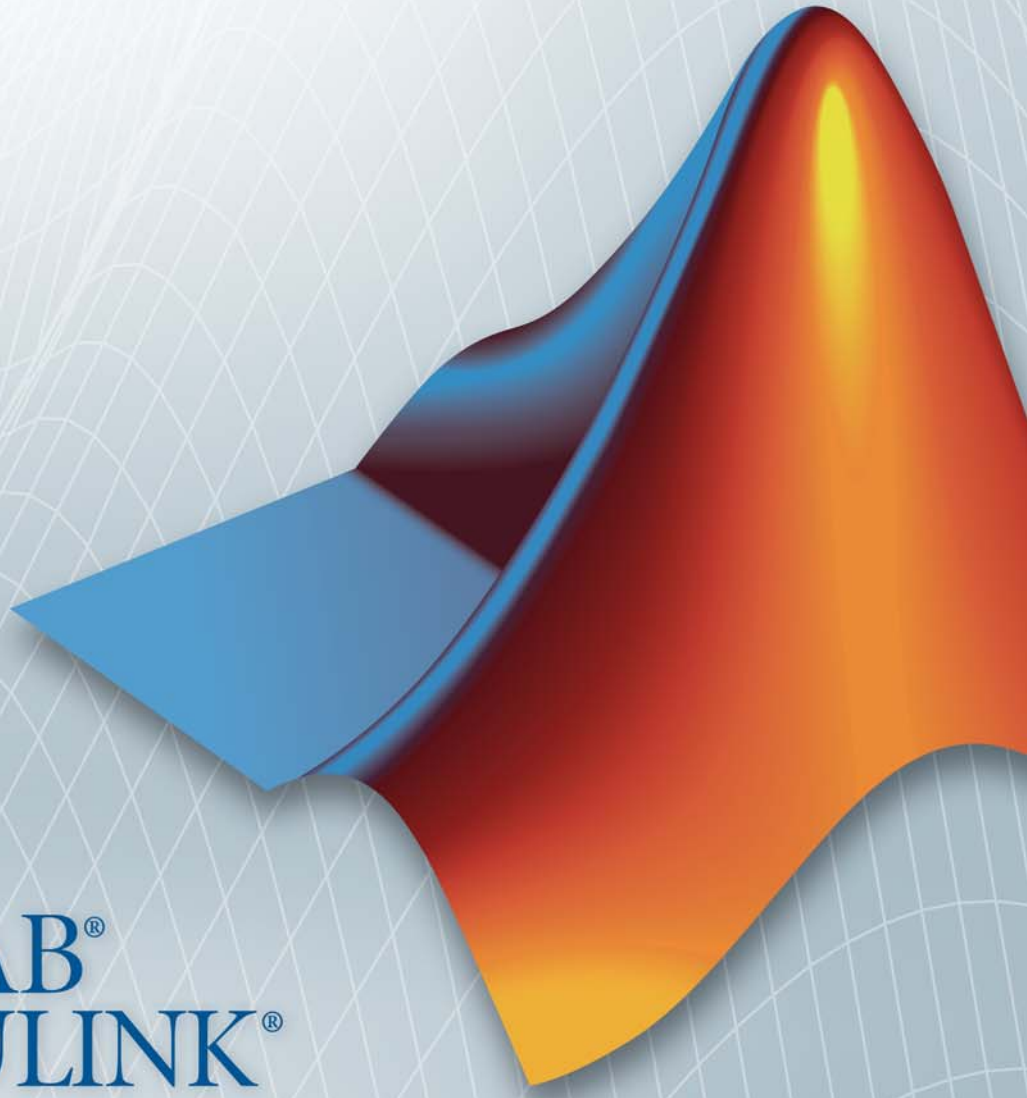
SimElectronics®

User's Guide

R2011b



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SimElectronics® User's Guide

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Getting Started

Product Overview

In this section...

Product Description

SimElectronics® provides component libraries for modeling and simulating electronic and mechatronic systems. It includes models of semiconductor, motor, drive, sensor, and actuator components. You can use these components to perform system-level design of electromechanical actuation systems and to evaluate analog circuit architectures using behavioral models. Models created from SimElectronics components support control and algorithm design in electronic and mechatronic systems, such as vehicle body electronics, aircraft servomechanisms, and audio power amplifiers. For circuit modeling, the semiconductor models include nonlinear and dynamic temperature effects, enabling you to select components in amplifiers, analog-to-digital converters, phase-locked loops, and other circuits.

Assumptions and Limitations

SimElectronics contains blocks that let you model electronic and mechatronic systems at a speed and level of fidelity that is appropriate for system-level analysis. The blocks let you perform tradeoff analyses to optimize system design, for example, by testing various algorithms with different circuit implementations. The library contains blocks that use either high-level or more detailed models to simulate components. SimElectronics does not have the capability to:

- Model large circuits with dozens of analog components, such as a complete transceiver.
- Perform either layout (physical design) tasks, or the associated implementation tasks such as layout versus schematic (LVS), design rule checking (DRC), parasitic extraction, and back annotation.

- Model 3-D parasitic effects that are typically important for high-frequency applications.

For these types of requirements, you must use an EDA package specifically designed for the implementation of analog circuits.

Another MathWorks® product, SimPowerSystems™ software, is better suited for power system networks where:

- The underlying equations are predominantly linear (e.g., transmission lines and linear machine models).
- Three-phase motors and generators are used.

SimPowerSystems has blocks and solvers specifically designed for these types of applications.

Modeling Physical Networks with SimElectronics Blocks

SimElectronics is part of the Simulink® Physical Modeling family. Models using SimElectronics are essentially Simscape™ block diagrams. To build a system-level model with electrical blocks, use a combination of SimElectronics blocks and other Simscape and Simulink blocks. You can connect SimElectronics blocks directly to Simscape blocks. You can connect Simulink blocks through the Simulink-PS Converter and PS-Simulink Converter blocks from the Simscape Utilities library. These blocks convert electrical signals to and from Simulink mathematical signals. For more information about connecting different types of blocks, see “Connecting Model Blocks” on page 2-17.

For more information about basic principles to follow when building an electrical model with SimElectronics, see “Basic Principles of Modeling Physical Networks” in the Simscape documentation.

Getting Online Help

Using the MATLAB Help System for Documentation and Demos

The MATLAB® Help browser allows you to access the documentation and demo models for all the MATLAB and Simulink based products that you have installed. Consult "Find Help and Documentation" in MATLAB documentation for more information about the Help system.

For...	See...
List of blocks	"Block Reference"
Advanced tutorials	Examples
Product demonstrations	SimElectronics Demos
What's new in this product	Release Notes

MathWorks Online

Point your Internet browser to the MathWorks Web site for additional information and support at http://www.mathworks.com/products/simelectronics/.

Required and Related Products

Product Requirements

SimElectronics software is an extension of Simscape product, expanding its capabilities to model and simulate electronic and electromechanical elements and devices.

SimElectronics software requires these products:

- MATLAB
- Simulink
- Simscape

Other Related Products

The SimElectronics product page at the MathWorks Web site lists the toolboxes and blocksets that extend the capabilities of MATLAB and Simulink. These products can enhance your use of SimElectronics software in various applications.

For more information about MathWorks software products, see:

- The online documentation for that product if it is installed
- The MathWorks Web site at `www.mathworks.com`

SimElectronics Block Libraries

In this section...

Overview of SimElectronics Libraries

SimElectronics libraries provide blocks for modeling electromechanical and electrical systems within the Simulink environment. You can also create custom components either by combining SimElectronics components as Simulink subsystems, or by using the Simscape language.

Note SimElectronics follows the standard Simulink conventions where block inputs and outputs are called *ports*. In SimElectronics, each port represents a single electrical terminal.

A SimElectronics model can contain blocks from the standard SimElectronics library, from the Simscape Foundation and Utilities libraries, or from a custom library you create, using the Simscape language, based on the Simscape Foundation electrical domain. A model can also include Simulink blocks and blocks from other products, such as those described in "Required and Related Products" on page 1-5.

For more information on modeling physical and electrical components, see "Modeling Electronic Components" on page 2-2.

Opening SimElectronics Libraries

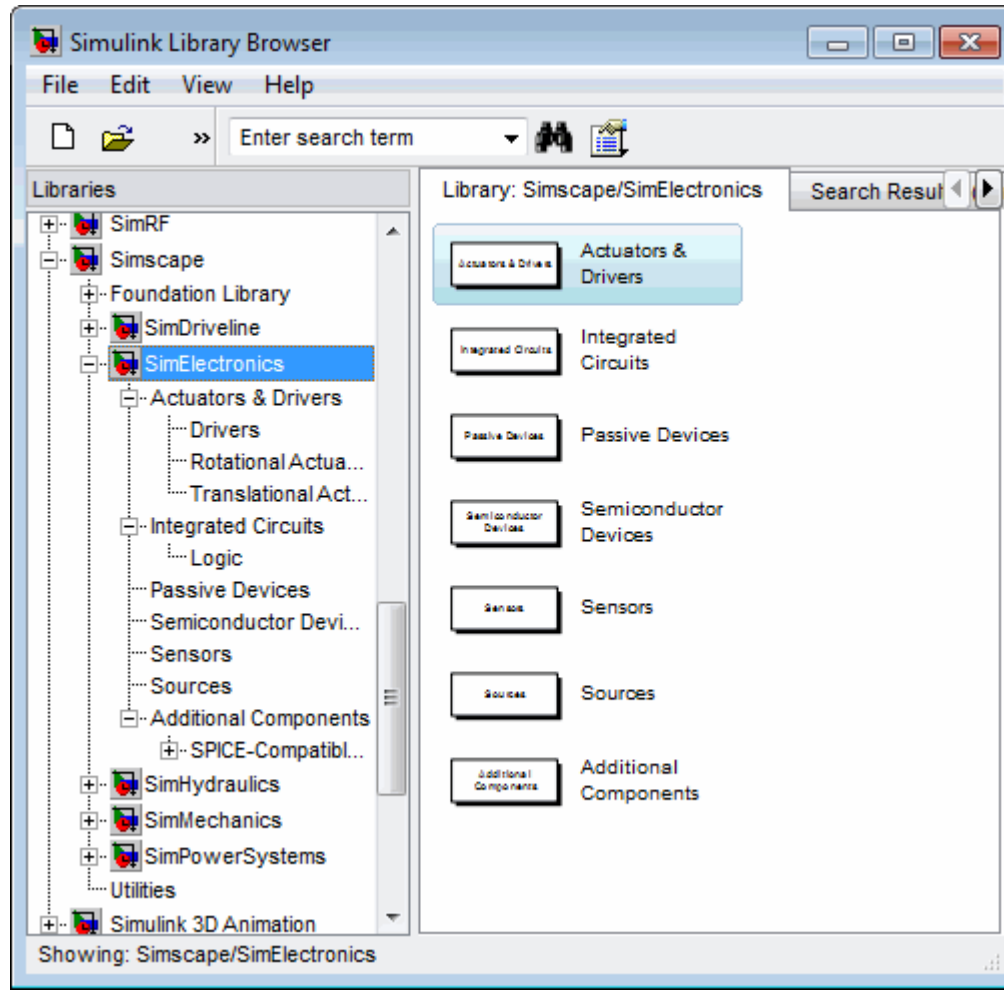
There are two ways to access SimElectronics blocks:

- "Using the Simulink Library Browser to Access the Block Libraries" on page 1-7
- "Using the Command Prompt to Access the Block Libraries" on page 1-8

Using the Simulink Library Browser to Access the Block Libraries

You can access the blocks through the Simulink Library Browser. To display the Library Browser, click the **Library Browser** button in the toolbar of the MATLAB desktop or Simulink model window:

Alternatively, you can type `simulink` in the MATLAB Command Window. Then expand the **Simscape** entry in the contents tree.



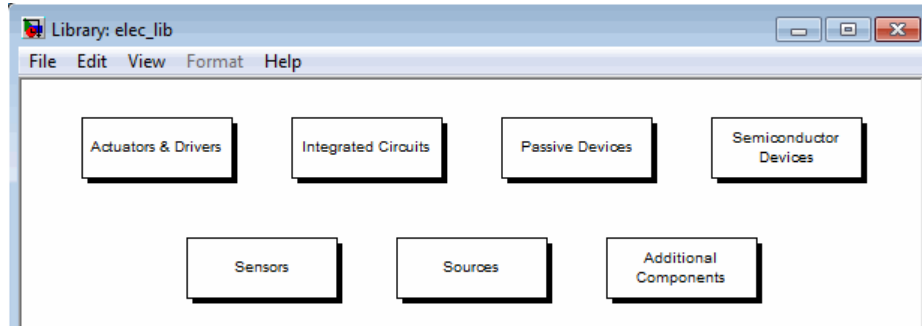
For more information on using the Library Browser, see "Library Browser" in the *Simulink Graphical User Interface* documentation.

Using the Command Prompt to Access the Block Libraries

Another way to access the block libraries is to open them individually by using the command prompt:

- To open just the SimElectronics library, type `elec_lib` in the MATLAB Command Window.
- To open the Simscape library (to access the utility blocks, as well as electrical sources, sensors, and other Foundation library blocks), type `simscape` in the MATLAB Command Window.
- To open the main Simulink library (to access generic Simulink blocks), type `simulink` in the MATLAB Command Window.

The SimElectronics library window is shown in the following figure. Each icon in the window represents a library. Some of these libraries contain second-level sublibraries. Double-click an icon to open the corresponding library.



Product Workflow

When you analyze an electronic or electromechanical system using SimElectronics software, your workflow might include the following tasks:

1. Create a Simulink model that includes electronic or electromechanical components.

   In the majority of applications, it is most natural to model the physical system using Simscape and SimElectronics blocks, and then develop the controller or signal processing algorithm in Simulink.

   For more information about modeling the physical system, see "Modeling Electronic Components" on page 2-2.

2. Define component data by specifying electrical or mechanical properties as defined on a datasheet.

3. Configure the solver options.

   For more information about the settings that most affect the solution of a physical system, see Chapter 3, "Simulating an Electronic System".

4. Run the simulation.

   For more information on how the product performs time-domain simulation of an electronic system, see "Running a Time-Domain Simulation" on page 3-6.

Example — Modeling a DC Motor

In this section...

Overview of DC Motor Example

In this example, you model a DC motor driven by a constant input signal that approximates a pulse-width modulated signal and look at the current and rotational motion at the motor output.

To see the completed model, open the Controlled DC Motor demo.

Selecting Blocks to Represent System Components

Select the blocks to represent the input signal, the DC motor, and the motor output displays.

The following table describes the role of the blocks that represent the system components.

Block	Description
Solver Configuration	Defines solver settings that apply to all physical modeling blocks.
DC Voltage Source	Generates a DC signal.
Controlled PWM Voltage	Generates the signal that approximates a pulse-width modulated motor input signal.
H-Bridge	Drives the DC motor.

Block	Description
Current Sensor	Converts the electrical current that drives the motor into a physical signal proportional to the current.
Ideal Rotational Motion Sensor	Converts the rotational motion of the motor into a physical signal proportional to the motion.
DC Motor	Converts input electrical signal into mechanical motion.
PS-Simulink Converter	Converts the input physical signal to a Simulink signal.
Scope	Displays motor current and rotational motion.
Electrical Reference	Provides the electrical ground.
Mechanical Rotational Reference	Provides the mechanical ground.

Building the Model

Create a Simulink model, add blocks to the model, and connect the blocks.

1. Create a model.

   If you are new to Simulink, see the "Creating a Simulink Model" example for information on how to create a model.

2. Add to the model the blocks listed in the following table. The Library column of the table specifies the hierarchical path to each block.

Block	Library Path	Quantity
Solver Configuration	**Simscape > Utilities**	1
DC Voltage Source	**Simscape > Foundation Library > Electrical > Electrical Sources**	1

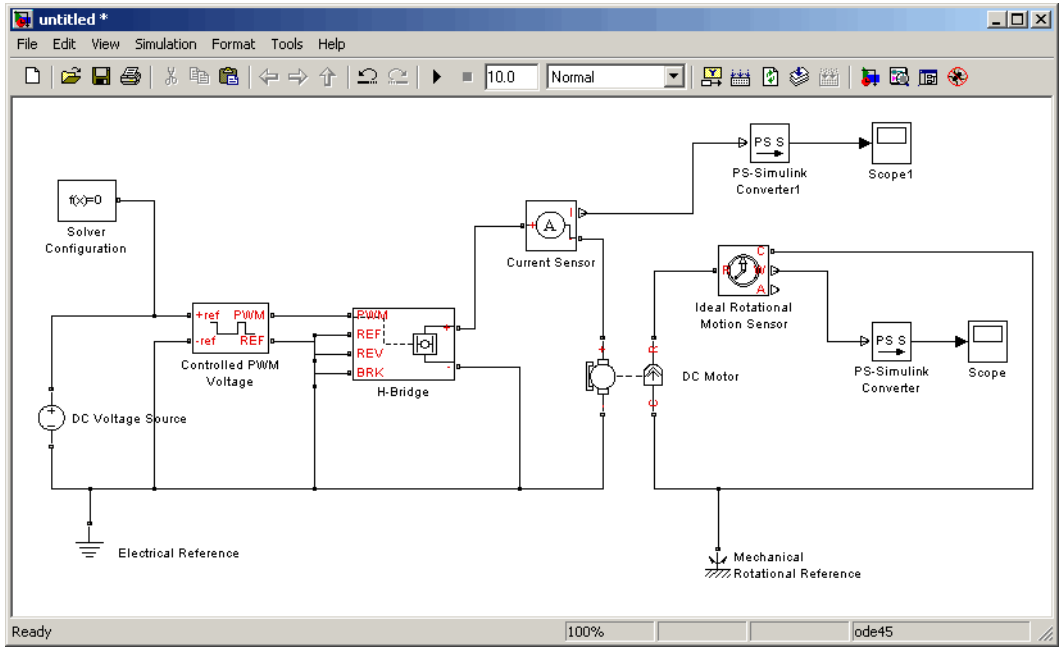
Block	Library Path	Quantity
Controlled PWM Voltage	**Simscape > SimElectronics > Actuators & Drivers > Drivers**	1
H-Bridge	**Simscape > SimElectronics > Actuators & Drivers > Drivers**	1
Current Sensor	**Simscape > Foundation Library > Electrical > Electrical Sensors**	1
Ideal Rotational Motion Sensor	**Simscape > Foundation Library > Mechanical > Mechanical Sensors**	1
DC Motor	**Simscape > SimElectronics > Actuators & Drivers > Rotational Actuators**	1
PS-Simulink Converter	**Simscape > Utilities**	2
Scope	**Simulink > Commonly Used Blocks**	2
Electrical Reference	**Simscape > Foundation Library > Electrical > Electrical Elements**	1
Mechanical Rotational Reference	**Simscape > Foundation Library > Mechanical > Rotational Elements**	1

Note You can use the Simscape function `ssc_new` with a domain type of `electrical` to create a Simscape model that contains the following blocks:

- **Simulink-PS Converter**
- **PS-Simulink Converter**
- **Scope**
- **Solver Configuration**
- **Electrical Reference**

This function also selects the Simulink `ode15s` solver.

3 Connect the blocks as shown in the following figure.



Now you are ready to specify block parameters.

Specifying Model Parameters

Specify the following parameters to represent the behavior of the system components:

Model Setup Parameters

The following blocks specify model information that is not specific to a particular block:

- Solver Configuration
- Electrical Reference
- Mechanical Rotational Reference

As with Simscape models, you must include a Solver Configuration block in each topologically distinct physical network. This example has a single physical network, so use one Solver Configuration block with the default parameter values.

You must include an Electrical Reference block in each SimElectronics network. You must include a Mechanical Rotational Reference block in each network that includes electromechanical blocks. These blocks do not have any parameters.

For more information about using reference blocks, see "Grounding Rules" in the Simscape documentation.

Motor Input Signal Parameters

You generate the motor input signal using three blocks:

- The DC Voltage Source block generates a constant signal.

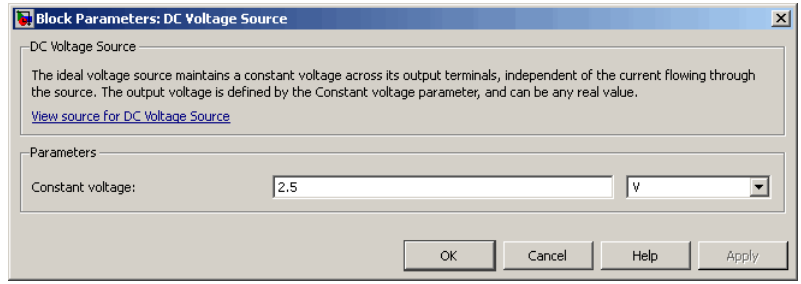
- The Controlled PWM Voltage block generates a pulse-width modulated signal.
- The H-Bridge block drives the motor.

In this example, all input ports of the H-Bridge block except the PWM port are connected to ground. As a result, the H-Bridge block behaves as follows:

- When the motor is on, the H-Bridge block connects the motor terminals to the power supply.
- When the motor is off, the H-Bridge block acts as a freewheeling diode to maintain the motor current.

In this example, you simulate the motor with a constant current whose value is the average value of the PWM signal. By using this type of signal, you set up a fast simulation that estimates the motor behavior.

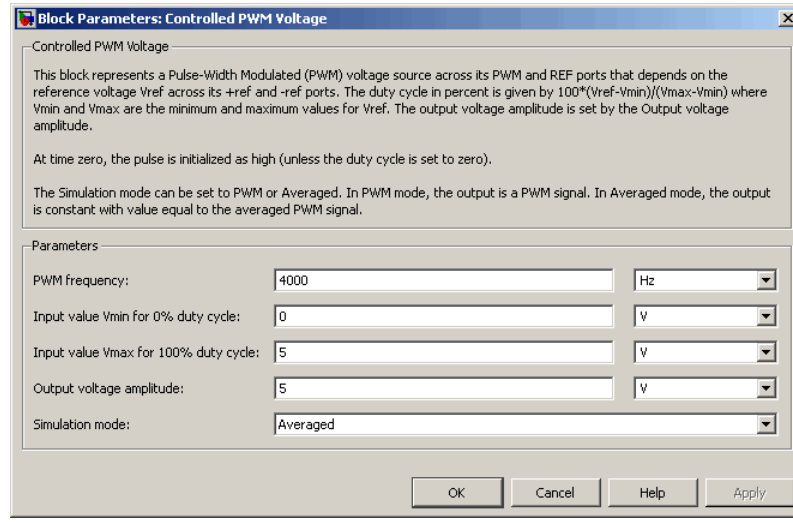
1. Set the DC Voltage Source block parameters as follows:
   - **Constant voltage** = `2.5`



2. Set the Controlled PWM Voltage block parameters as follows:
   - **PWM frequency** = `4000`

- **Simulation mode** = `Averaged`

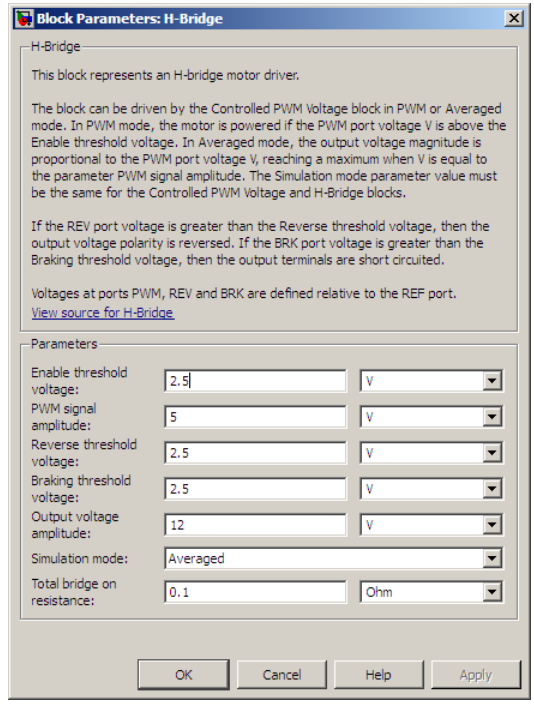
  This value tells the block to generate an output signal whose value is the average value of the PWM signal. Simulating the motor with an averaged signal estimates the motor behavior in the presence of a PWM signal. To validate this approximation, use value of `PWM` for this parameter.



3 Set the H-Bridge block parameters as follows:

- **Simulation mode** = `Averaged`

  This value tells the block to generate an output signal whose value is the average value of the PWM signal. Simulating the motor with an averaged signal estimates the motor behavior in the presence of a PWM signal. To validate this approximation, use value of `PWM` for this parameter to validate this approximation.



Motor Parameters

Configure the block that models the motor.

Set the Motor block parameters as follows, leaving the unit settings at their default values where applicable:

- **Electrical Torque** tab:

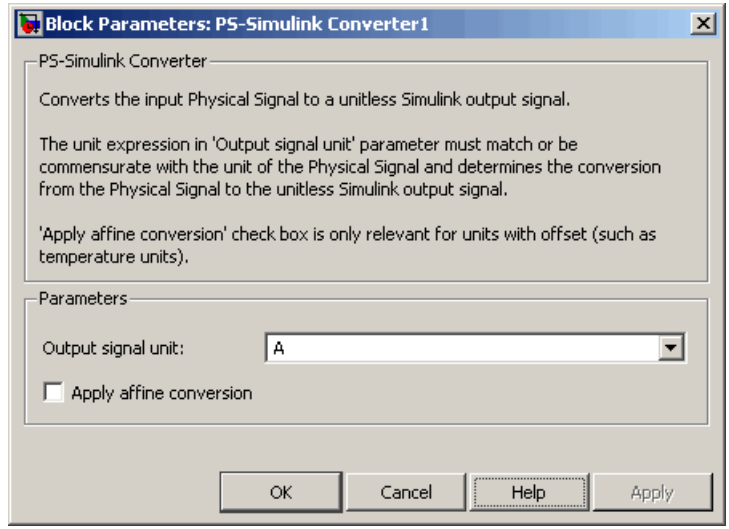
  - **Model parameterization** = `By rated power, rated speed & no-load speed`
  - **Armature inductance** = `0.01`
  - **No-load speed** = `4000`
  - **Rated speed (at rated load)** = `2500`
  - **Rated load (mechanical power)** = `10`
  - **Rated DC supply voltage** = `12`
- **Mechanical** tab:
  - **Rotor inertia** = `2000`
  - **Rotor damping** = `1e-06`

Current Display Parameters

Specify the parameters of the blocks that create the motor current display:

- Current Sensor block
- PS-Simulink Converter1 block
- Scope1 block

Of the three blocks, only the PS-Simulink Converter1 block has parameters. Set the PS-Simulink Converter1 block **Output signal unit** parameter to `A` to indicate that the block input signal has units of amperes.



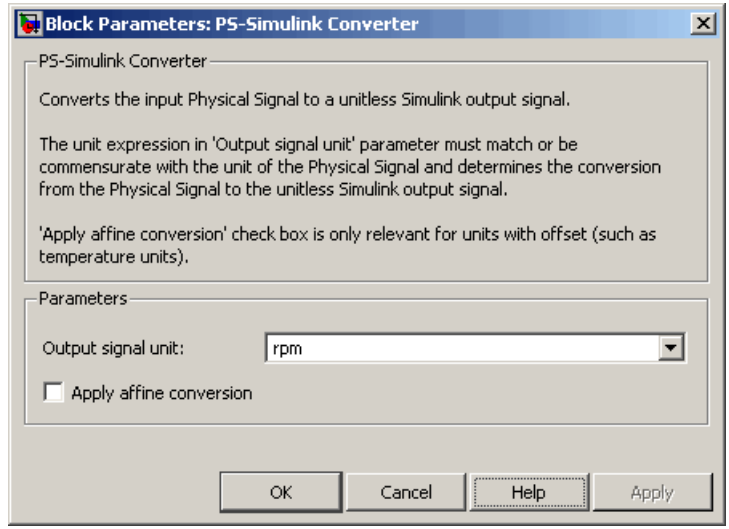
Torque Display Parameters

Specify the parameters of the blocks that create the motor torque display:

- Ideal Rotational Motion Sensor block
- PS-Simulink Converter block
- Scope block

Of the three blocks, only the PS-Simulink Converter block has parameters you need to configure for this example. Set the PS-Simulink Converter block **Output signal unit** parameter to `rpm` to indicate that the block input signal has units of revolutions per minute.

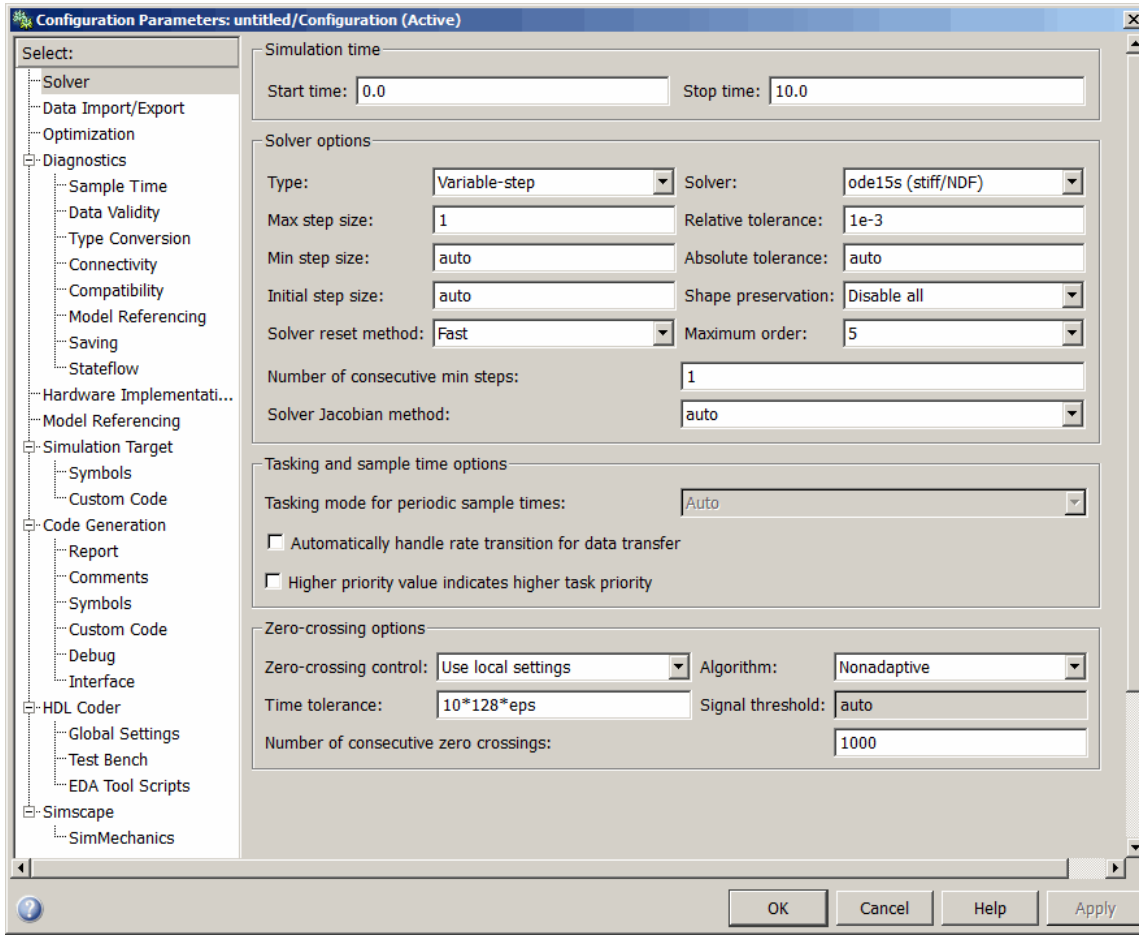
Note You must type this parameter value. It is not available in the drop-down list.



Configuring the Solver Parameters

Configure the solver parameters to use a continuous-time solver because SimElectronics models only run with a continuous-time solver. Increase the maximum step size the solver can take so the simulation runs faster.

1. In the model window, select **Simulation > Configuration Parameters** to open the **Configuration Parameters** dialog box.
2. Select `ode15s (Stiff/NDF)` from the **Solver** list.
3. Enter `1` for the **Max step size** parameter value.
4. Click **OK**.



For more information about configuring solver parameters, see Chapter 3, “Simulating an Electronic System”.

Running the Simulation and Analyzing the Results

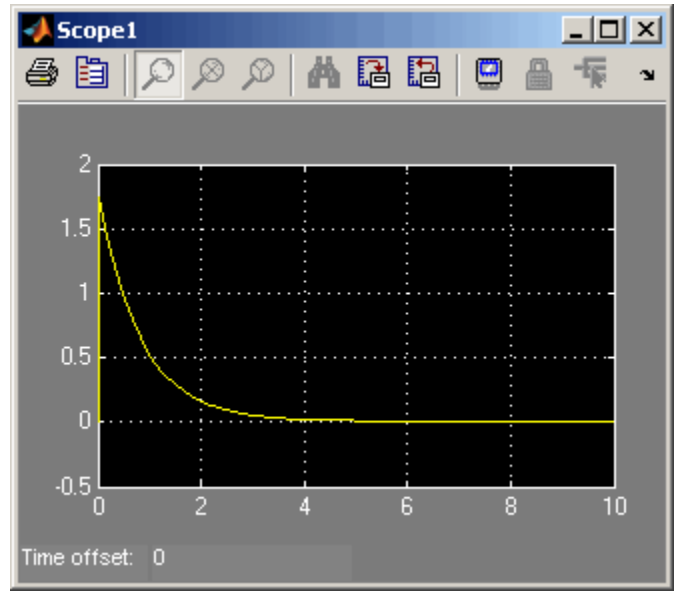
In this part of the example, you run the simulation and plot the results.

In the model window, select **Simulation > Start** to run the simulation.

To view the motor current and torque in the Scope windows, double-click the Scope blocks. You can do this before or after you run the simulation.

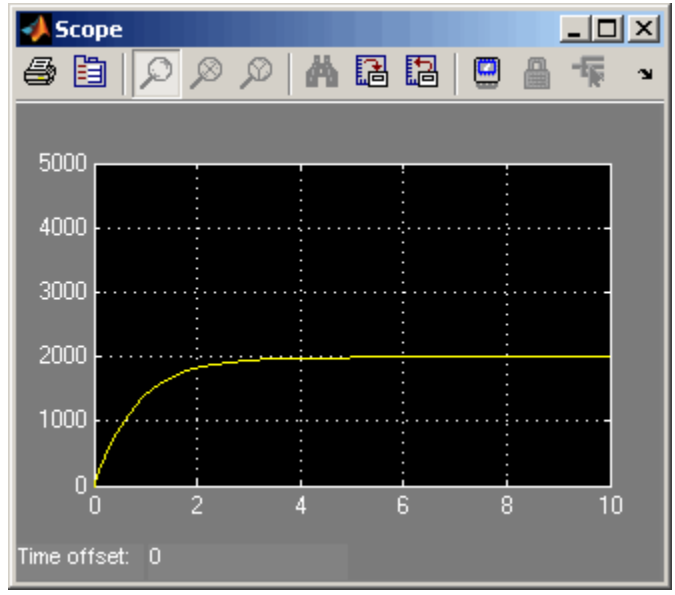
Note By default, the scope displays appear stacked on top of each other on the screen, so you can only see one of them. Click and drag the windows to reposition them.

The following plot shows the motor current.



Motor Current

The next plot shows the motor rpm.



Motor RPM

As expected, the motor runs at about 2000 rpm when the applied DC voltage is 2.5 V.

Example — Modeling a Triangle Wave Generator

In this section...

Overview of Triangle Wave Generator Example

In this example, you model a triangle wave generator using SimElectronics electrical blocks and custom SimElectronics electrical blocks, and then look at the voltage at the wave generator output.

You use a classic circuit configuration consisting of an integrator and a noninverting amplifier to generate the triangle wave, and use datasheets to specify block parameters. For more information, see "Parameterizing Blocks" on page 2-2.

To see the completed model, open the Triangle Wave Generator demo.

Selecting Blocks to Represent System Components

First, you select the blocks to represent the input signal, the triangle wave generator, and the output signal display.

You model the triangle wave generator with a set of physical blocks bracketed by a Simulink-PS Converter block and a PS-Simulink Converter block. The wave generator consists of:

- Two operational amplifier blocks
- Resistors and a capacitor that work with the operational amplifiers to create the integrator and noninverting amplifier

- Simulink-PS Converter and PS-Simulink Converter blocks. The function of the Simulink-PS Converter and PS-Simulink Converter blocks is to bridge the physical part of the model, which uses bidirectional physical signals, and the rest of the model, which uses unidirectional Simulink signals.

You have a manufacturer datasheet for the two operational amplifiers you want to model. Later in the example, you use the datasheet to parameterize the SimElectronics Band-Limited Op-Amp block.

The following table describes the role of the blocks that represent the system components.

Block	Description
Sine Wave	Generates a sinusoidal signal that controls the resistance of the Variable Resistor block.
Simulink-PS Converter	Converts the sinusoidal Simulink signal to a physical signal.
Solver Configuration	Defines solver settings that apply to all physical modeling blocks.
Electrical Reference	Provides the electrical ground.
Capacitor	Works with an operational amplifier and resistor block to create the integrator.
Resistor	Works with the operational amplifier and capacitor blocks to create the integrator and noninverting amplifier.
Variable Resistor	Supplies a time-varying resistance that adjusts the gain of the integrator, which in turn varies the frequency and amplitude of the generated triangular wave.
DC Voltage Source	Generates a DC reference signal for the operational amplifier block of the noninverting amplifier.
Voltage Sensor	Converts the electrical voltage at the output of the integrator into a physical signal proportional to the current.

Block	Description
PS-Simulink Converter	Converts the output physical signal to a Simulink signal.
Scope	Displays the triangular output wave.
Band-Limited Op-Amp	Works with the capacitor and resistor to create an integrator and a noninverting amplifier.
Diode	Limit the output of the Band-Limited Op-Amp block, to make the output waveform independent of supply voltage.

Building the Model

Create a Simulink model, add blocks to the model, and connect the blocks.

1 Create a model.

If you are new to Simulink, see the "Creating a Simulink Model" example for information on how to create a model.

2 Add to the model the blocks listed in the following table. The Library Path column of the table specifies the hierarchical path to each block.

Block	Library Path	Quantity
Sine Wave	**Simulink > Sources**	1
Simulink-PS Converter	**Simscape > Utilities**	1
Solver Configuration	**Simscape > Utilities**	1
Electrical Reference	**Simscape > Foundation Library > Electrical > Electrical Elements**	1
Capacitor	**Simscape > Foundation Library > Electrical > Electrical Elements**	1

Block	Library Path	Quantity
Resistor	**Simscape > Foundation Library > Electrical > Electrical Elements**	3
Variable Resistor	**Simscape > Foundation Library > Electrical > Electrical Elements**	1
DC Voltage Source	**Simscape > Foundation Library > Electrical > Electrical Sources**	1
Voltage Sensor	**Simscape > Foundation Library > Electrical > Electrical Sensors**	1
PS-Simulink Converter	**Simscape > Utilities**	1
Scope	**Simulink > Commonly Used Blocks**	1
Band-Limited Op-Amp	**Simscape > SimElectronics > Integrated Circuits**	2
Diode	**Simscape > SimElectronics > Semiconductor Devices**	2

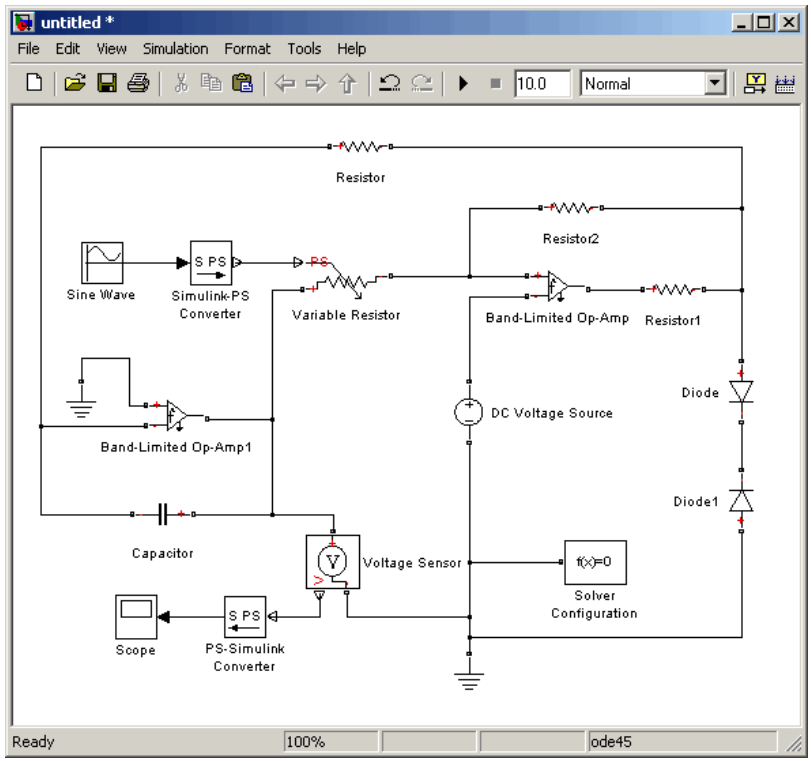
Note You can use the Simscape function `ssc_new` with a domain type of `electrical` to create a Simscape model that contains the following blocks:

- **Simulink-PS Converter**
- **PS-Simulink Converter**
- **Scope**
- **Solver Configuration**
- **Electrical Reference**

This function also selects the Simulink `ode15s` solver.

3 Connect the blocks as shown in the following figure.

> **Note** Use **Ctrl+R** to rotate blocks so that their orientations match those shown in the figure.



Now you are ready to specify block parameters.

Specifying Model Parameters

Specify the following parameters to represent the behavior of the system components:

- “Model Setup Parameters” on page 1-30

Model Setup Parameters

The following blocks specify model information that is not specific to a particular block:

- Solver Configuration
- Electrical Reference

As with Simscape models, you must include a Solver Configuration block in each topologically distinct physical network. This example has a single physical network, so use one Solver Configuration block with the default parameter values.

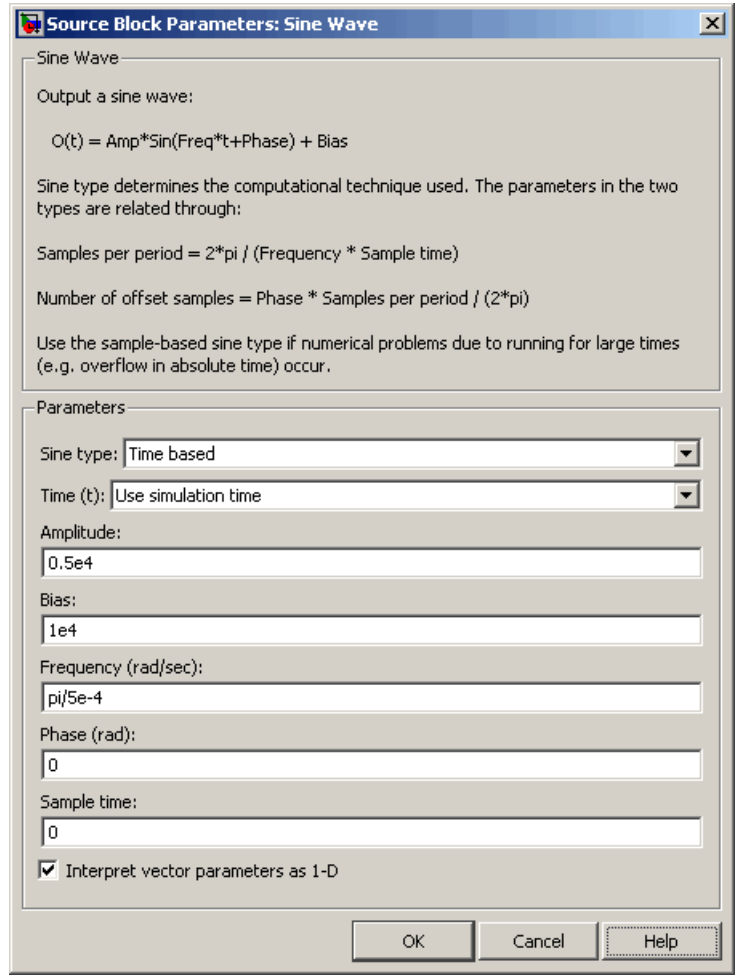
You must include an Electrical Reference block in each SimElectronics network. This block does not have any parameters.

Input Signal Parameters

Generate the sinusoidal control signal using the Sine Wave block.

Set the Sine Wave block parameters as follows:

- **Amplitude** = `0.5e4`
- **Bias** = `1e4`
- **Frequency (rad/sec)** = `pi/5e-4`



Triangle Wave Generator Parameters

Configure the blocks that model the physical system that generates the triangle wave:

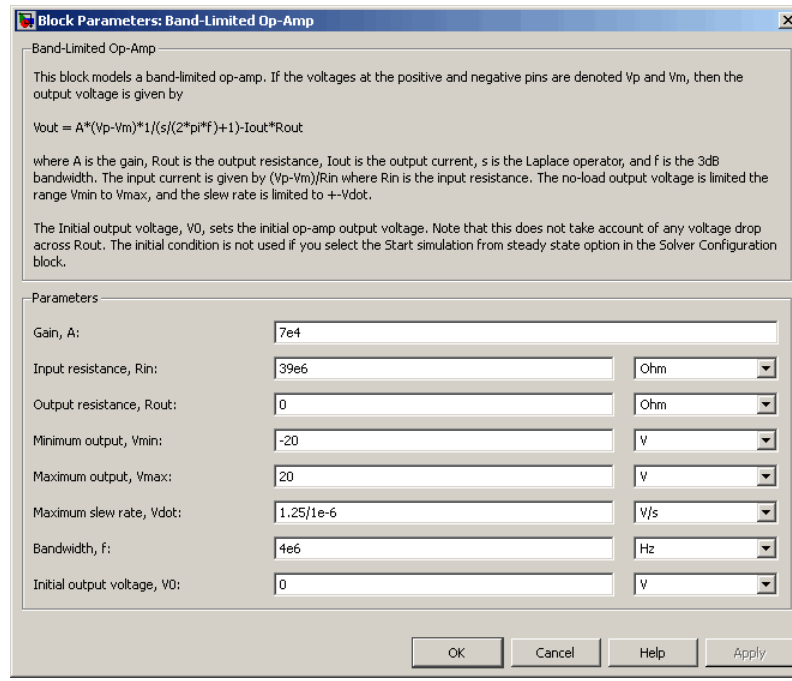
- Integrator — Band-Limited Op-Amp, Capacitor, and Resistor blocks
- Noninverting amplifier — Band-Limited Op-Amp1, Resistor2, and Variable Resistor blocks

- Resistor1
- Diode and Diode1
- Simulink-PS Converter and PS-Simulink Converter blocks that bridge the physical part of the model and the Simulink part of the model.

1 Accept the default parameters for the Simulink-PS Converter block. These parameters establish the units of the physical signal at the block output such that they match the expected default units of the Variable Resistor block input.

2 Set the two Band-Limited Op-Amp block parameters for the LM7301 device with a +–20V power supply:

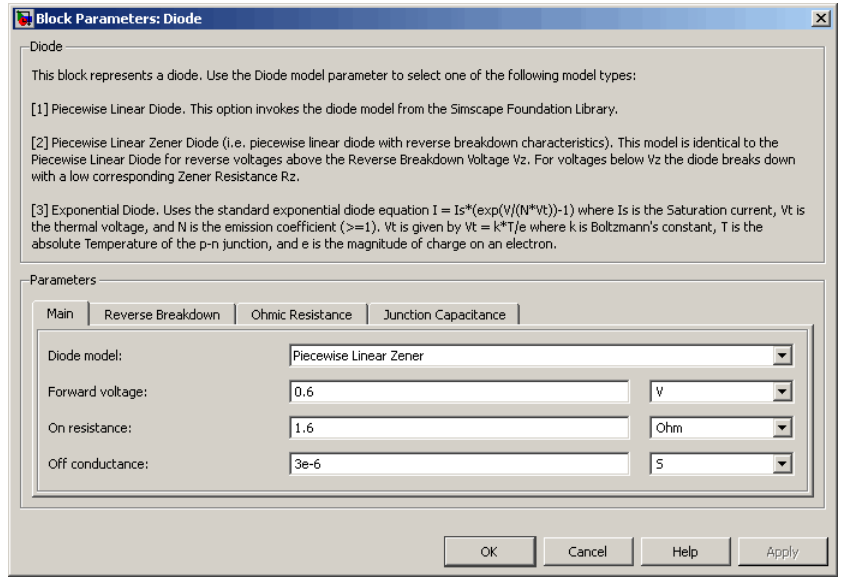
- The datatsheet gives the gain as 97dB, which is equivalent to 10^(97/20)=7.080e4. Set the **Gain, A** parameter to `7e4`.
- The datatsheet gives input resistance as 39Mohms. Set **Input resistance, Rin** to `39e6`.
- Set **Output resistance, Rout** to `0` ohms. The datatsheet does not quote a value for Rout, but the term is insignificant compared to the output resistor that it drives.
- Set minimum and maximum output voltages to –20 and +20 volts, respectively.
- The datatsheet gives the maximum slew rate as 1.25V/µs. Set the **Maximum slew rate, Vdot** parameter to `1.25e6` V/s.

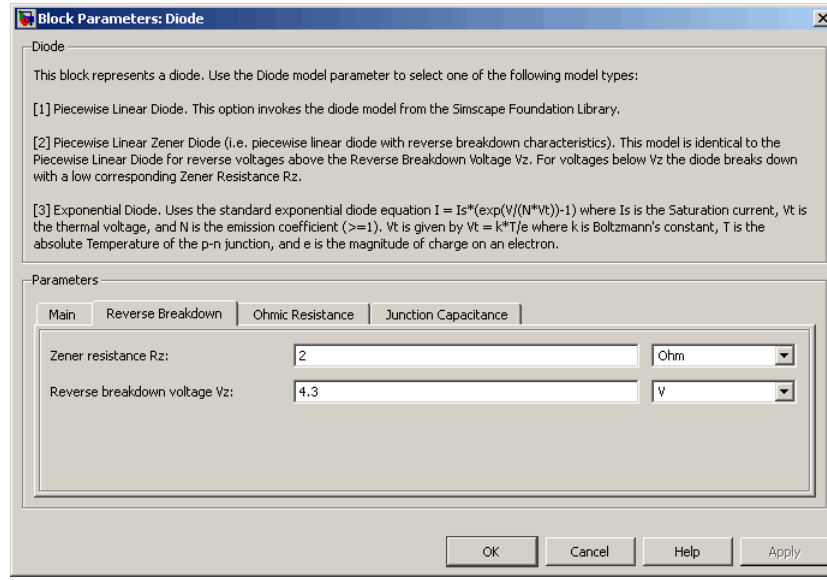


3 Set the two Diode block parameters for a 4.3V zener diode. To model a BZX384-B4V3, set block parameters as follows:

- On the Main tab, set **Diode model** to `Piecewise Linear Zener`. This selects a simplified zener diode model that is more than adequate to test the correct operation of this circuit.
- Leave the **Forward voltage** as 0.6V — this is a typical value for most diodes.
- The datatsheet gives the forward current as 250mA when the forward voltage is 1V. So that the Diode block matches this, set the **On resistance** to (1V – 0.6V)/250mA = `1.6` ohms.
- The datatsheet gives the reverse leakage current as 3µA at a reverse voltage of 1V. Therefore, set the **Off conductance** to 3µA/1V = `3e-6` S.
- The datatsheet gives the reverse voltage as 4.3V. On the Reverse Breakdown tab, set the **Reverse breakdown voltage Vz** to `4.3` V.

- Set the **Zener resistance Rz** to a suitably small number. The datatsheet quotes the zener voltage for a reverse current of 5mA. For the Diode block to be representative of the real device, the simulated reverse voltage should be close to 4.3V at 5mA. As Rz tends to zero, the reverse breakdown voltage will tend to Vz regardless of current, as the voltage-current gradient becomes infinite. However, for good numerical properties, Rz must not be made too small. If, say, you allow a 0.01V error on the zener voltage at 5mA, then Rz will be 0.01V/5mA = 2 ohms. Set the **Zener resistance Rz** parameter to this value.





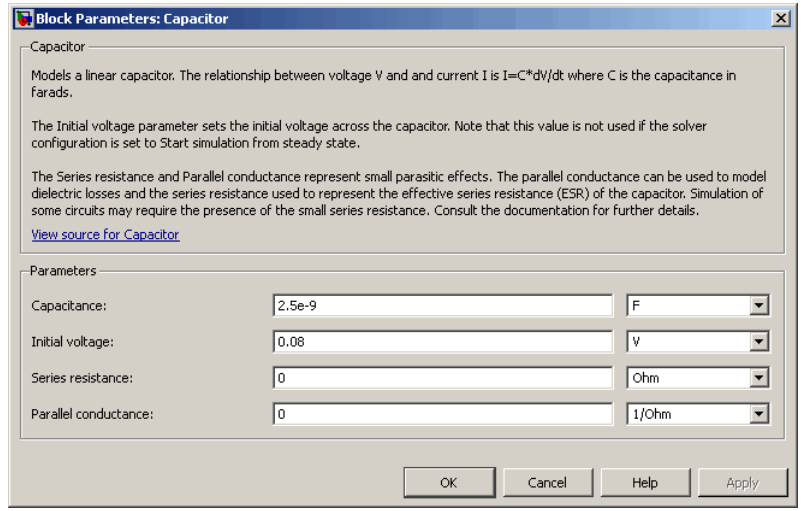
4 The Voltage Sensor block does not have any parameters.

5 Accept the default parameters for the Variable Resistor block. These parameters establish the units of the physical signal at the block output such that they match the expected default units of the Variable Resistor block input.

6 Set the Capacitor block parameters as follows:

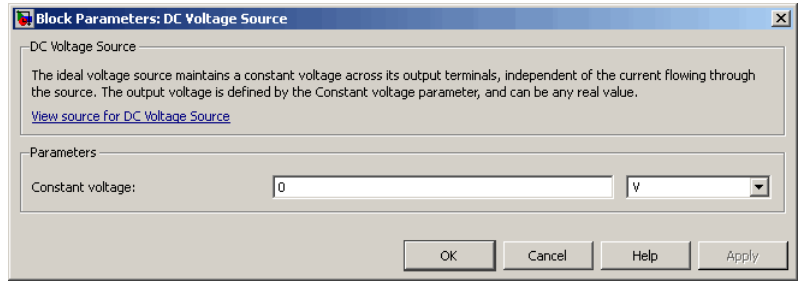
- **Capacitance** = `2.5e-9`
- **Initial voltage** = `0.08`

  This value starts the oscillation in the feedback loop.
- **Series resistance** = `0`



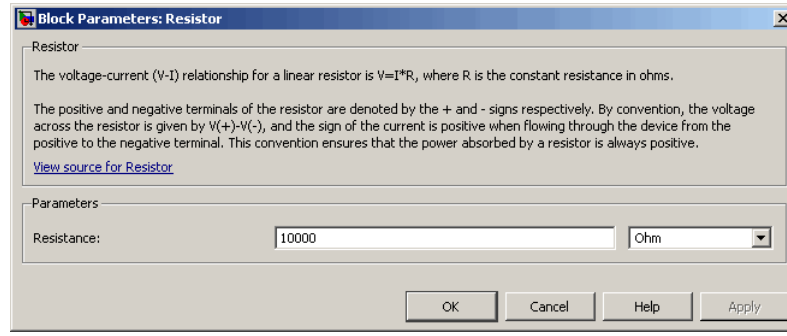
7 Set the DC Voltage Source block parameters as follows:

- **Constant voltage** = 0



8 Set the Resistor block parameters as follows:

- **Resistance** = 10000



9 Set the Resistor1 block parameters as follows:

- **Resistance** = 1000

10 Set the Resistor2 block parameters as follows:

- **Resistance** = 10000

11 Accept the default parameters for the PS-Simulink Converter block. These parameters establish the units of the physical signal at the block output such that they match the expected default units of the Scope block input.

Signal Display Parameters

Specify the parameters of the Scope block to display the triangular output signal.

Double-click the Scope block and then double-click the **Parameters** button  to open the Scope parameters dialog box. On the **Data history** tab, clear the **Limit data points to last** check box.

Configuring the Solver Parameters

Configure the solver parameters to use a continuous-time solver because SimElectronics models only run with a continuous-time solver. You also change the simulation end time, tighten the relative tolerance for a more accurate simulation, and remove the limit on the number of simulation data points Simulink saves.

1. In the model window, select **Simulation > Configuration Parameters** to open the **Configuration Parameters** dialog box.
2. In the **Solver** category in the **Select** tree on the left side of the dialog box:
   - Enter `2000e-6` for the **Stop time** parameter value.
   - Select `ode23t (Mod. stiff/Trapezoidal)` from the **Solver** list.
   - Enter `4e-5` for the **Max step size** parameter value.
   - Enter `1e-6` for the **Relative tolerance** parameter value.
3. In the **Data Import/Export** category in the **Select** tree:
   - Clear the **Limit data points to last** check box.
4. Click **OK**.

For more information about configuring solver parameters, see Chapter 3, "Simulating an Electronic System".

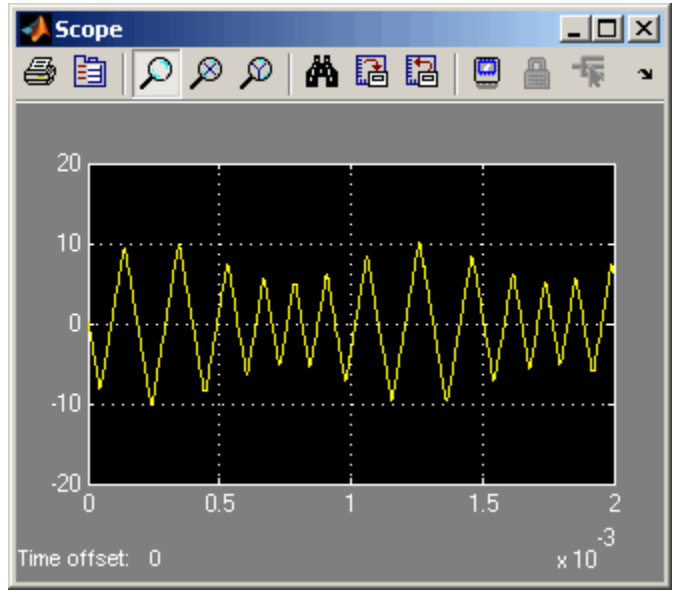
Running the Simulation and Analyzing the Results

Run the simulation and plot the results.

In the model window, select **Simulation > Start** to run the simulation.

To view the triangle wave in the Scope window, double-click the Scope block. You can do this before or after you run the simulation.

The following plot shows the voltage waveform. As the resistance of the Variable Resistor block increases, the amplitude of the output waveform increases and the frequency decreases.



Triangle Waveform Voltage

2

Modeling an Electronic System

Modeling Electronic Components

In this section...

Parameterizing Blocks

SimElectronics software is a system-level simulation tool, which provides blocks with a commensurate level of fidelity. Block parameters are designed, where possible, to match the data found on manufacturer datasheets. For example, the bipolar transistor blocks support parameterization in terms of the small-signal quantities usually quoted on a datasheet, and the underlying model is simpler than that typically used by specialist EDA simulation tools. The smaller number of parameters and simpler underlying models can support MATLAB system performance analysis better, and thereby support design choices. Following system design, you can perform validation in hardware or more detailed modeling and validation using an EDA simulation tool.

This section contains the following parameterization examples:

- "Example 1 – Parameterizing a Piecewise Linear Diode Model" on page 2-3
- "Example 2 – Parameterizing an Exponential Diode from a Datasheet" on page 2-6
- "Example 3 – Parameterizing an Exponential Diode from a SPICE Netlist" on page 2-10
- "Example 4 – Parameterizing an Op-Amp from a Datasheet" on page 2-13

Most of the time, datasheets should be a sufficient source of parameters for SimElectronics blocks (see Examples 1, 2, and 4). Sometimes, there is need for more information than is available on the datasheet, and data can be augmented from a manufacturer SPICE netlist. For example,

circuit performance may depend on one or two critical components, and increased accuracy is needed either for parameter values or the underlying model. SimElectronics libraries contain a SPICE-compatible sublibrary to support this case, and this is illustrated by Example 3. If you have many components that need to be modeled to a high level of accuracy, then Simulink cosimulation with a specialist circuit simulator may be a better option.

In mechatronic applications in particular, you may need to model input-output behavior of integrated circuits, such as PWM waveform generators and H-bridges. For these two examples, SimElectronics libraries contain abstracted-behavior equivalent blocks that you can use. Where you need to model other devices, possible options include creating your own abstracted model using the Simscape language, or using Simulink blocks. For an example of using Simulink blocks, see the Modeling an Integrated Circuit demo.

When looking for a datasheet, make sure you have the originating manufacturer datasheet because some resellers abbreviate them.

Example 1 – Parameterizing a Piecewise Linear Diode Model

The Triangle Wave Generator demo model, also described in "Example — Modeling a Triangle Wave Generator" on page 1-25, contains two zener diodes that regulate the maximum output voltage from an op-amp amplifier circuit. Each of these diodes is implemented with the SimElectronics Diode block, parameterized using the `Piecewise Linear Zener` option. This simple model is sufficient to check correct operation of the circuit, and requires fewer parameters than the `Exponential` option of the Diode block. However, when specifying the parameters, you need to take into account the bias condition that will be used in the circuit. This example explains how to do this.

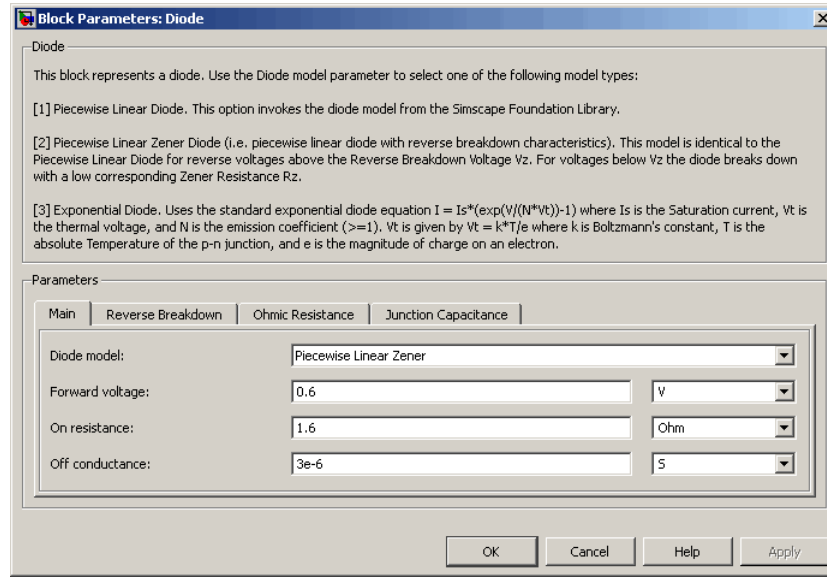
The Phillips Semiconductors datasheet for a BZX384–B4V3 gives the following data:

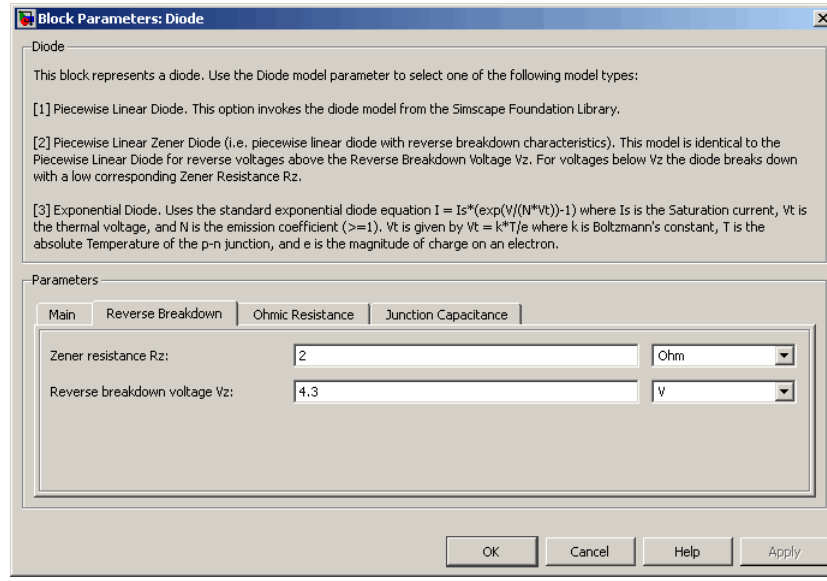
Working voltage, V_Z(V) at I_{Ztest} = 5 mA	4.3
Diode capacitance, C_d(pF)	450
Reverse current, I_R(µA) at V_R = 1 V	3
Forward voltage, V_F(V) at I_F = 5 mA	0.7

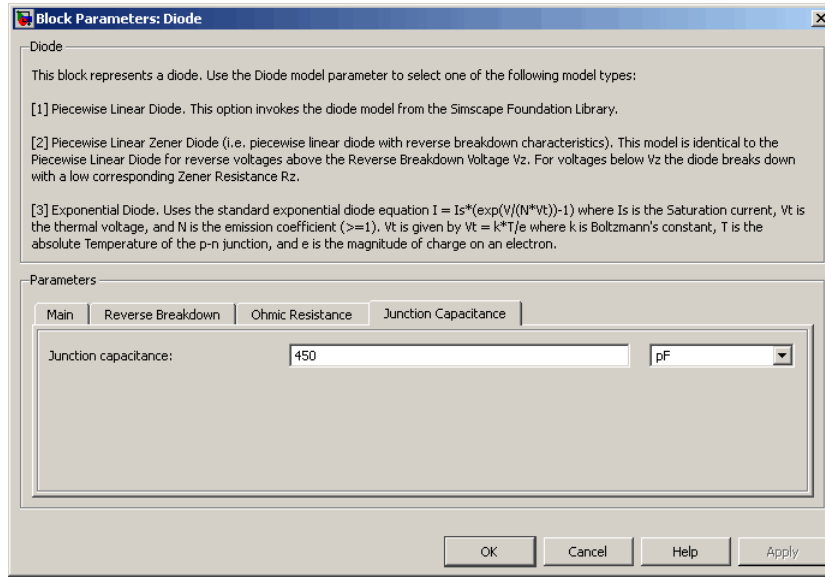
In the datasheet, the tabulated values for V_F are for higher forward currents. This value of 0.7V at 5mA is extracted from the datasheet current-voltage curve, and is chosen as it matches the zener current used when quoting the working voltage of 4.3V.

To match the datasheet values, the demo sets the piecewise linear zener diode block parameters as follows:

- **Forward voltage**. Leave as default value of 0.6V. This is a typical value for most diodes, and the exact value is not critical. However, it is important that the value set is taken into account when calculating the **On resistance** parameter.
- **On resistance**. This is set using the datasheet information that the forward voltage is 0.7V when the current is 5mA. The voltage to be dropped by the **On resistance** parameter is 0.7V minus the **Forward voltage** parameter, that is 0.1V. Hence the **On resistance** is 0.1V / 5mA = 20 Ω.
- **Off conductance**. This is set using the datasheet information on reverse current. The reverse current is 3µA for a reverse voltage of 1V. Hence the **Off conductance** should be set to 3µA / 1V = 3e-6 S.
- **Reverse breakdown voltage Vz**. This parameter should be set to the datasheet working voltage parameter, 4.3V.
- **Zener resistance Rz**. This needs to be set to a suitable small number. Too small, and the voltage-current relationship becomes very steep, and simulation convergence may not be as efficient. Too large, and the zener voltage will be incorrect. For the Diode block to be representative of the real device, the simulated reverse voltage should be close to 4.3V at 5mA (the reverse bias current provided by the circuit). Allowing a 0.01 V error on the zener voltage at 5mA, R_Z will be 0.01V / 5mA = 2 Ω.
- **Junction capacitance**. This parameter is set to the datasheet diode capacitance value, 450 pF.


Block Parameters: Diode
Diode
This block represents a diode. Use the Diode model parameter to select one of the following model types:
[1] Piecewise Linear Diode. This option invokes the diode model from the Simscape Foundation Library.
[2] Piecewise Linear Zener Diode (i.e. piecewise linear diode with reverse breakdown characteristics). This model is identical to the Piecewise Linear Diode for reverse voltages above the Reverse Breakdown Voltage Vz. For voltages below Vz the diode breaks down with a low corresponding Zener Resistance Rz.
[3] Exponential Diode. Uses the standard exponential diode equation I = Is*(exp(V/(N*Vt))-1) where Is is the Saturation current, Vt is the thermal voltage, and N is the emission coefficient (>=1). Vt is given by Vt = k*T/e where k is Boltzmann's constant, T is the absolute Temperature of the p-n junction, and e is the magnitude of charge on an electron.
Parameters
Main
Reverse Breakdown
Ohmic Resistance
Junction Capacitance
Diode model:
Piecewise Linear Zener
Forward voltage:
0.6
V
On resistance:
1.6
Ohm
Off conductance:
3e-6
S
OK
Cancel
Help
Apply


Block Parameters: Diode
Diode
This block represents a diode. Use the Diode model parameter to select one of the following model types:
[1] Piecewise Linear Diode. This option invokes the diode model from the Simscape Foundation Library.
[2] Piecewise Linear Zener Diode (i.e. piecewise linear diode with reverse breakdown characteristics). This model is identical to the Piecewise Linear Diode for reverse voltages above the Reverse Breakdown Voltage Vz. For voltages below Vz the diode breaks down with a low corresponding Zener Resistance Rz.
[3] Exponential Diode. Uses the standard exponential diode equation I = Is*(exp(V/(N*Vt))-1) where Is is the Saturation current, Vt is the thermal voltage, and N is the emission coefficient (>=1). Vt is given by Vt = k*T/e where k is Boltzmann's constant, T is the absolute Temperature of the p-n junction, and e is the magnitude of charge on an electron.
Parameters
Main
Reverse Breakdown
Ohmic Resistance
Junction Capacitance
Zener resistance Rz:
2
Ohm
Reverse breakdown voltage Vz:
4.3
V
OK
Cancel
Help
Apply



Example 2 – Parameterizing an Exponential Diode from a Datasheet

Example 1 uses a piecewise linear approximation to the diode's exponential current-voltage relationship. This results in more efficient simulation, but requires some thought to go into the setting of block parameter values. An alternative is to use a more complex model that is valid for a wider range of voltage and current values. This example uses the `Exponential` parameterization option of the Diode block.

This model either requires two data points from the diode current-voltage relationship, or values for the underlying equation coefficients, namely the saturation current IS and the emission coefficient N. The BZX384-B4V3 datasheet only provides values for the former case. Some datasheets do not give the necessary data for either case, and you must follow the processes in Example 1 or Example 3 instead.

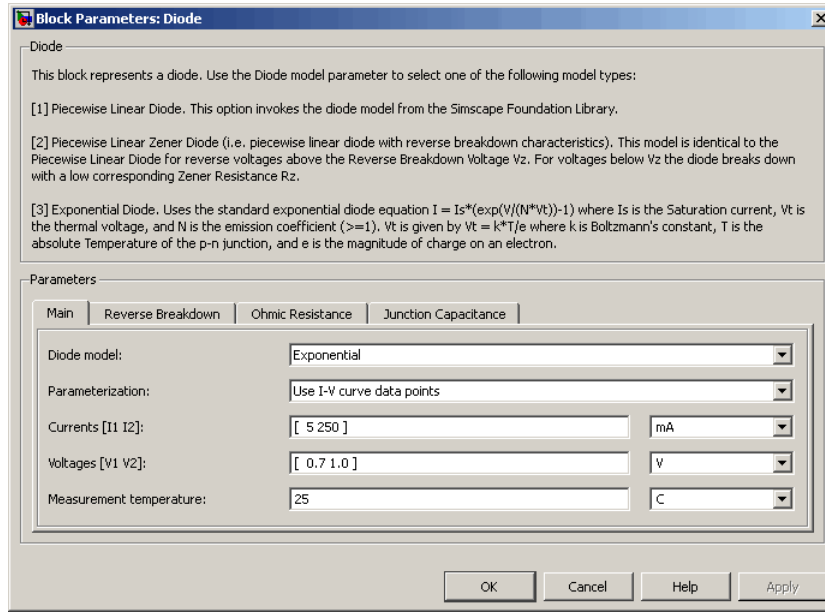
The two data points in the table below are from the BZX384-B4V3 datasheet current-voltage curve:

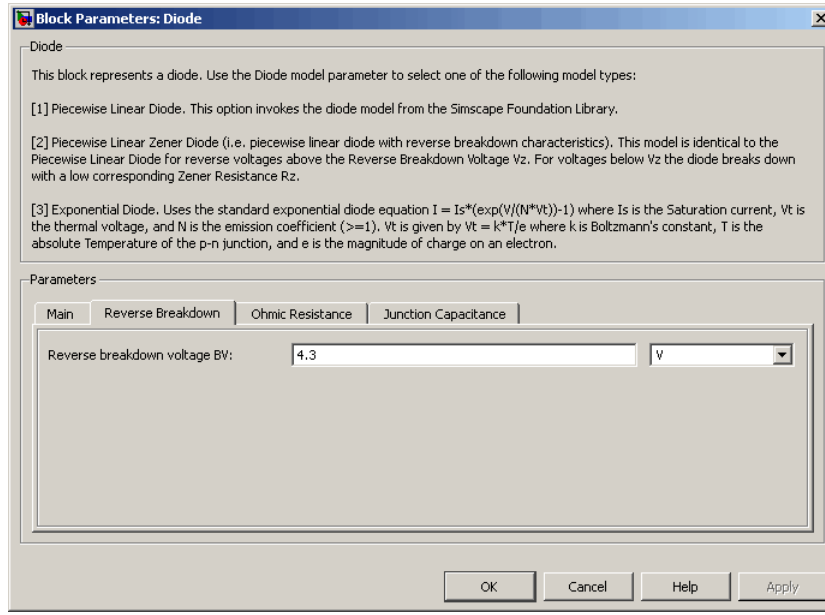
Diode forward voltage, V_F	0.7V	1V
Diode forward current, I_F	5mA	250mA

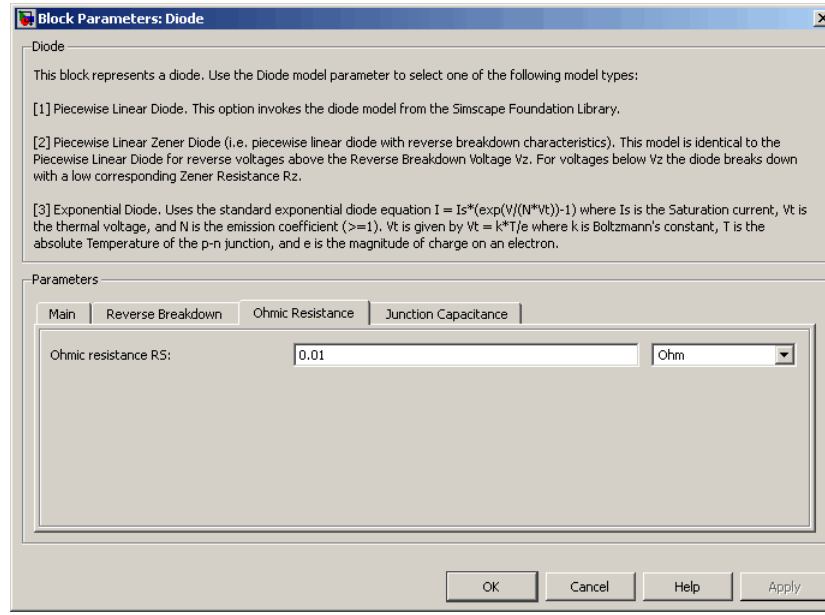
Set the exponential diode block parameters as follows:

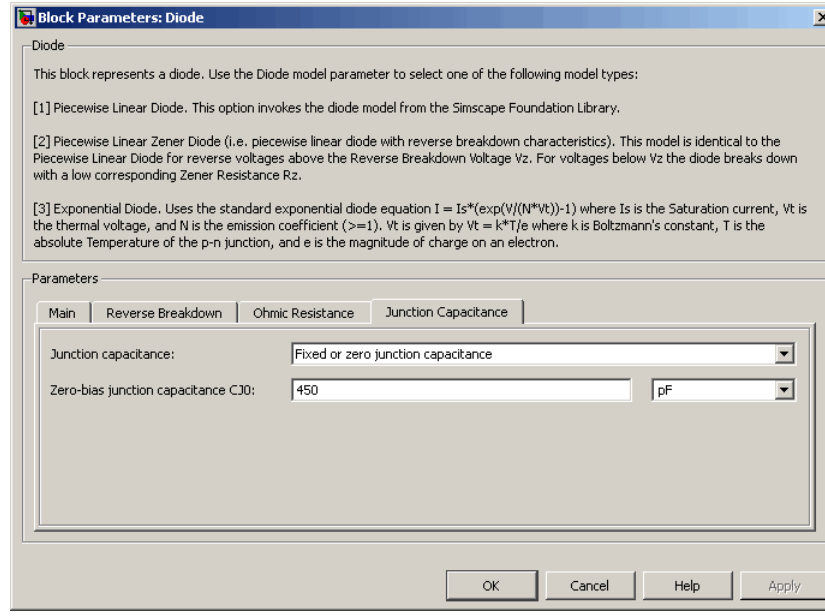
- **Currents [I1 I2]**. Set to [5 250] mA.
- **Voltages [V1 V2]**. Set to [0.7 1.0] V.
- **Reverse breakdown voltage BV**. Set to the datasheet working voltage value, 4.3V.
- **Ohmic resistance**. Leave at its default value of 0.01 Ω. This is an example of a parameter that cannot be determined from the datasheet. However, setting its value to zero is not necessarily a good idea, because a small value can help simulation convergence for some circuit topologies. The default value has negligible effect at the working current of 5mA, the additional voltage drop being 5e-3 times 0.01 = 5e-5V. Physically, this term will not be zero because of the connection resistances.
- **Zero-bias junction capacitance CJ0**. Set to the datasheet diode capacitance value, 450 pF.

  A more complex capacitance model is also available for the Diode component with the exponential equation option. However, the datasheet does not provide the necessary data. Moreover, the operation of this circuit is not sufficiently sensitive to voltage-dependent capacitance effects to warrant the extra detail.


Block Parameters: Diode
Diode
This block represents a diode. Use the Diode model parameter to select one of the following model types:
[1] Piecewise Linear Diode. This option invokes the diode model from the Simscape Foundation Library.
[2] Piecewise Linear Zener Diode (i.e. piecewise linear diode with reverse breakdown characteristics). This model is identical to the Piecewise Linear Diode for reverse voltages above the Reverse Breakdown Voltage Vz. For voltages below Vz the diode breaks down with a low corresponding Zener Resistance Rz.
[3] Exponential Diode. Uses the standard exponential diode equation I = Is*(exp(V/(N*Vt))-1) where Is is the Saturation current, Vt is the thermal voltage, and N is the emission coefficient (>=1). Vt is given by Vt = k*T/e where k is Boltzmann's constant, T is the absolute Temperature of the p-n junction, and e is the magnitude of charge on an electron.
Parameters
Main
Reverse Breakdown
Ohmic Resistance
Junction Capacitance
Diode model:
Exponential
Parameterization:
Use I-V curve data points
Currents [I1 I2]:
[5 250]
mA
Voltages [V1 V2]:
[0.7 1.0]
V
Measurement temperature:
25
C
OK
Cancel
Help
Apply


Block Parameters: Diode
Diode
This block represents a diode. Use the Diode model parameter to select one of the following model types:
[1] Piecewise Linear Diode. This option invokes the diode model from the Simscape Foundation Library.
[2] Piecewise Linear Zener Diode (i.e. piecewise linear diode with reverse breakdown characteristics). This model is identical to the Piecewise Linear Diode for reverse voltages above the Reverse Breakdown Voltage Vz. For voltages below Vz the diode breaks down with a low corresponding Zener Resistance Rz.
[3] Exponential Diode. Uses the standard exponential diode equation I = Is*(exp(V/(N*Vt))-1) where Is is the Saturation current, Vt is the thermal voltage, and N is the emission coefficient (>=1). Vt is given by Vt = k*T/e where k is Boltzmann's constant, T is the absolute Temperature of the p-n junction, and e is the magnitude of charge on an electron.
Parameters
Main
Reverse Breakdown
Ohmic Resistance
Junction Capacitance
Reverse breakdown voltage BV:
4.3
V
OK
Cancel
Help
Apply


Block Parameters: Diode
Diode
This block represents a diode. Use the Diode model parameter to select one of the following model types:
[1] Piecewise Linear Diode. This option invokes the diode model from the Simscape Foundation Library.
[2] Piecewise Linear Zener Diode (i.e. piecewise linear diode with reverse breakdown characteristics). This model is identical to the Piecewise Linear Diode for reverse voltages above the Reverse Breakdown Voltage Vz. For voltages below Vz the diode breaks down with a low corresponding Zener Resistance Rz.
[3] Exponential Diode. Uses the standard exponential diode equation I = Is*(exp(V/(N*Vt))-1) where Is is the Saturation current, Vt is the thermal voltage, and N is the emission coefficient (>=1). Vt is given by Vt = k*T/e where k is Boltzmann's constant, T is the absolute Temperature of the p-n junction, and e is the magnitude of charge on an electron.
Parameters
Main
Reverse Breakdown
Ohmic Resistance
Junction Capacitance
Ohmic resistance RS:
0.01
Ohm
OK
Cancel
Help
Apply


Block Parameters: Diode
Diode
This block represents a diode. Use the Diode model parameter to select one of the following model types:
[1] Piecewise Linear Diode. This option invokes the diode model from the Simscape Foundation Library.
[2] Piecewise Linear Zener Diode (i.e. piecewise linear diode with reverse breakdown characteristics). This model is identical to the Piecewise Linear Diode for reverse voltages above the Reverse Breakdown Voltage Vz. For voltages below Vz the diode breaks down with a low corresponding Zener Resistance Rz.
[3] Exponential Diode. Uses the standard exponential diode equation I = Is*(exp(V/(N*Vt))-1) where Is is the Saturation current, Vt is the thermal voltage, and N is the emission coefficient (>=1). Vt is given by Vt = k*T/e where k is Boltzmann's constant, T is the absolute Temperature of the p-n junction, and e is the magnitude of charge on an electron.
Parameters
Main
Reverse Breakdown
Ohmic Resistance
Junction Capacitance
Junction capacitance:
Fixed or zero junction capacitance
Zero-bias junction capacitance CJ0:
450
pF
OK
Cancel
Help
Apply

Example 3 – Parameterizing an Exponential Diode from a SPICE Netlist

If a datasheet does not provide all of the data required by the component model, another source is a SPICE netlist for the component. Components are defined by a particular type of SPICE netlist called a subcircuit. The subcircuit defines the coefficients for the defining equations. Most component manufacturers make subcircuits available on their websites. The format is ASCII, and you can directly read off the parameters. The BZX384-B4V3 subcircuit can be obtained from Philips Semiconductors http://www.nxp.com/models/index.html.

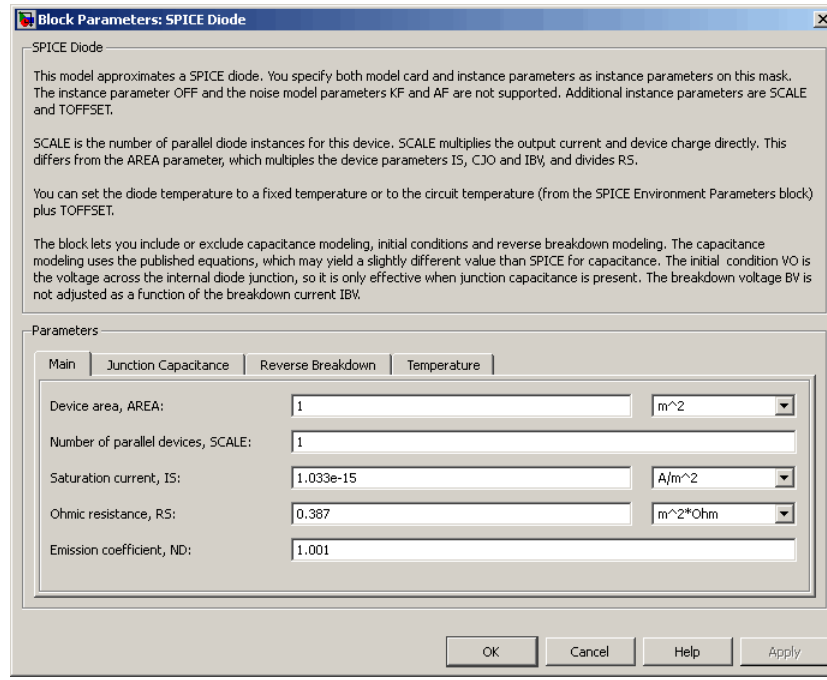
The subcircuit data can be used to parameterize the SimElectronics Diode block either in conjunction with the datasheet, or on its own. For example, the Ohmic resistance is defined in the subcircuit as RS = 0.387, thus providing the missing piece of information in Example 2.

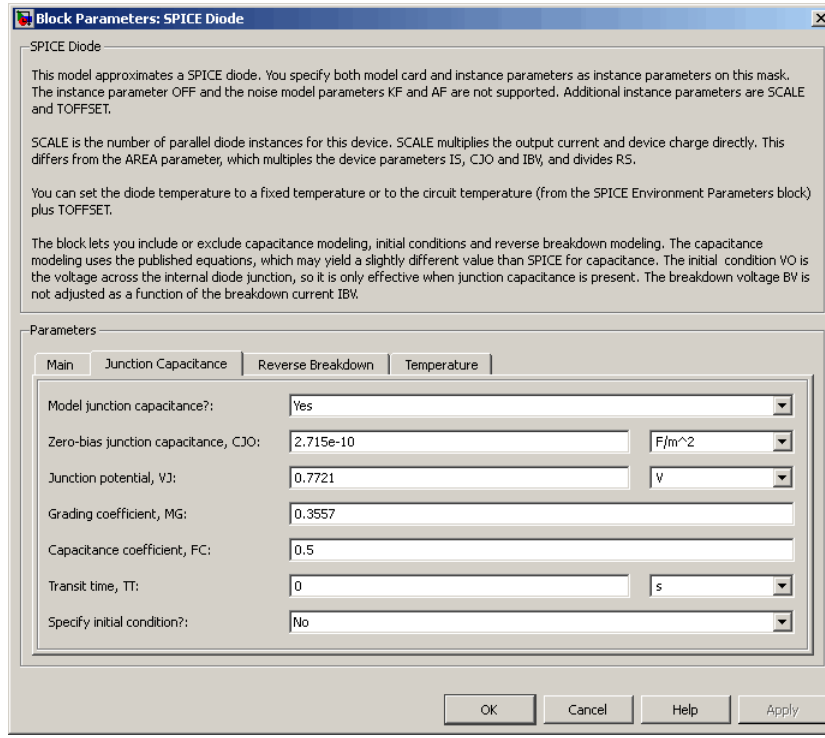
An alternative workflow is to use the SimElectronics Additional Components/SPICE-Compatible Components sublibrary. The SPICE Diode block in this sublibrary can be directly parameterized from the subcircuit by setting:

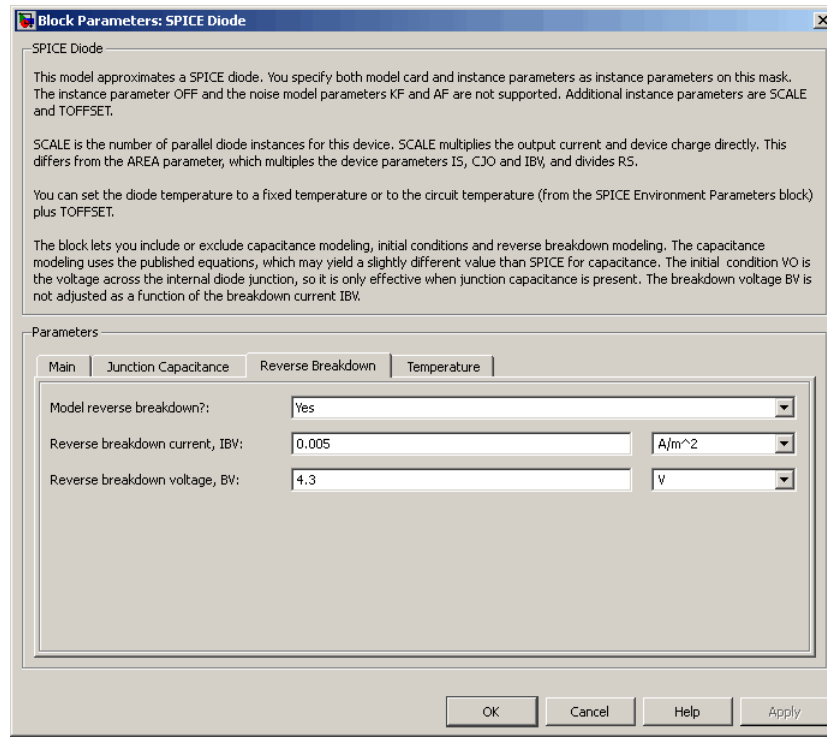
- **Saturation current, IS** to `1.033e-15`
- **Ohmic resistance, RS** to `0.387`
- **Emission coefficient, ND** to `1.001`
- **Zero-bias junction capacitance, CJO** to `2.715e-10`
- **Junction potential, VJ** to `0.7721`
- **Grading coefficient, MG** to `0.3557`
- **Capacitance coefficient, FC** to `0.5`
- **Reverse breakdown current, IBV** to `0.005`
- **Reverse breakdown voltage, BV** to `4.3`

Note that where there is a one-to-one correspondence between subcircuit parameters and datasheet values, the numbers often differ. One reason for this is that datasheet values are sometimes given for maximum values, whereas subcircuit values are normally for nominal values. In this example,

the CJO value of 271.5 pF differs from the datasheet capacitance of 450 pF at zero bias for this reason.




Block Parameters: SPICE Diode
SPICE Diode
This model approximates a SPICE diode. You specify both model card and instance parameters as instance parameters on this mask. The instance parameter OFF and the noise model parameters KF and AF are not supported. Additional instance parameters are SCALE and TOFFSET.
SCALE is the number of parallel diode instances for this device. SCALE multiplies the output current and device charge directly. This differs from the AREA parameter, which multiples the device parameters IS, CJO and IBV, and divides RS.
You can set the diode temperature to a fixed temperature or to the circuit temperature (from the SPICE Environment Parameters block) plus TOFFSET.
The block lets you include or exclude capacitance modeling, initial conditions and reverse breakdown modeling. The capacitance modeling uses the published equations, which may yield a slightly different value than SPICE for capacitance. The initial condition VO is the voltage across the internal diode junction, so it is only effective when junction capacitance is present. The breakdown voltage BV is not adjusted as a function of the breakdown current IBV.
Parameters
Main
Junction Capacitance
Reverse Breakdown
Temperature
Model junction capacitance?:
Yes
Zero-bias junction capacitance, CJO:
2.715e-10
F/m^2
Junction potential, VJ:
0.7721
V
Grading coefficient, MG:
0.3557
Capacitance coefficient, FC:
0.5
Transit time, TT:
0
s
Specify initial condition?:
No
OK
Cancel
Help
Apply



Example 4 – Parameterizing an Op-Amp from a Datasheet

The Triangle Wave Generator demo model, also described in "Example — Modeling a Triangle Wave Generator" on page 1-25, contains two op-amps, parameterized based on a datasheet for an LM7301. The National Semiconductor datasheet gives the following data for this device:

Gain	97dB = 7.1e4
Input resistance	39MΩ
Slew rate	1.25V/µs
Bandwidth	4MHz

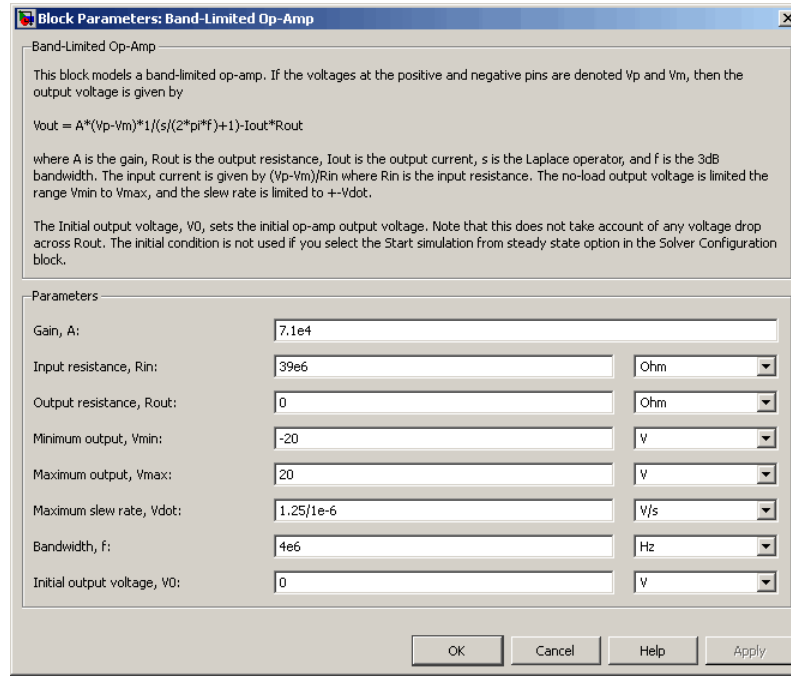
The Band-Limited Op-Amp and Finite-Gain Op-Amp blocks have been designed to work from manufacturer datasheets. Implementing detailed

op-amp device models, derived from manufacturer SPICE netlist models, is not recommended, because it provides more accuracy than is typically warranted and slows down simulations. The simple parameterization of the SimElectronics op-amp blocks allows you to determine the sensitivity of your circuit to abstracted performance values, such as maximum slew rate and bandwidth. Because of this behavior-based parameterization, you can determine which specification of op-amp is required for a given application. A circuit designer can later match these behavioral parameters, determined from the model, against specific op-amp devices.

Based on the datasheet values above, set the Band-Limited Op-Amp block parameters as follows:

- **Gain** set to `7.1e4`
- **Input resistance, Rin** set to `39e6`Ω
- **Output resistance, Rout** set to zero. The value is not defined, but will be small compared to the 1000Ω load seen by the op-amp.
- **Minimum output, Vmin** set to the negative supply voltage, `-20`V in this model
- **Maximum output, Vmax** set to the positive supply voltage, `20`V in this model
- **Maximum slew rate, Vdot** set to `1.25/1e-6` V/s
- **Bandwidth, f** set to `4e6` Hz

Note that these parameters correspond to the values for +-5 volt operation. The datasheet also gives values for +-2.2V and +-30V operation. It is usually better to pick values for a supply voltage below what your circuit uses, because performance is worse at lower voltages; for example, the gain is less, and the input impedance is less. You can use the variation in op-amp parameters with supply voltage to suggest a typical range of parameter values for which you should check the operation of your circuit.



Additional Parameterization Workflows

There are several other ways to parameterize and validate your model:

- "Validation Using Data from SPICE Tool" on page 2-15
- "Parameter Tuning Against External Data" on page 2-16
- "Building an Equivalent Model of a SPICE Netlist" on page 2-16

Validation Using Data from SPICE Tool

One way to validate a parameterized SimElectronics component is to compare its behavior to data from specialist circuit simulation tool that uses a manufacturer SPICE netlist of the device. If doing this, it is important to create a test harness for the component that exercises it over the relevant operating points and frequencies

Parameter Tuning Against External Data

If you have lab measurements of the device, or data from another simulation environment, you can use this to tune the parameters of the equivalent SimElectronics component. For an example of parameter tuning, see the demo Solar Cell Parameter Extraction From Data.

Building an Equivalent Model of a SPICE Netlist

In Example 3, parameterization from a SPICE netlist is relatively straightforward because the netlist defines a single device (the diode) plus corresponding model card (the parameters). Conversely, a netlist for an op-amp may have more than ten devices, plus supporting model cards. In principle it is possible to build your own equivalent model of a more complex device by making use of the SPICE-Compatible Components sublibrary, and connecting them together using the information in the netlist. Before embarking on this you should ensure that the SPICE-Compatible Components sublibrary has all of the component models that you need.

If the device models you wish to model are complex (hundreds of components), then cosimulation with an external circuit simulator may be a better approach.

Adding SimElectronics Blocks to a Model

You can include blocks from the SimElectronics library in a Simulink model. For more information on the library and the SimElectronics blocks, see "SimElectronics Block Libraries" on page 1-6.

This section contains the following topics:

Required Blocks

Each topologically distinct physical network in a diagram requires exactly one Solver Configuration block, found in the Simscape Utilities library. The Solver Configuration block specifies global environment information for simulation and provides parameters for the solver that your model needs before you can begin simulation. For more information, see the Solver Configuration block reference page.

Each electrical network requires an Electrical Reference block. This block establishes the electrical ground for the circuit. Networks with electromechanical blocks also require a Mechanical Rotational Reference block. For more information about using reference blocks, see "Grounding Rules" in the Simscape documentation.

How to Add SimElectronics Blocks to a Model

To add SimElectronics blocks to a Simulink model:

1. Type `elec_lib` at the MATLAB prompt to open the SimElectronics library.
2. Navigate to the desired library or sublibrary.
3. Drag instances of SimElectronics blocks into the model window using the mouse.

Note You can also access SimElectronics blocks and other Simulink blocks from the Simulink Library Browser window. Type `simulink` at the MATLAB prompt to open this window. Add blocks to the model by dragging them from this window and dropping them into the model window.

Connecting Model Blocks

You follow the same procedure for connecting SimElectronics blocks as for connecting Simulink blocks: click a port and drag the mouse to draw a line to another port on a different block. For more information on connecting blocks, see in the Simulink documentation.

You can only connect blocks that use the same type of signal. SimElectronics blocks use the same physical signals that Simscape blocks use. These signals are different than Simulink signals, and are represented graphically by a different port style. Therefore, you can freely connect pairs of SimElectronics blocks and other Simscape blocks.

However, you cannot directly connect SimElectronics blocks to Simulink blocks. Instead, you must use the Simscape PS-Simulink Converter and Simulink-PS Converter blocks to bridge them.

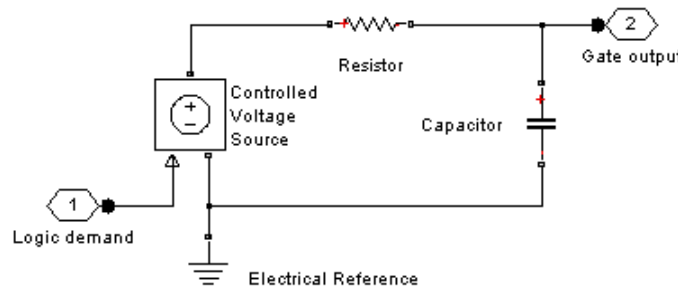
The following topics in the Simscape documentation explain how physical ports work and how to bridge physical blocks and Simulink blocks.

- "Connector Ports and Connection Lines"
- "Connecting Simscape Diagrams to Simulink Sources and Scopes"

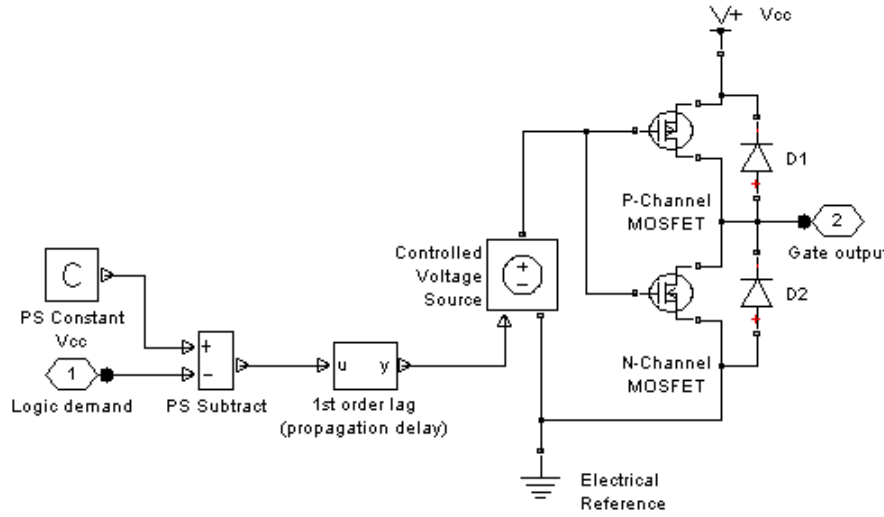
Selecting the Output Model for Logic Blocks

The blocks in the Logic sublibrary of the Integrated Circuits library provide a choice of two output models:

- `Linear` — Models the gate output as a voltage source driving a series resistor and capacitor connected to ground. This is suitable for logic circuit operation under normal conditions and when the logic gate drives other high-impedance CMOS gates. The block sets the value of the gate output capacitor such that the resistor-capacitor time constant equals the **Propagation delay** parameter value. The linear output model is shown in the following illustration.



- `Quadratic` — Models the gate output in terms of a complementary N-channel and P-channel MOSFET pair. This adds more fidelity, which becomes relevant if drawing higher currents from the gate output, or if exercising the gate under fault conditions. In addition, the gate input demand is lagged to approximate the **Propagation delay** parameter value. Default parameters are representative of the 74HC logic gate family. The quadratic output model is shown in the next illustration.



Use the **Output current-voltage relationship** parameter on the **Outputs** tab of the block dialog box to specify the output model.

For most system models, MathWorks recommends selecting the linear option because it supports faster simulation. If necessary, you can use the more detailed output model to validate simulation results obtained from the simpler model.

Quadratic Model Output and Parameters

If you select the quadratic model, use the following parameters to control the block output:

- **Supply voltage** — Supply voltage value (Vcc) applied to the gate in your circuit. The default value is 5 V.
- **Measurement voltage** — The gate supply voltage for which mask data output resistances and currents are defined. The default value is 5 V.
- **Logic HIGH output resistance at zero current and at I_OH** — A row vector [*R_OH1 R_OH2*] of two resistance values. The first value *R_OH1* is the gradient of the output voltage-current relationship when the gate is

logic HIGH and there is no output current. The second value *R_OH2* is the gradient of the output voltage-current relationship when the gate is logic HIGH and the output current is *I_OH*. The default value is `[ 25 250 ]` Ω.

- **Logic HIGH output current I_OH when shorted to ground** — The resulting current when the gate is in the logic HIGH state, but the load forces the output voltage to zero. The default value is `63` mA.
- **Logic LOW output resistance at zero current and at I_OL** — A row vector [*R_OL1 R_OL2*] of two resistance values. The first value *R_OL1* is the gradient of the output voltage-current relationship when the gate is logic LOW and there is no output current. The second value *R_OL2* is the gradient of the output voltage-current relationship when the gate is logic LOW and the output current is *I_OL*. The default value is `[ 30 800 ]` Ω.
- **Logic LOW output current I_OL when shorted to Vcc** — The resulting current when the gate is in the logic LOW state, but the load forces the output voltage to the supply voltage Vcc. The default value is `-45` mA.
- **Propagation delay** — Time it takes for the output to swing from `LOW` to `HIGH` or `HIGH` to `LOW` after the input logic levels change. For quadratic output, it is implemented by the lagged gate input demand. The default value is `25` ns.
- **Protection diode on resistance** — The gradient of the voltage-current relationship for the protection diodes when forward biased. The default value is `5` Ω.
- **Protection diode forward voltage** — The voltage above which the protection diode is turned on. The default value is `0.6` V.

The following graphic illustrates the quadratic output model parameterization, using the default parameter output characteristics for a +5V supply.

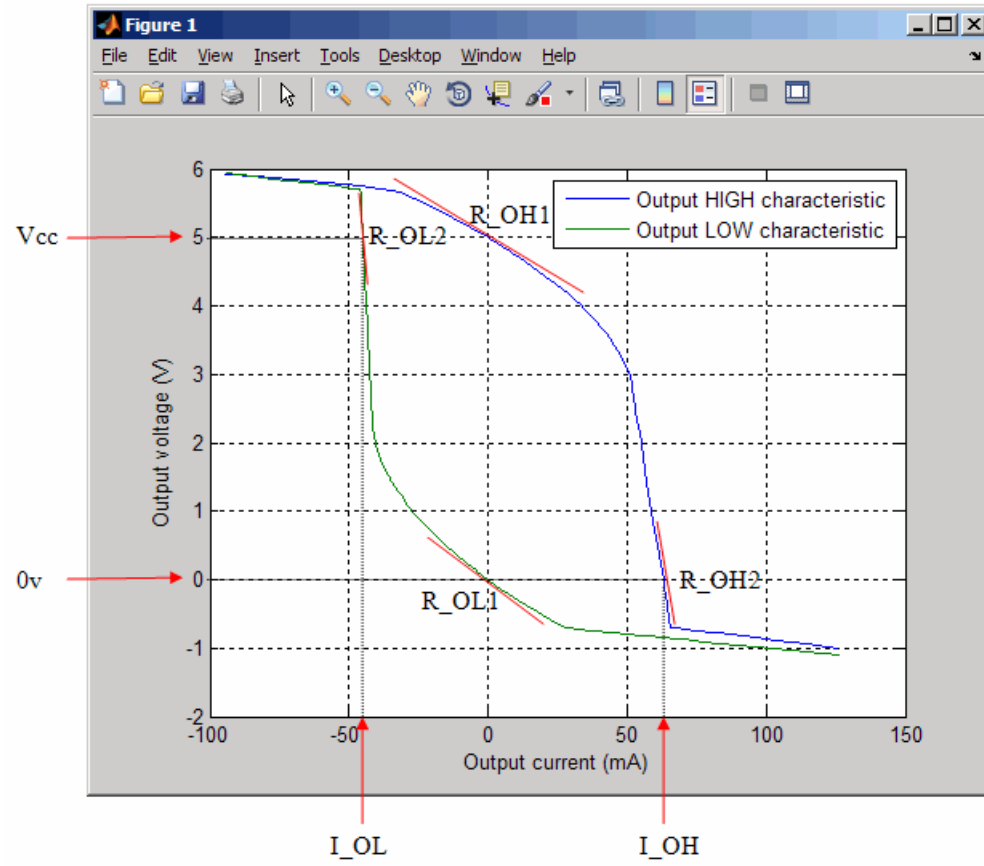


Figure 1
File Edit View Insert Tools Desktop Window Help
Output HIGH characteristic
Output LOW characteristic
R_OH1
R_OL2
R_OL1
R_OH2
Vcc
0v
Output voltage (V)
Output current (mA)
I_OL
I_OH
6
5
4
3
2
1
0
-1
-2
-100
-50
0
50
100
150

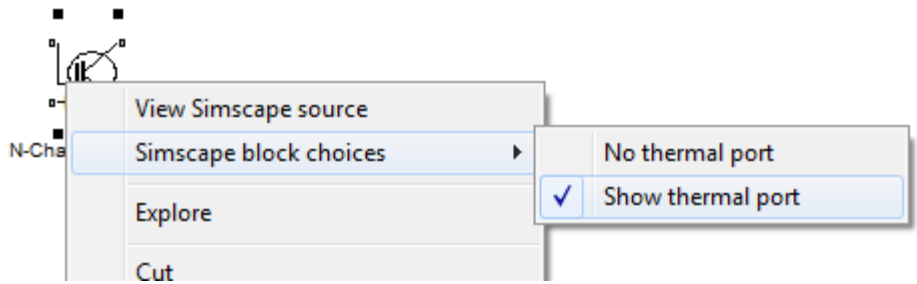
Simulating Thermal Effects

In this section...

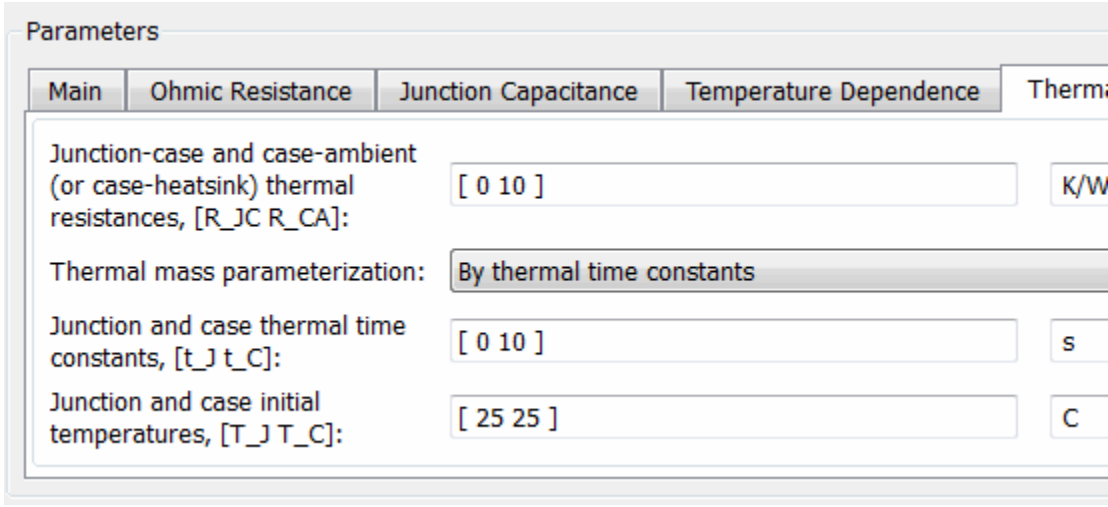
Using the Thermal Ports

Certain SimElectronics blocks, for example, the blocks in the Semiconductors library, contain an optional thermal port. This port is hidden by default. If you want to simulate the generated heat and device temperature, expose the thermal port on a particular block instance in your block diagram:

1. Right-click the block where you want to show the thermal port.
2. From the context menu, select **Simscape block choices** > **Show thermal port**.



When the thermal port is exposed, the block dialog box contains an additional tab, **Thermal Port**. For semiconductor devices, the tab always contains the same set of parameters.



- **Junction case and case-ambient (or case-heatsink) thermal resistances, [R_JC R_CA]** — A row vector [*R_JC R_CA*] of two thermal resistance values, represented by the two Conductive Heat Transfer blocks in the "Thermal Model" on page 2-24. The first value *R_JC* is the thermal resistance between the junction and case. The second value *R_CA* is the thermal resistance between port H and the device case. See "Thermal Model" on page 2-24 for further details. The default value is `[ 0 10 ]`K/W.
- **Thermal mass parameterization** — Select whether you want to parameterize the thermal masses in terms of thermal time constants (`By thermal time constants`), or specify the thermal mass values directly (`By thermal mass`). For more information, see "Thermal Mass Parameterization" on page 2-25. The default is `By thermal time constants`.
- **Junction and case thermal time constants, [t_J t_C]** — A row vector [*t_J t_C*] of two thermal time constant values. The first value *t_J* is the junction time constant. The second value *t_C* is the case time constant. This parameter is only visible when you select `By thermal time constants` for the **Thermal mass parameterization** parameter. The default value is `[ 0 10 ]` s.
- **Junction and case thermal masses, [M_J M_C]** — A row vector [*M_J M_C*] of two thermal mass values. The first value *M_J* is the

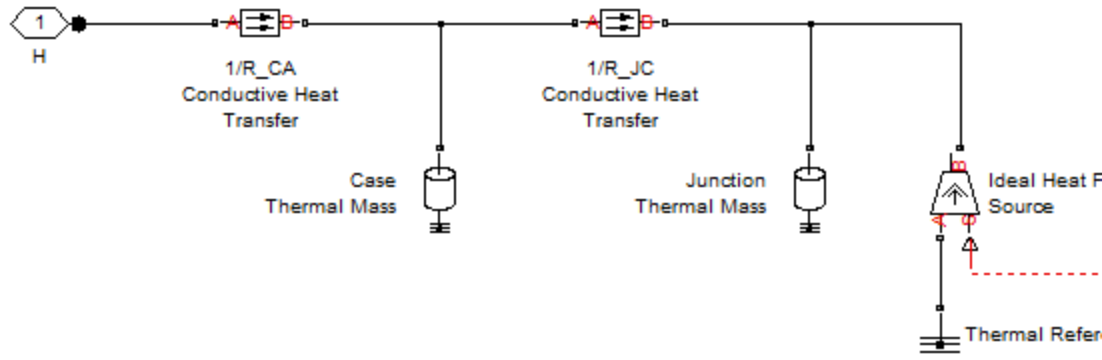
junction thermal mass. The second value *M_C* is the case thermal mass. This parameter is only visible when you select `By thermal mass` for the **Thermal mass parameterization** parameter. The default value is `[ 0 1 ]` J/K.

- **Junction and case initial temperatures, [T_J T_C]** — A row vector [*T_J T_C*] of two temperature values. The first value *T_J* is the junction initial temperature. The second value *T_C* is the case initial temperature. The default value is `[ 25 25 ]` C.

For more information on selecting the parameter values, see "Thermal Model" on page 2-24 and "Improving Numerical Performance" on page 2-27. For explanation of the relationship between the **Thermal Port** and **Temperature Dependence** tabs in a block dialog box, see "Electrical Behavior Depending on Temperature" on page 2-26.

Thermal Model

All blocks with optional thermal ports include an internal thermal model with thermal masses and resistances. The purpose of including this model internally is to keep your diagram uncluttered by the thermal model. The following figure shows an equivalent model of the internal thermal model for semiconductor devices.



The port H in the diagram corresponds to the thermal port H of the block. The two Thermal Mass blocks represent the thermal mass of the device case and the thermal mass of the semiconductor junction, respectively. The Ideal

Heat Flow Source block inputs heat to the model with value equal to the electrically generated heat from the device.

The two Conductive Heat Transfer blocks model the thermal resistances. Resistance *R_JC* (conductance 1/R_JC) represents the thermal resistance between junction and case. Because of this resistance, under normal conditions the junction will be hotter than the case. Resistance *R_CA* represents the thermal resistance between port H and the device case. If the device has no heatsink, then in your model you should connect port H to an Ideal Temperature Source with its temperature set to ambient conditions. If your device does have an external heatsink, then you must model the heatsink externally to the device, and connect the heatsink thermal mass directly to port H.

If you wish to keep all or part of the thermal model of the device external to the model, you can set the necessary block parameters to zero. The following rules apply:

- Case thermal mass must be greater than zero.
- Junction thermal mass can only be set to zero if the junction-case resistance is also set to zero.
- If both case and junction thermal masses are defined, but junction-case resistance is zero, then the initial temperatures assigned to junction and case must be identical.

Thermal Mass Parameterization

Datasheets usually quote both of the thermal resistances, but rarely give values for thermal masses. There are two parameterization options for the thermal masses:

- `By thermal time constants` — Parameterize the thermal masses in terms of thermal time constants. This is the default.
- `By thermal mass` — Specify the thermal mass values directly.

The thermal time constants *t_J* and *t_C* are defined as follows:

$$t\_J = M\_J \cdot R\_JC$$

$$t\_C = M\_C \cdot R\_CA$$

where *M_J* and *M_C* are the junction and case thermal masses, respectively, *R_JC* is the thermal resistance between junction and case, and *R_CA* is the thermal resistance between port H and the device case.

You can determine the case time constant by experimental measurement. If data is not available for the junction time constant, you can either omit it and set the junction-case resistance to zero, or you can set the junction time constant to a typical value of one tenth of the case time constant. The alternative is to estimate thermal masses based on device dimensions and averaged material specific heats.

Electrical Behavior Depending on Temperature

For blocks with optional thermal ports, there are two simulation options:

- Simulate the generated heat, device temperature, and the effect of temperature on the electrical equations.
- Simulate the generated heat and device temperature, but do not include effect of temperature on the electrical equations. Use this option when the impact of temperature on the electrical equations is small over the temperature range to be simulated, or where the primary task of the simulation is to capture the heat generated to support system-level design.

The thermal port and the **Thermal Port** tab of the block dialog box let you simulate the generated heat and device temperature. The **Thermal Dependence** tab of the block dialog box lets you model the effect of temperature of the semiconductor junction on the electrical equations. Therefore:

- To simulate all the temperature effects, show the block's thermal port and set the **Parameterization** parameter on the **Thermal Dependence** tab to `Model temperature dependence` (or, for blocks with a choice of options for modeling temperature dependence, select one of these options, for example, `Use an I-V data point at second measurement temperature`).
- To simulate just the generated heat and device temperature, show the block's thermal port but set the **Parameterization** parameter on

the **Thermal Dependence** tab to `None  Simulate at parameter measurement temperature`.

Improving Numerical Performance

It is very important that you set realistic values for thermal masses and resistances. Otherwise, junction temperatures can become extreme, and out of range for valid results, which in turn may manifest itself as numerical difficulties when simulating. A simple test to see if numerical difficulties are a result of unrealistic thermal values is to turn off the temperature dependence for the electrical equations, by setting the **Parameterization** parameter on the **Thermal Dependence** tab to `None  Simulate at parameter measurement temperature`.

The thermal time constants are generally much slower than electrical time constants, so the thermal aspects of your model are unlikely to dictate the maximum fixed time step you can simulate at (for example, for hardware-in-the-loop simulations). However, if you need to remove detail (for example, to speed up simulation), the junction thermal mass time constant is typically an order of magnitude faster than the case thermal mass time constant. You can remove the effect of the junction thermal mass by setting the junction thermal mass to zero and also setting the junction-case thermal resistance to zero.

Working with Simulink Blocks

In this section...

Modeling Instantaneous Events

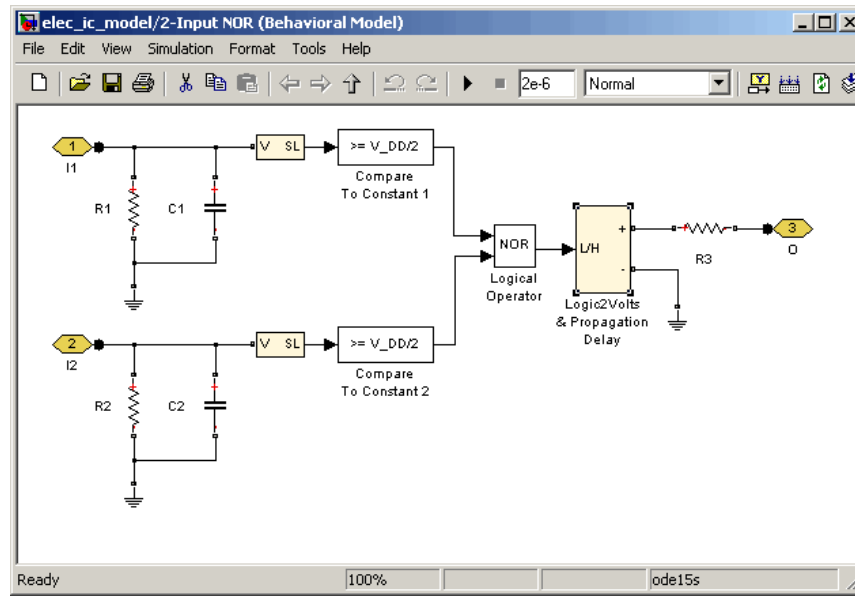
When working with SimElectronics software, your model may include Simulink blocks that create instantaneous changes to the physical system inputs through the Simulink-PS Converter block, such as those associated with events or discrete sampling. When you build this type of model, make sure the corresponding zero crossings are generated.

Many blocks in the Simulink library generate these zero crossings by default. For example, the Pulse Generator block produces a discrete-time output by default, and generates the corresponding zero crossings. To model instantaneous events, select `Use local settings` or `Enable all` for the **Zero crossing control** option under the model's Solver Configuration Parameters to generate zero crossings. For more information about zero crossing control, see "Zero-crossing control" in the Simulink documentation.

Using Simulink Blocks to Model Physical Components

To run a fast simulation that approximates the behavior of the physical components in a system, you may want to use Simulink blocks to model of one or more physical components.

The Modeling an Integrated Circuit demo uses Simulink to model a physical component. The Simulink Logical Operator block implements the behavioral model of the two-input NOR gate, as shown in the following figure.



Using Simulink in this manner introduces algebraic loops, unless you place a lag somewhere between the physical signal inputs and outputs. In this case, a first-order lag is included in the Logic2Volts & Propagation Delay subsystem to represent the delay due to gate capacitances. For applications where no lag is required, use blocks from the Physical Signals sublibrary in the Simscape Foundation Library to implement the desired functionality.

3

Simulating an Electronic System

Selecting a Solver

In this section...

Available Solvers

SimElectronics software supports all of the continuous-time solvers that Simscape supports. For more information, see "Setting Up Solvers for Physical Models" in the Simscape documentation.

You can select any of the supported solvers for running a SimElectronics simulation. The variable-step solvers, `ode23t` and `ode15s`, are recommended for most applications because they run faster and copy better for systems with a range of both fast and slow dynamics. The `ode23t` solver is closest to the solver that SPICE traditionally uses.

To use Simulink® Coder™ software to generate standalone C or C++ code from your model, you must use the `ode14x` solver. For more information about code generation, see "Code Generation " in the Simscape documentation.

How to Select a Solver

To specify a solver:

1. Open the **Configuration Parameters** dialog box from the **Simulation** menu.
2. In the **Solver** pane (which opens by default), select the desired solver from the **Solver** list.

Specifying Simulation Accuracy/Speed Tradeoff

In this section...

Parameters that Affect Accuracy and Speed

To trade off accuracy and simulation time, adjust one or more of the following parameters:

- **Relative tolerance** (in the Configuration Parameters dialog box)
- **Absolute tolerance** (in the Configuration Parameters dialog box)
- **Max step size** (in the Configuration Parameters dialog box)
- **Constraint Residual Tolerance** (in the Solver Configuration block dialog box)

Determining Appropriate Accuracy/Speed Parameter Values

In most cases, the default tolerance values produce accurate results without sacrificing unnecessary simulation time. The parameter value that is most likely to be inappropriate for your simulation is **Max step size**, because the default value, `auto`, depends on the simulation start and stop times rather than on the amount by which the signals are changing during the simulation. If you are concerned about the solver's missing significant behavior, change the parameter to prevent the solver from taking too large a step.

The Simulink documentation describes the following parameters in more detail and provides tips on how to adjust them:

- "Relative tolerance"
- "Absolute tolerance"
- "Max step size"

The Solver Configuration block reference page in the Simscape documentation explains when to adjust the **Constraint Residual Tolerance** parameter value.

Avoiding Simulation Issues

In this section...

General Troubleshooting for Simscape Models

If you experience a simulation issue, first read "Troubleshooting Simulation Errors" in the Simscape documentation to learn about general troubleshooting techniques.

Note As mentioned in the "Product Overview" on page 1-2, SimElectronics software does not have the ability to model large circuits with dozens of analog components. If you encounter convergence issues when trying to simulate a model with more than a few tens of transistors, you may find that the limitations of SimElectronics software prevent you from achieving convergence with any set of simulation parameter values.

Troubleshooting for Simscape Models that Include SimElectronics Blocks

There are a few techniques you can apply to any SimElectronics model to overcome simulation issues:

- Add parasitic capacitors and/or resistors (specifically, junction capacitance and ohmic resistance) to the circuit to avoid numerical issues. The Astable Oscillator demo uses these devices.
- Adjust the current and voltage sources so they start at zero and ramp up to their final values rather than starting at nonzero values.

"Working with Simulink Blocks" on page 2-28 describes how to avoid simulation errors in the presence of specific SimElectronics model configurations.

Running a Time-Domain Simulation

When you run a time-domain simulation, SimElectronics software uses the Simscape solver to analyze the physical system in the Simulink environment. For more information about how Simscape simulation works, see “How Simscape Simulation Works” in the Simscape documentation.

Running a Small-Signal Frequency-Domain Analysis

In this section...

Linearizing SimElectronics Models

The Simulink commands `linmod` and `dlinmod` create continuous- or discrete-time linear time-invariant (LTI) state-space models from Simulink models. You can use these commands to generate an LTI state-space model from a model containing Simscape components.

For more information about linearizing models that contain blocks from the Simulink Physical Modeling family, see "Linearizing at an Operating Point".

After you linearize your model, you can perform small-signal analyses such as:

- Bode
- Step
- Impulse
- Nyquist

Note If you have Simulink® Control Design™ software installed, you can use its Control and Estimation Tools Manager GUI to linearize models. For more information about using this software for linearization, see .

Analyzing Small-Signal Behavior Using Bode Plots

After you create an LTI state-space model from your SimElectronics model, you can create a Bode plot for small-signal analysis using one of the following approaches:

- "Using MATLAB for Bode Analysis" on page 3-8
- "Using Control System Toolbox Software for Bode Analysis" on page 3-8

Using MATLAB for Bode Analysis

You can write a MATLAB script to generate a bode plot of the frequency response of the model from the LTI state-space model. The demo Small-Signal Frequency-Domain Analysis uses a linear passive bandpass filter example to show how to use MATLAB to create a Bode plot from an LTI model. The demo shows how to use both the state-space and transfer-function forms of the LTI model.

Using Control System Toolbox Software for Bode Analysis

You can use the built-in analysis and plotting capabilities of Control System Toolbox™ to understand the behavior of a linearized model.

- The toolbox function `ss` converts the state-space model returned by `linmod` to a continuous-time state-space model.
- The toolbox function `tf` converts the transfer function model returned by `linmod` to a continuous-time transfer function model.
- The toolbox function `ltiview` opens the LTI viewer for LTI system response analysis.

The following example shows how to create a Bode plot of the frequency-response of the model in the demo Small-Signal Frequency-Domain Analysis.

At the MATLAB prompt:

1. Type the following to create a LTI state-space model of `elec_ss_analysis`:

   ```
   [A B C D] = linmod('elec_ss_analysis',[],[],[1e-5 0 1]);
   ```

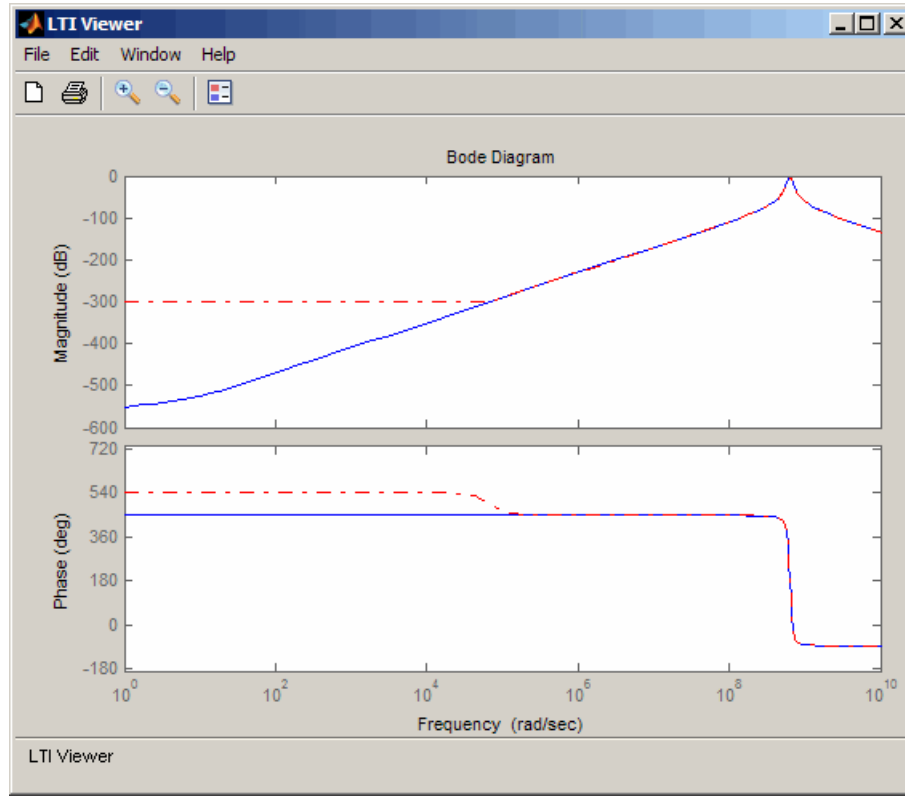
2. Type the following to create a LTI transfer function model of `elec_ss_analysis`:

   ```
   [num den] = linmod('elec_ss_analysis',[],[],[1e-5 0 1]);
   ```

3. Type the following to plot both the state-space and transfer function models on a Bode plot:

   ```
   ltiview('bode',ss(A,B,C,D),'b',tf(num,den),'r-.');
   ```

The toolbox creates the following plot:



The bandpass filter frequency response for the state-space and transfer function representations are different far from the center frequency. These differences arise from numerical noise introduced when calculating the transfer function representation. `linmod` implicitly derives a state-space representation for a linearized model, and computes the transfer function representation from this state-space model.

Note If you have Simulink Control Design software installed, you can use its Control and Estimation Tools Manager GUI to analyze models. This software uses the Control System Toolbox LTI viewer to display and analyze the dynamic behavior of a model.

A

Examples

Use this list to find examples in the documentation.

Examples

Index