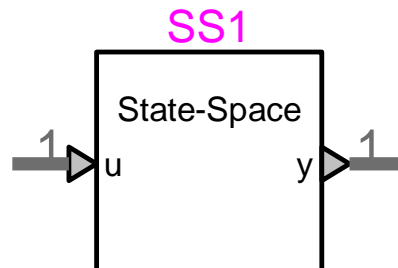


Control device: State-Space



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Jean Mahseredjian, 2018-02-24 11:02:00 PM

1 Theoretical background

This device provides the capability in control systems to use state-space equations given at any time t by:

$$\dot{\mathbf{x}} = \mathbf{Ax} + \mathbf{Bu} \quad (1)$$

$$\mathbf{y} = \mathbf{Cx} + \mathbf{Du} \quad (2)$$

Bold characters are used to denote vectors and matrices. The four constant state matrices are \mathbf{A} , \mathbf{B} , \mathbf{C} and \mathbf{D} ; \mathbf{x} is the vector of state variables, \mathbf{u} is the vector of inputs and \mathbf{y} holds the outputs.

There are two modeling options: continuous and discrete. The continuous model integrates equation (1) using the trapezoidal integration method:

$$\mathbf{x}_{t+\Delta t} = \left(\mathbf{1} - \frac{\Delta t}{2} \mathbf{A} \right)^{-1} \left(\mathbf{1} + \frac{\Delta t}{2} \mathbf{A} \right) \mathbf{x}_t + \left(\mathbf{1} - \frac{\Delta t}{2} \mathbf{A} \right)^{-1} \frac{\Delta t}{2} \mathbf{B} (\mathbf{u}_t + \mathbf{u}_{t+\Delta t}) \quad (3)$$

Equation (2) is then calculated for $t + \Delta t$.

For the discrete model:

$$\mathbf{x}_{t+\Delta t} = \mathbf{Ax}_t + \mathbf{Bu}_t \quad (4)$$

2 Parameters

The device main data tab requires entering all state matrices.

2.1 Direct input method in Data tab

In the direct input method ("Use File input" is not checked), it is needed to enter state-space model matrices A, B, C, and D.

Matrices are entered line-by-line in free format style. Brackets ("[" for opening and "]" for closing) are optional and will be automatically discarded. It is also acceptable to use semicolons ";" for separating matrix lines entered on the same text line.

The dimensions of the square matrix A define the number of states n_states .

Matrix B must have n_states rows and n_inputs columns.

Matrix C must have $n_outputs$ rows and n_states columns.

Matrix D must have $n_outputs$ rows and n_inputs columns.

All matrix dimensions are tested when entered directly. Data input errors are detected in EMTP when named values are used.

2.2 File input method in Data tab

In the File input method ("Use File input" is checked) the user must enter the name of the file which contains all necessary matrix data.

The format of the file is as follows:

- First line, free format, space separated numbers: n_outs n_inputs n_states 0
- Matrix A rows, free format, space separated cells, one matrix row by text line
- Matrix B rows, free format, space separated cells, one matrix row by text line
- Matrix C rows, free format, space separated cells, one matrix row by text line
- Matrix D rows, free format, space separated cells, one matrix row by text line

The mandatory zero (0) at the end of the first line is for compatibility with the 'State-space equations' in the power network. It indicates that there is no D1 matrix.

2.3 History data tab: Initial conditions for states

This tab allows entering initial values for states: the History matrix. The initial value can be any real number or a user-defined function $f(t)$.

The History matrix is a two column matrix, entered line-by-line and in free format. First column is for identifying initialized state number, second column is for initial value of state. There are as many rows as initialized states. If a state number is omitted it is automatically initialized to 0. The History matrix can be left empty when there are no initial conditions for all states.

2.4 State variables

In addition to its output signals, the state-space device creates one signal for each of its state variables. These signals are each given a name of the form " $devname_xi$ ", where $devname$ is the name of the device, and i is the index of the state. For example, " $SS1_x2$ " would be the name given to the 2nd state of the state-space element named " $SS1$ ".

The name of a state variable can be used by other devices of the same subcircuit like any other signal. It can be used as input to a device, and it can be referenced by name in a mathematical expression.

When a scope is requested for a state-space element, the values of its states are identified with these signal names.

2.5 Scopes

Setting the scope flag enables monitoring of the output and state values of a device during the simulation. The output values are identified as "*devname_yi*" and the state values as "*devname_xi*", where *devname* is the name of the device, and *i* is the index of the output or the state.

3 Device pins

When the device data is completed its bundle pin is automatically updated to include the required number of input and output pins. In the figure below the number 2 indicates two pins. To connect to any pin it is necessary to extend the bundle signal and right-click to select the Breakout command. The available pins are listed in the appearing panel. Non-required pins must be erased from this panel before clicking the OK button. In the case of Figure 2 all pins have been selected for both inputs and outputs.

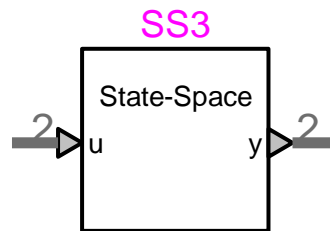


Figure 1 A state-space device with two input and two output pins

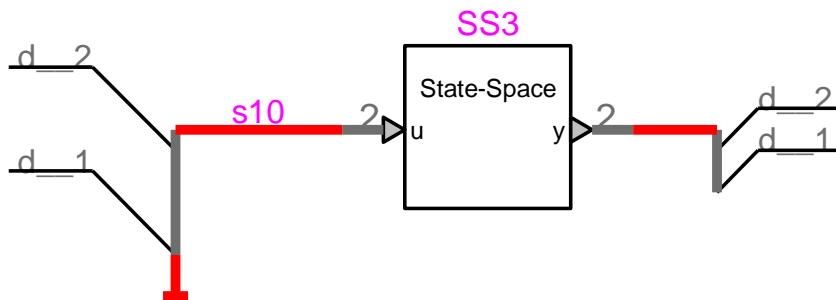


Figure 2 Selected connectivity pins after using the Breakout command

The pin names are standard, so that several devices can be connected together using the bundle signal. In the case of Figure 3 two state-space devices are connected in series. Special connections with control bundle pins can be achieved using the "Control signal connector" device. The user must use the correct vector sizes according to connectivity requirements of the given design.

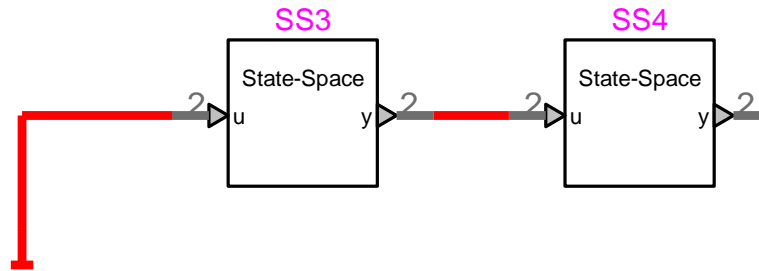


Figure 3 State-space devices connected in series

4 Output signal interpolation

During the simulation, the output and state values of this device are calculated at successive instants t at intervals Δt . Between these simulation instants, the values can be set to vary in one of two modes, ramped or stepped:

mode	output value between $t - \Delta t$ and t^-	value at t^-	value at t
ramped	interpolated linearly between values $out(t - \Delta t)$ and $out(t^-)$	calculated at t^-	calculated at t
stepped	remains at $out(t - \Delta t)$	remains at $out(t - \Delta t)$	calculated at t

5 Time-domain representation

According to theory explained in the Section 1 on theoretical background.

6 Steady-state representation

In the steady-state calculation at $t=0$, the output and state values are calculated as follows:

$$\begin{aligned} \mathbf{x}(0) &= \mathbf{history} \\ \mathbf{y}(0) &= \mathbf{C} \mathbf{x}(0) + \mathbf{D} \mathbf{u}(0) \end{aligned} \quad (5)$$

where **history** is the history vector with members initialized by the user or defaulted to 0.

7 Netlist format

This device allows method-based scripting. The object data and methods are described in the script file referenced by the device Script.Open.Dev attribute.

Sample Netlist data:

```

_cm_sscon;SS1;4;4;s9d__1,s9d__2,s10d__1,s10d__2,
2,2,2,0,0,,S0,?s,
0.1 0
0 0.1
0.1 0
0 0.1
1 0
0 1
1 0
0 1

```

Field	Description
_cm_sscon	Part name, cm_ssdis for discrete model
SS1	Instance name, any name.
4	Total number of pins
4	Number of pins given in this data section
s9d__1	First output pin in bundle s9
s9d__2	Second output pin in bundle s9
s10d__1	First input pin in bundle s10
s10d__2	Second input pin in bundle s10
2	Number of outputs (size of current vector)
2	Number of inputs (size of voltage vector)
2	Number of states
0	Number of rows in the history matrix
0	Number of rows in D1 matrix (not used in this version)
0 or empty	1 means file input method
S0 or S1	output interpolation option, S1 for stepped and S0 for ramped
file name	File name for file input method or matrices
Matrices	Matrices A, B, C, D, and History. History is optional. All matrices are appearing row-by-row. The History data (as many rows as needed) is entered one pair per row, as follows: state_number,history

Device data fields are saved in ParamsA and ModelData device attributes.