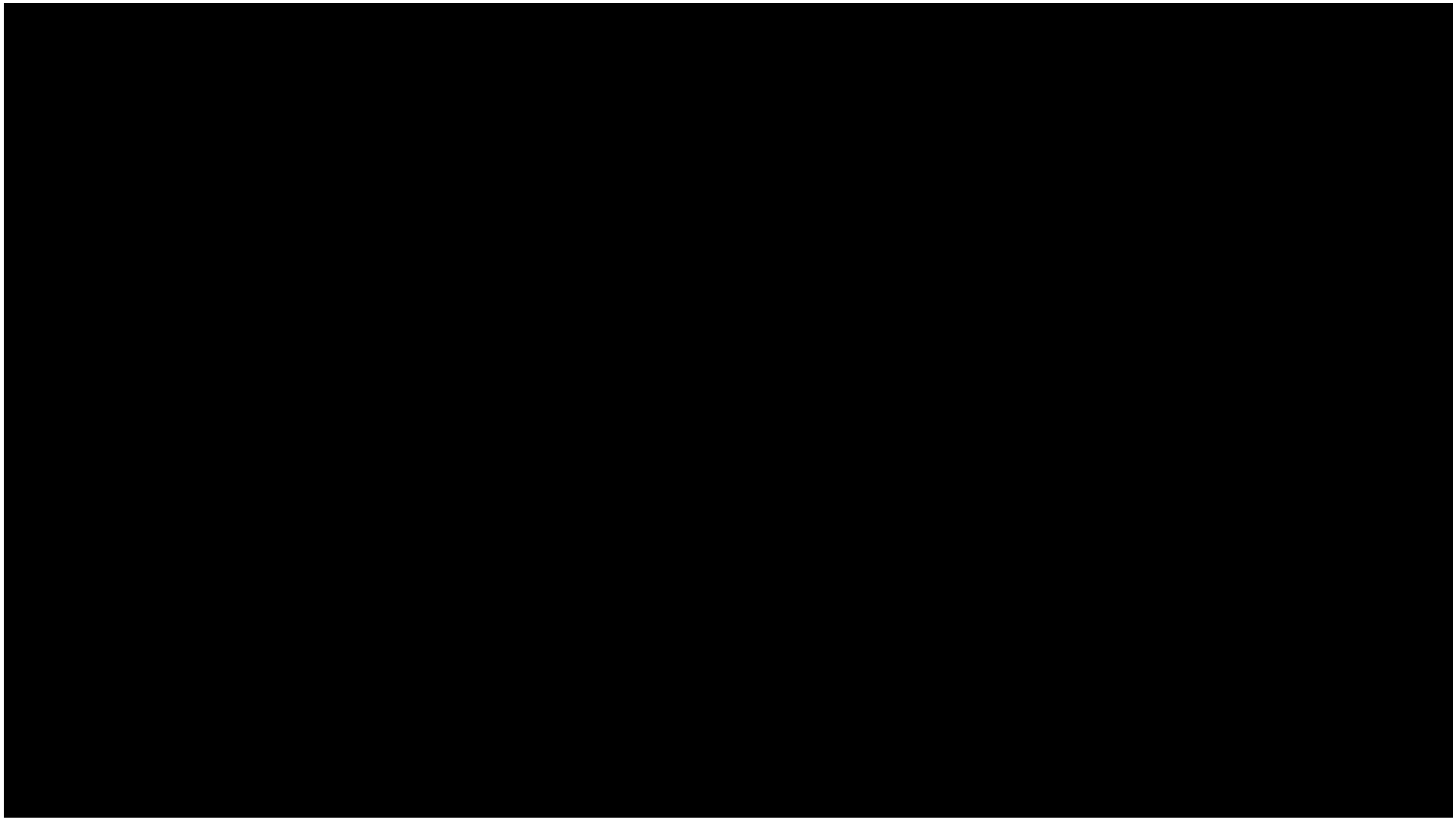
16.2 Начало работы в Simulink

(https://www.youtube.com/watch?v=_gDsghQ-Y1s)



16.2 Начало работы в Simulink

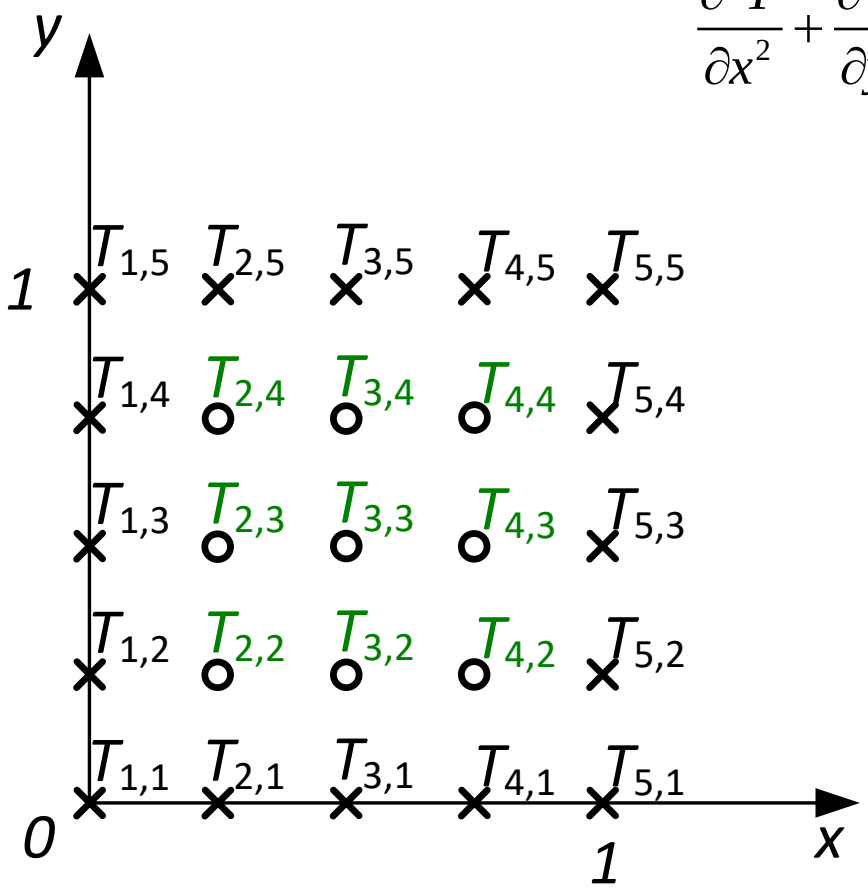
(https://www.youtube.com/watch?v=K61lx2WklyI)



16.3 Пример моделирования физического процесса в Simulink

16.3.1 Пример моделирования процесса теплопередачи в плоской пластине

$$\frac{\partial^2 T}{\partial x^2} + \frac{\partial^2 T}{\partial y^2} = 0 \qquad (16.1)$$



$$T_{1,1} = T_{1,2} = T_{1,3} = T_{1,4} = T_{1,5} = 0$$

$$T_{5,1} = T_{5,2} = T_{5,3} = T_{5,4} = T_{5,5} = 100$$

$$T_{2,1} = 25;\ T_{3,1} = 50;\ T_{4,1} = 75$$

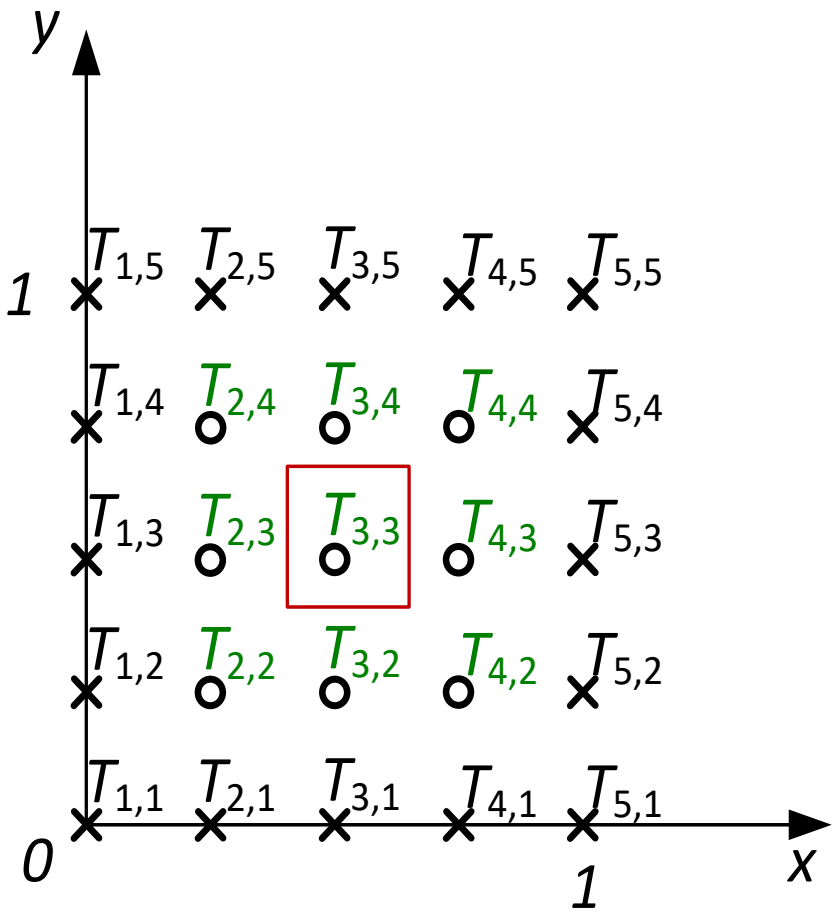
$$T_{2,5} = 6.25;\ T_{3,5} = 25;\ T_{4,5} = 56.25$$

$$h = h_x = h_y = 0.25$$

16.3.2 Метод конечных разностей и форма Коши

$$
\begin{cases}
\dfrac{dT_{2,2}}{dt} = \dfrac{T_{3,2} - 2T_{2,2} + T_{1,2}}{h^2} + \dfrac{T_{2,3} - 2T_{2,2} + T_{2,1}}{h^2} \\
\dfrac{dT_{3,2}}{dt} = \dfrac{T_{4,2} - 2T_{3,2} + T_{2,2}}{h^2} + \dfrac{T_{3,3} - 2T_{3,2} + T_{3,1}}{h^2} \\
\dfrac{dT_{4,2}}{dt} = \dfrac{T_{5,2} - 2T_{4,2} + T_{3,2}}{h^2} + \dfrac{T_{4,3} - 2T_{4,2} + T_{4,1}}{h^2} \\
\dfrac{dT_{2,3}}{dt} = \dfrac{T_{3,3} - 2T_{2,3} + T_{1,3}}{h^2} + \dfrac{T_{2,4} - 2T_{2,3} + T_{2,2}}{h^2} \\
\dfrac{dT_{3,3}}{dt} = \dfrac{T_{4,3} - 2T_{3,3} + T_{2,3}}{h^2} + \dfrac{T_{3,4} - 2T_{3,3} + T_{3,2}}{h^2} \\
\dfrac{dT_{4,3}}{dt} = \dfrac{T_{5,3} - 2T_{4,3} + T_{3,3}}{h^2} + \dfrac{T_{4,4} - 2T_{4,3} + T_{4,2}}{h^2} \\
\dfrac{dT_{2,4}}{dt} = \dfrac{T_{3,4} - 2T_{2,4} + T_{1,4}}{h^2} + \dfrac{T_{2,5} - 2T_{2,4} + T_{2,3}}{h^2} \\
\dfrac{dT_{3,4}}{dt} = \dfrac{T_{4,4} - 2T_{3,4} + T_{2,4}}{h^2} + \dfrac{T_{3,5} - 2T_{3,4} + T_{3,3}}{h^2} \\
\dfrac{dT_{4,4}}{dt} = \dfrac{T_{5,4} - 2T_{4,4} + T_{3,4}}{h^2} + \dfrac{T_{4,5} - 2T_{4,4} + T_{4,3}}{h^2}
\end{cases}
\qquad (16.2)
$$

16.3.3 Учтем источник тепла

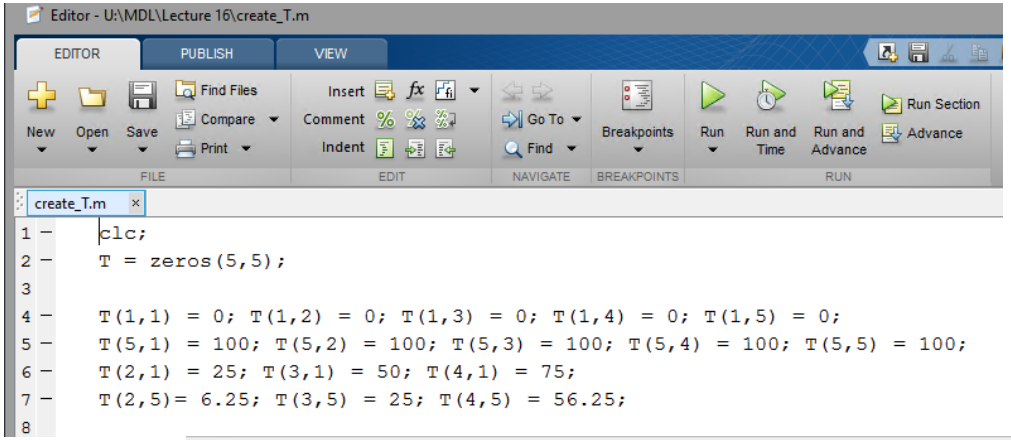


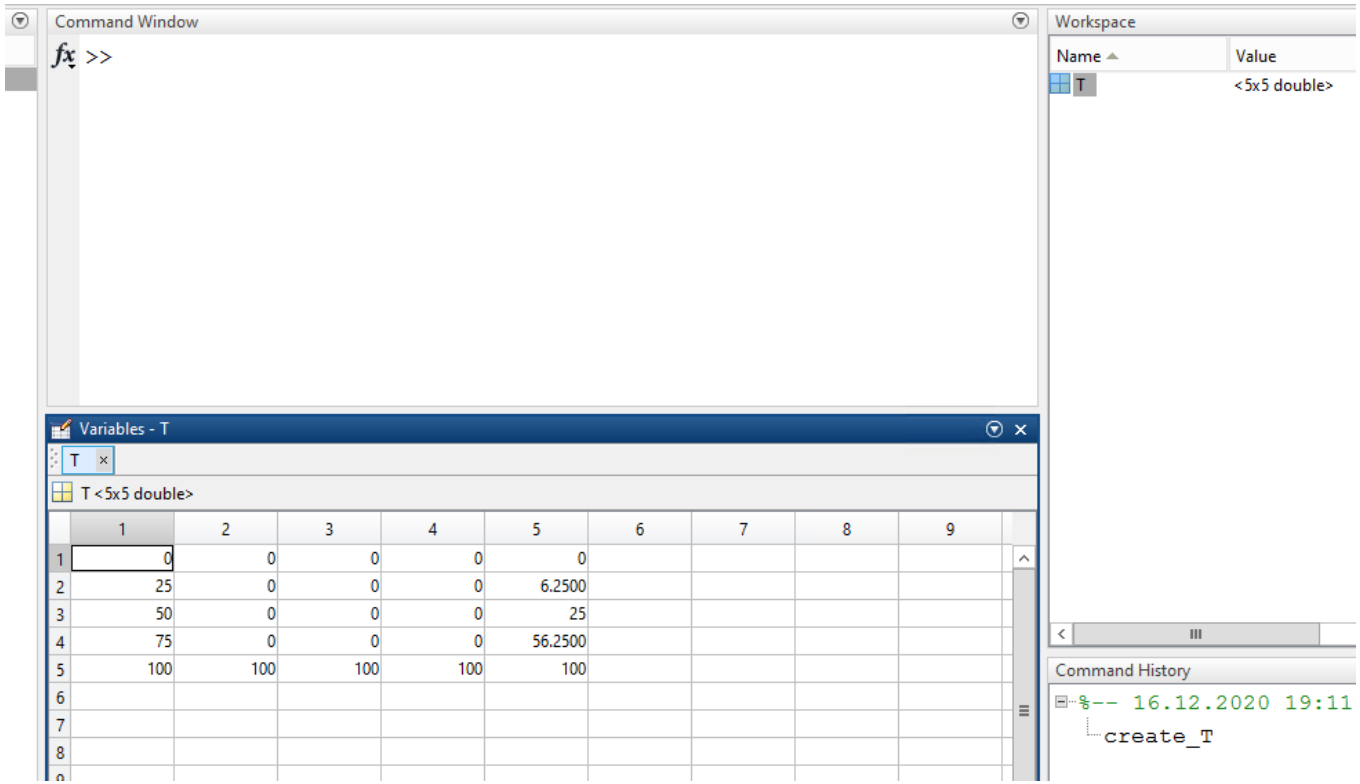
16.3.3 Учтем источник тепла

$$
\begin{cases}
\frac{dT_{2,2}}{dt} = \frac{T_{3,2} - 2T_{2,2} + T_{1,2}}{h^2} + \frac{T_{2,3} - 2T_{2,2} + T_{2,1}}{h^2} \\
\frac{dT_{3,2}}{dt} = \frac{T_{4,2} - 2T_{3,2} + T_{2,2}}{h^2} + \frac{T_{3,3} - 2T_{3,2} + T_{3,1}}{h^2} \\
\frac{dT_{4,2}}{dt} = \frac{T_{5,2} - 2T_{4,2} + T_{3,2}}{h^2} + \frac{T_{4,3} - 2T_{4,2} + T_{4,1}}{h^2} \\
\frac{dT_{2,3}}{dt} = \frac{T_{3,3} - 2T_{2,3} + T_{1,3}}{h^2} + \frac{T_{2,4} - 2T_{2,3} + T_{2,2}}{h^2} \\
\frac{dT_{3,3}}{dt} = \frac{T_{4,3} - 2T_{3,3} + T_{2,3}}{h^2} + \frac{T_{3,4} - 2T_{3,3} + T_{3,2}}{h^2} + \frac{Q}{m_q \cdot C_p} \\
\frac{dT_{4,3}}{dt} = \frac{T_{5,3} - 2T_{4,3} + T_{3,3}}{h^2} + \frac{T_{4,4} - 2T_{4,3} + T_{4,2}}{h^2} \\
\frac{dT_{2,4}}{dt} = \frac{T_{3,4} - 2T_{2,4} + T_{1,4}}{h^2} + \frac{T_{2,5} - 2T_{2,4} + T_{2,3}}{h^2} \\
\frac{dT_{3,4}}{dt} = \frac{T_{4,4} - 2T_{3,4} + T_{2,4}}{h^2} + \frac{T_{3,5} - 2T_{3,4} + T_{3,3}}{h^2} \\
\frac{dT_{4,4}}{dt} = \frac{T_{5,4} - 2T_{4,4} + T_{3,4}}{h^2} + \frac{T_{4,5} - 2T_{4,4} + T_{4,3}}{h^2}
\end{cases}
\qquad (16.3)
$$

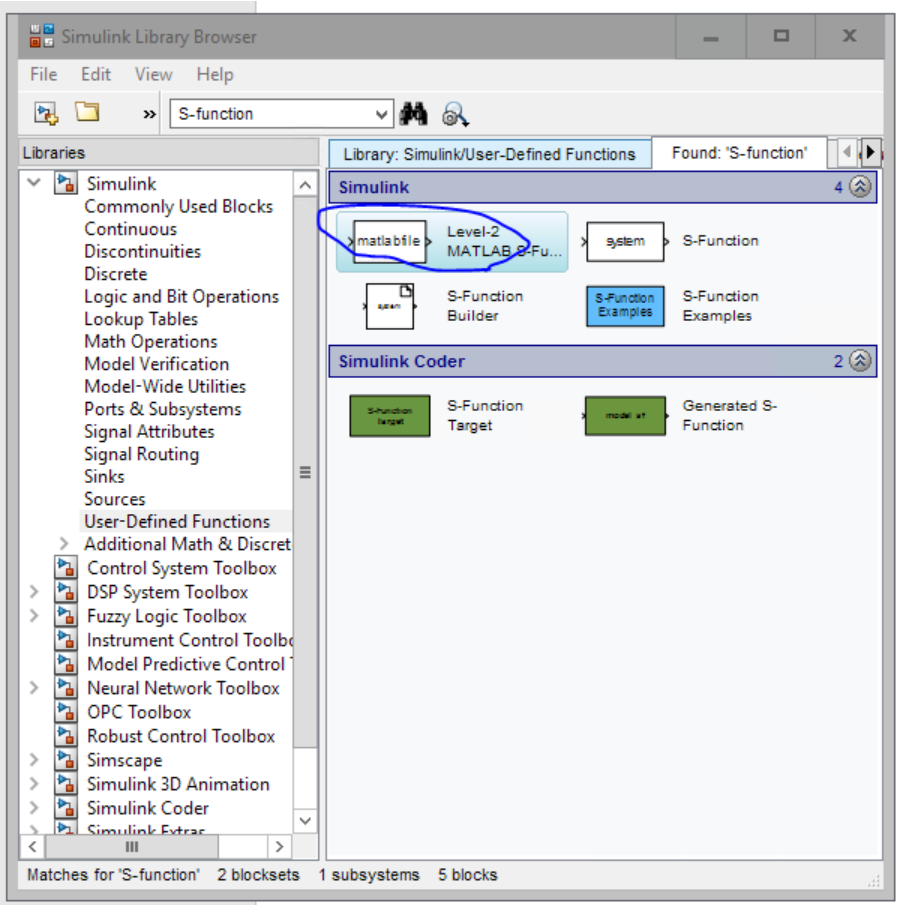
Q – источник тепла, Вт (Дж/с),
m_q – масса источника тепла, кг,
C_p – теплоемкость материала, Дж/(кг·°С)

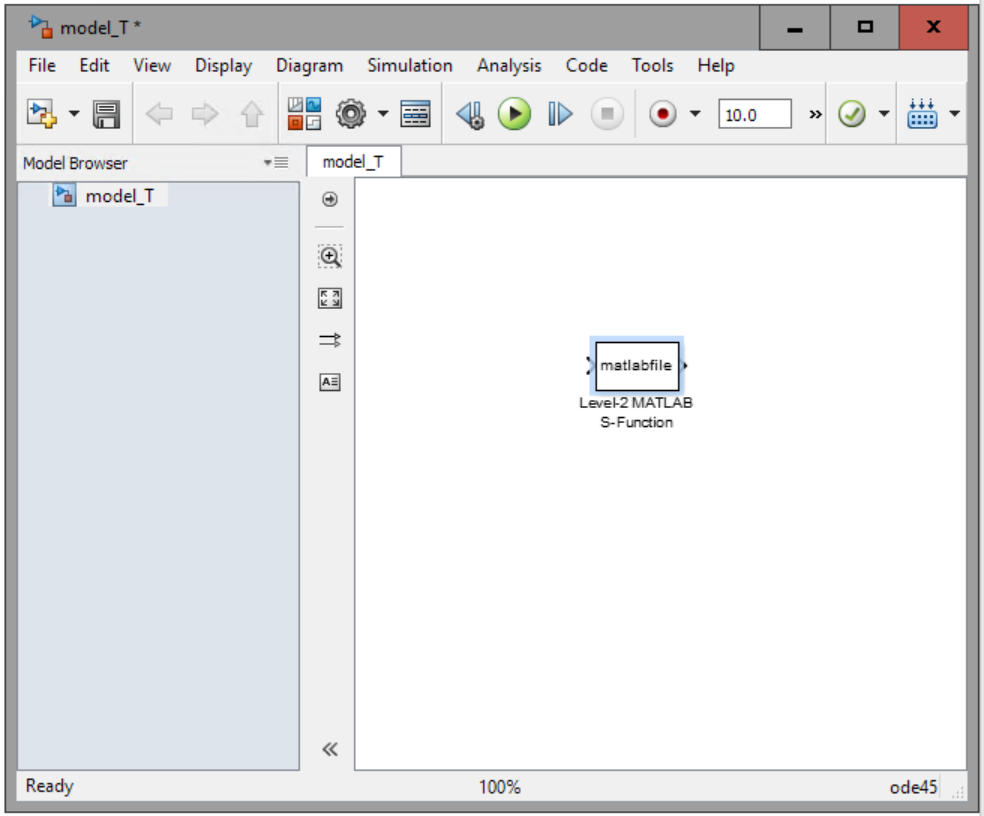
16.3.4 Формируем граничные и начальные условия



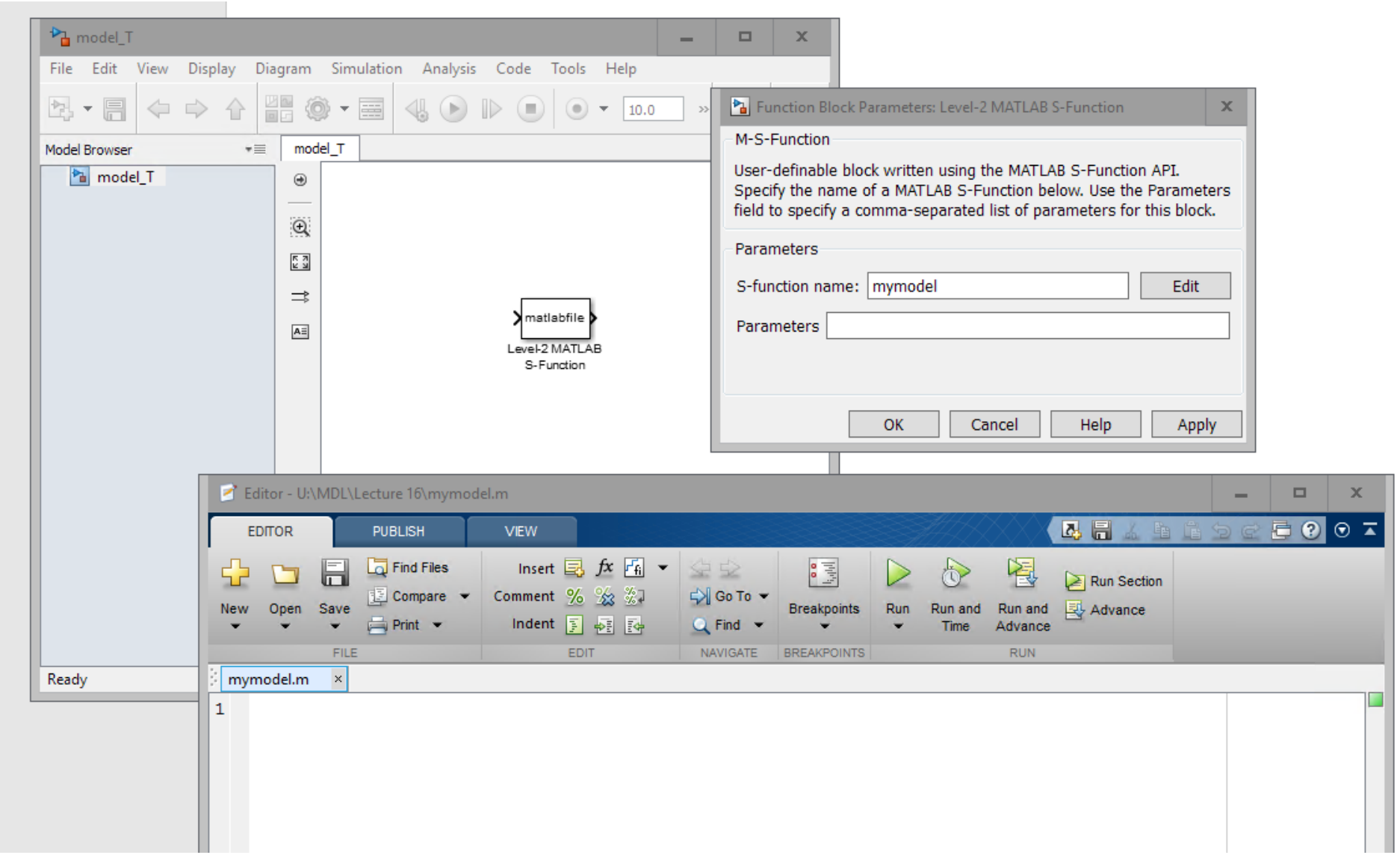


16.3.5 Создание S-функции в Simulink





16.3.5 Создание S-функции в Simulink



16.3.5 Создание S-функции в Simulink (настройка входов и выходов)

mymodel.m*

```
function mymodel(block)
setup(block);
function setup(block)
%% Register number of input and output ports
  block.NumInputPorts  = 1;
  block.NumOutputPorts = 9;

  %% Setup functional port properties to dynamically
  %% inherited.
  block.SetPreCompInpPortInfoToDynamic;
  block.SetPreCompOutPortInfoToDynamic;

  block.InputPort(1).SamplingMode = 'Sample';
  block.InputPort(1).Dimensions   = 1;

  block.OutputPort(1).SamplingMode = 'Sample';
  block.OutputPort(1).Dimensions   = 1;
  block.OutputPort(2).SamplingMode = 'Sample';
  block.OutputPort(2).Dimensions   = 1;
  block.OutputPort(3).SamplingMode = 'Sample';
  block.OutputPort(3).Dimensions   = 1;
  block.OutputPort(4).SamplingMode = 'Sample';
  block.OutputPort(4).Dimensions   = 1;
  block.OutputPort(5).SamplingMode = 'Sample';
  block.OutputPort(5).Dimensions   = 1;
  block.OutputPort(6).SamplingMode = 'Sample';
```

16.3.5 Создание S-функции в Simulink (настройка входов и выходов)

mymodel.m*

```
28 -    block.OutputPort(7).SamplingMode = 'Sample';
29 -    block.OutputPort(7).Dimensions   = 1;
30 -    block.OutputPort(8).SamplingMode = 'Sample';
31 -    block.OutputPort(8).Dimensions   = 1;
32 -    block.OutputPort(9).SamplingMode = 'Sample';
33 -    block.OutputPort(9).Dimensions   = 1;
34      %% Set block sample time to inherited
35 -    block.SampleTimes = [0 0];
36
37      %% Register methods
38 -    block.RegBlockMethod('InitializeConditions', @InitConditions);
39 -    block.RegBlockMethod('Outputs',              @Output);
40 -    block.RegBlockMethod('Derivatives',          @Derivatives);
41 -    block.NumContStates = 9;
42      %% endfunction
43
44
```

16.3.5 Создание S-функции в Simulink (настройка инициализации, начальные условия)

mymodel.m

```
40 -    block.RegBlockMethod('Derivatives',          @Der
41 -    block.NumContStates = 9;
42      %% endfunction
43
44
45
46      function InitConditions(block)
47      %% Initialize Dwork
48 -    T = evalin('base','T');
49 -    block.ContStates.Data(1) = T(2,2);
50 -    block.ContStates.Data(2) = T(3,2);
51 -    block.ContStates.Data(3) = T(4,2);
52 -    block.ContStates.Data(4) = T(2,3);
53 -    block.ContStates.Data(5) = T(3,3);
54 -    block.ContStates.Data(6) = T(4,3);
55 -    block.ContStates.Data(7) = T(2,4);
56 -    block.ContStates.Data(8) = T(3,4);
57 -    block.ContStates.Data(9) = T(4,4);
58
```

16.3.5 Создание S-функции в Simulink (запись системы уравнений в форме Коши)

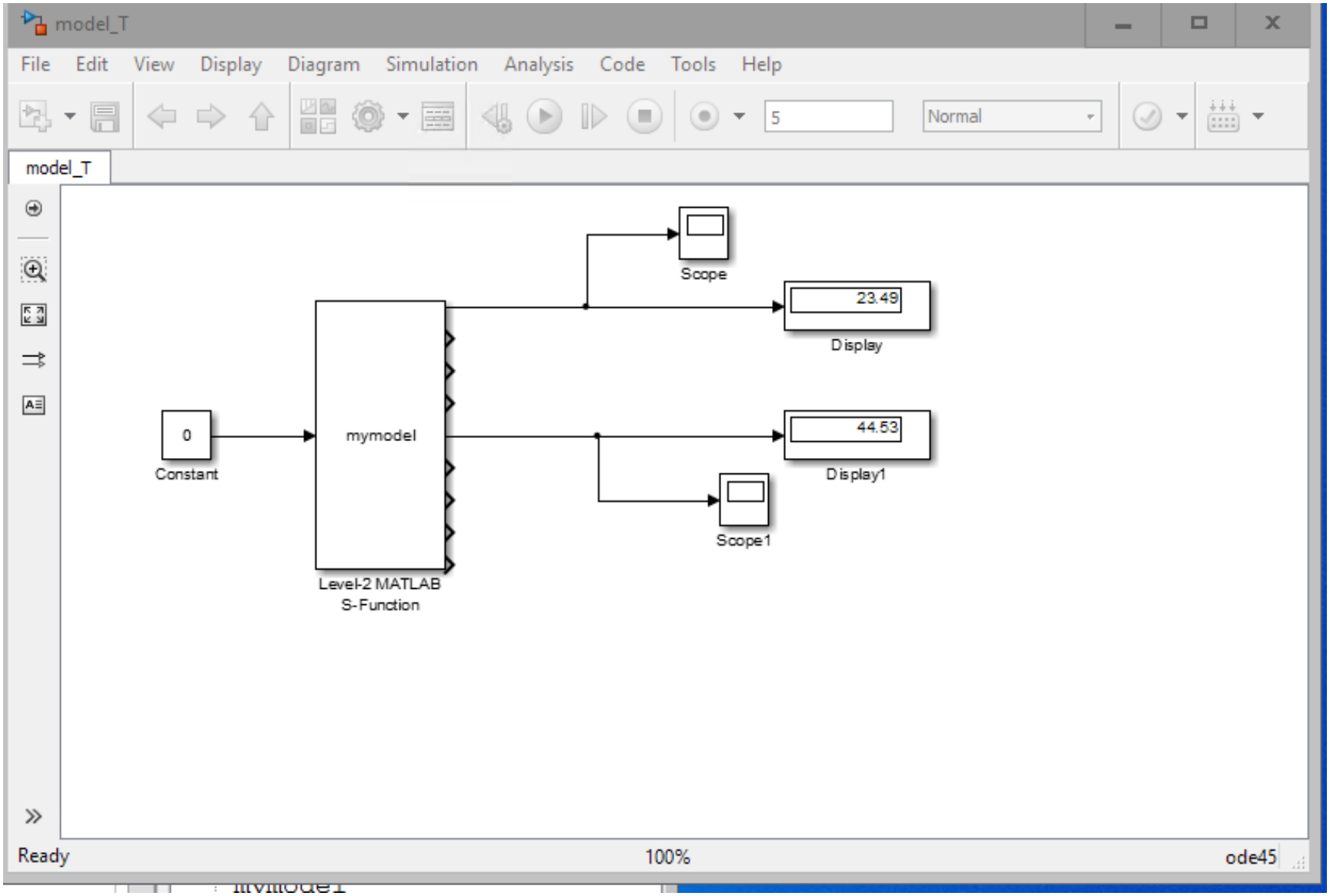

```
function Derivatives(block)
T = evalin('base','T');
h = 0.25;
m = 0.02; Cp = 460;
T(2,2) = block.ContStates.Data(1);
T(3,2) = block.ContStates.Data(2);
T(4,2) = block.ContStates.Data(3);
T(2,3) = block.ContStates.Data(4);
T(3,3) = block.ContStates.Data(5);
T(4,3) = block.ContStates.Data(6);
T(2,4) = block.ContStates.Data(7);
T(3,4) = block.ContStates.Data(8);
T(4,4) = block.ContStates.Data(9);

Q = block.InputPort(1).Data;
dT22_dt = (T(3,2)-2*T(2,2)+T(1,2))/h^2 + (T(2,3)-2*T(2,2)+T(2,1))/h^2;
dT32_dt = (T(4,2)-2*T(3,2)+T(2,2))/h^2 + (T(3,3)-2*T(3,2)+T(3,1))/h^2;
dT42_dt = (T(5,2)-2*T(4,2)+T(3,2))/h^2 + (T(4,3)-2*T(4,2)+T(4,1))/h^2;
dT23_dt = (T(3,3)-2*T(2,3)+T(1,3))/h^2 + (T(2,4)-2*T(2,3)+T(2,2))/h^2;
dT33_dt = (T(4,3)-2*T(3,3)+T(2,3))/h^2 + (T(3,4)-2*T(3,3)+T(3,2))/h^2 + Q/(m*Cp);
dT43_dt = (T(5,3)-2*T(4,3)+T(3,3))/h^2 + (T(4,4)-2*T(4,3)+T(4,2))/h^2;
dT24_dt = (T(3,4)-2*T(2,4)+T(1,4))/h^2 + (T(2,5)-2*T(2,4)+T(2,3))/h^2;
dT34_dt = (T(4,4)-2*T(3,4)+T(2,4))/h^2 + (T(3,5)-2*T(3,4)+T(3,3))/h^2;
dT44_dt = (T(5,4)-2*T(4,4)+T(3,4))/h^2 + (T(4,5)-2*T(4,4)+T(4,3))/h^2;
```

16.3.5 Создание S-функции в Simulink (запись системы уравнений в форме Коши)

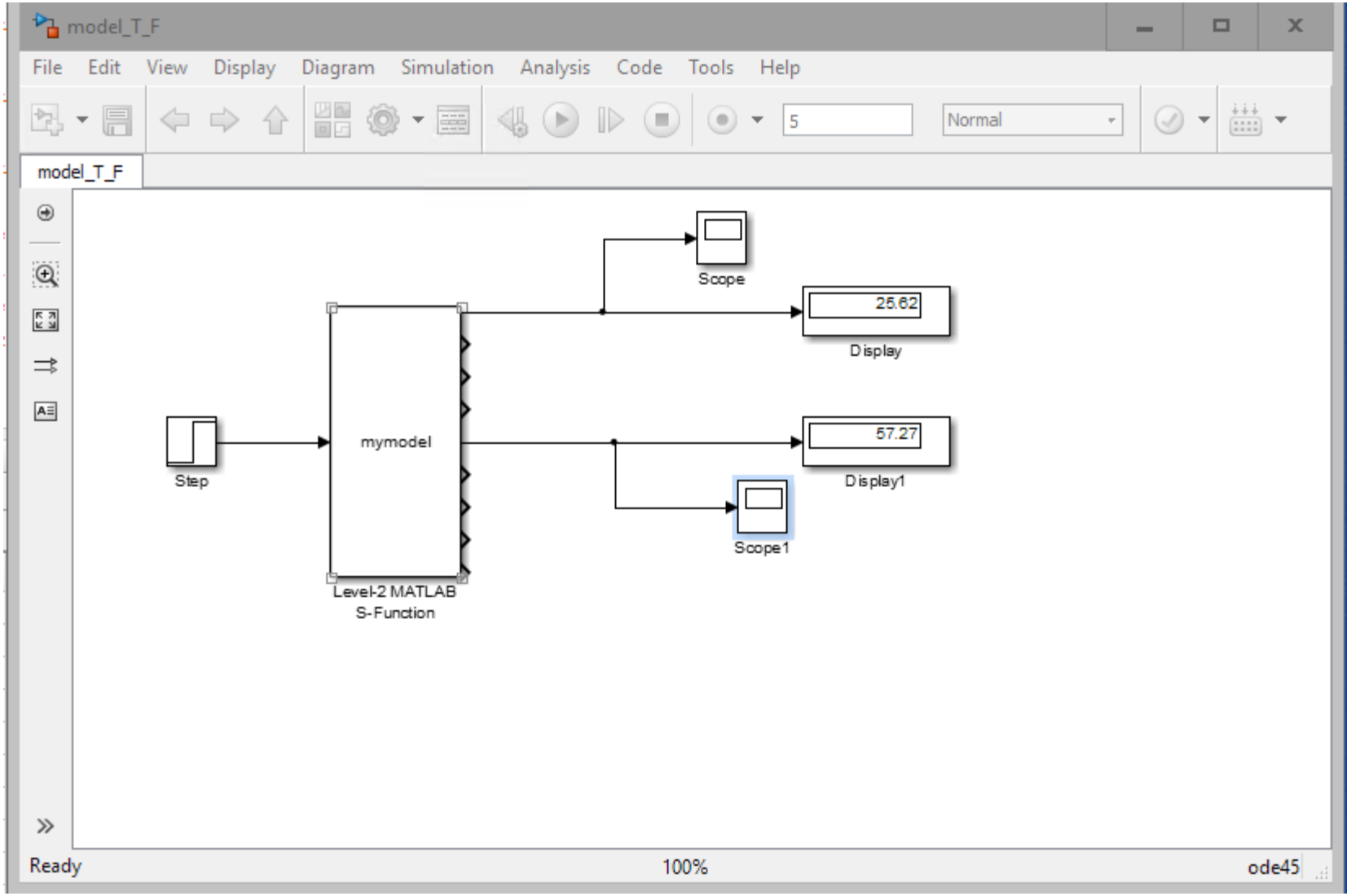
mymodel.m

```
dT43_dt = (T(5,3)-2*T(4,3)+T(3,3))/h^2 + (T(4,4)-2*T(4,3)+T(4,2))/h
dT24_dt = (T(3,4)-2*T(2,4)+T(1,4))/h^2 + (T(2,5)-2*T(2,4)+T(2,3))/h
dT34_dt = (T(4,4)-2*T(3,4)+T(2,4))/h^2 + (T(3,5)-2*T(3,4)+T(3,3))/h
dT44_dt = (T(5,4)-2*T(4,4)+T(3,4))/h^2 + (T(4,5)-2*T(4,4)+T(4,3))/h

block.Derivatives.Data(1) = dT22_dt;
block.Derivatives.Data(2) = dT32_dt;
block.Derivatives.Data(3) = dT42_dt;
block.Derivatives.Data(4) = dT23_dt;
block.Derivatives.Data(5) = dT33_dt;
block.Derivatives.Data(6) = dT43_dt;
block.Derivatives.Data(7) = dT24_dt;
block.Derivatives.Data(8) = dT34_dt;
block.Derivatives.Data(9) = dT44_dt;


function Output(block)
  block.OutputPort(1).Data = block.ContStates.Data(1); %%T(2,2)
  block.OutputPort(2).Data = block.ContStates.Data(2); %%T(3,2)
  block.OutputPort(3).Data = block.ContStates.Data(3); %%T(4,2)
  block.OutputPort(4).Data = block.ContStates.Data(4); %%T(2,3)
  block.OutputPort(5).Data = block.ContStates.Data(5); %%T(3,3)
  block.OutputPort(6).Data = block.ContStates.Data(6); %%T(4,3)
  block.OutputPort(7).Data = block.ContStates.Data(7); %%T(2,4)
  block.OutputPort(8).Data = block.ContStates.Data(8); %%T(3,4)
  block.OutputPort(9).Data = block.ContStates.Data(9); %%T(4,4)
```

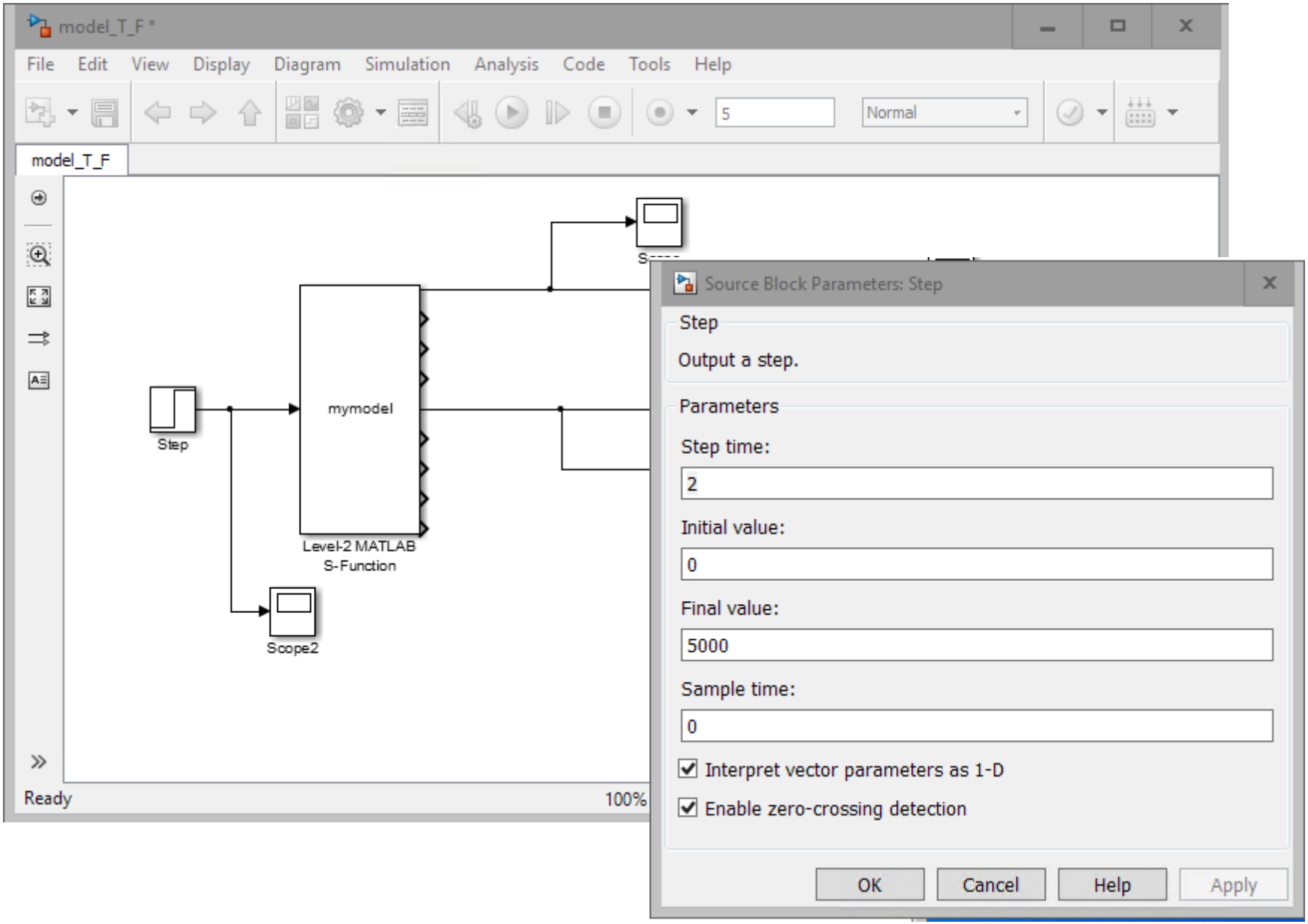
16.3.6 Работа с моделью в Simulink



16.3.6 Работа с моделью в Simulink



16.3.6 Работа с моделью в Simulink



16.3.6 Работа с моделью в Simulink